Friends of The Gwent Levels

Ymddiriedolaeth Natur Gwent Wildlife Trust

Julie James
Minister for Climate Change
14th October 2022

Re: A Temporary Halt on Major Development on the Gwent Levels SSSI

Annwyl Weinidog,

As proposed in FOGL's previous letter of 21st July this year, Friends Of the Gwent Levels (FOGL) and Gwent Wildlife Trust (GWT) are now writing to you to provide you with evidence of a systemic failure to control, mitigate or compensate for serious damage to the Gwent Levels SSSI from development. This evidence consists of the results of post-construction monitoring for the only constructed solar farm on the Gwent Levels SSSI (Llanwern), and a mounting and widespread momentum for further, vastly accelerated deployment of solar on the SSSI. You may recall that our previous letter requested a temporary halt on major development on the SSSI for a period of 2-3 years, for the above reasons, and we are now reiterating that request.

FOGL and GWT's General Approach to Renewable Energy

We fully recognise that climate change is the biggest threat to biodiversity globally, and that concerted action at all levels and in all policy areas, including renewable energy generation, is needed. We further support the Welsh Government's renewable energy generation aspirations as set out in its Net Zero 2 document. However, climate change mitigation through renewable energy generation should not come at the expense of biodiversity, a fact recognised by the Senedd's declaration of a joint Climate and Biodiversity Emergency. There are many thousands of hectares of land and rooftops throughout Wales, (including Gwent) which are eminently suitable for solar generation, and there are many constructed and proposed solar projects in Gwent to which we have not objected. Developments are now approved on the basis that developers promise a benefit for biodiversity but our research shows no benefit and indeed shows further damage to the SSSI.

Results of Post-Construction Monitoring at Llanwern Solar Farm show pollution and biodiversity loss

Pollution:
The post-construction monitoring report for the Llanwern solar farm shows that levels of several **waterborne pollutants** arising from the constructed solar farm have risen hugely since construction. For example, the pre-construction levels of suspended solids (silt) inside the development site were up to 7.4 million µg / litre respectively, compared with pre-construction sample levels of a maximum of 0.53 million µg / litre. Thus, the levels of this damaging pollutant produced by the solar farm were over 14 times higher than pre-construction levels.

Very high levels of total **petroleum hydrocarbons** TPHCWG (a very damaging pollutant adversely affecting the aquatic invertebrate and plant citation interest of the SSSI) were recorded inside the solar farm site, at 230 µg / litre, compared with a pre-construction level on the site of less than 10 µg / litre.

Even these very high levels of pollutants caused by the solar farm may be underestimates, because other pollutants, for example Nitrite as N and Nitrite as N02, were recorded at very much higher levels post-construction compared with pre-construction, but no NRW concern trigger level exists. It is important to stress that the wildlife interest of the SSSI is wholly dependent on a very high quality of water in the reens and ditches.

Biodiversity Loss:
No breeding **lapwings** used the "Lapwing Mitigation (really compensation) Area". Numbers of breeding lapwings fell from eight pairs pre-construction to two pairs post-construction, with only one nest found on site. Lapwing are a red list species with numbers dropping by 80% in Wales in the last fifty years.

A breeding pair of **cranes** was lost from the site. This is a species which had not bred in Wales for over 400 years. The return of these cranes a few years ago was marked as a success story for the Levels. Cranes as a species are making a slight recovery but the Llanwern development appears to have done the very opposite of assisting their recovery.

The diversity of **bat** species decreased markedly, and for the majority of locations, abundance of species has dropped dramatically (95- 100%).

The **flora** on the site has been severely damaged by the construction process and there is no evidence of any attempts to mitigate against this. The ground appears compacted and the panels have large areas of bare earth under and around them, with brambles starting to take over the area, in stark contrast to the grazing marsh habitat of the site before construction.

It should be stressed that this is merely a snapshot of the damage caused to the SSSI, and that further damage is likely to manifest itself as the years go by.

<u>The Levels as a whole under threat</u>

It is also important to bear in mind that in addition to the damage done directly to the SSSI by solar farms, such as that set out above, indirect damage b(oth cumulative with other developments and in combination with other damaging activities) would manifest themselves if further solar farms were constructed on the SSSI. The destruction of ecological connectivity and resilience would be inevitable if more and more projects were constructed on this fragile and complex wetland SSSI. This would be completely at odds with the Welsh Government DECCA (Diversity, Extent, Condition, Connectivity, Adaptability) approach to reversing climate change and biodiversity loss.

The catastrophic failure of mitigation measures delivered through planning conditions for the only constructed solar farm on the SSSI (or indeed any wetland SSSI in Wales) shows that mitigation has not remedied damage to the SSSI by development, even though the conditions were approved by the Inspector at the hearing, and by NRW, and set out in the Inspector's Report and Recommendations. Rather than delivering a measurable benefit, the Llanwern scheme has delivered only measurable losses.

All constructed developments on the Gwent Levels in recent decades will have had "mitigation" commitments attached to their planning permissions, and all of these will have been delivered through planning conditions and/or agreements or similar. Nevertheless, the damage continues and the Levels are acknowledged to be in decline. Ironically, it is the very fact that the Levels have been allowed to reach an unfavourable condition as a result of inappropriate management and damaging development that they are now being seen as 'fair game' for development which promises – but has failed to deliver – a net benefit for biodiversity.

There is a very real disconnect between the ambitions of the Welsh Government and the Senedd for the Levels and the reality of the DNS planning process within PEDW. Our experience, drawn from being objectors, and appearing at DNS Hearings is that the big picture of protecting and enhancing this NNRMA does not appear to be shared by all major stakeholders or PEDW. Each application is considered in isolation, with no consideration of cumulative impacts, and there has been no attempt at all to learn from the results of post-construction monitoring in respect of constructed solar development such as the Llanwern example cited above. Without the urgent intervention of Welsh Government in the form of a temporary halt, there is a real possibility that all the excellent work set out in Future Wales in relation to the Gwent Levels NNRMA will come to nothing.

In any event, conditions cannot be significantly adjusted to take account of the damage that results from solar development; realistically, no enforcement action would result in the removal of the development and the reinstatement of the SSSI - once it's gone it's gone.

This is a very grim picture indeed, especially when one takes into account the “shifting baseline” phenomenon. NRW estimates that between 1993 and 2014, 28% of the Rhymney and Peterstone SSSI alone (one of the constituent SSSIs of the composite Gwent Levels SSSI) was destroyed by development.

The situation is now urgent; we are faced with the immediate likelihood that at least another 200 hectares of SSSI would be lost via the Rush Wall and Wentlooge solar applications (using broadly the same mitigation measures and conditions as those for Llanwern) in addition to the 95 hectares of Llanwern solar. Further, another at least 52 hectares are in the consent pipeline (Magor Solar Farm), which would also be lost in due course. Only last week we heard of yet another enormous scheme on the SSSI, near the Newport Wetlands Nature Reserve, which is at the early stages of the consent process.

We are aware that a substantial proportion of all of the Levels’ farming community on the SSSI are regularly approached by developers with a view to promoting major solar development on their land. Every consented solar farm on the SSSI would trigger further waves of approaches to the farming community of the SSSI on the part of developers, and thus further applications.

Every new consent for solar projects would add to the probability that further projects would be consented, in a positive feedback loop due to precedent and momentum. The developers of the Wentlooge resubmission application have included a KC's legal opinion with their application; the opinion states that the previous Inspector's recommendation of approval in respect of the first Wentlooge application, in conjunction with the approval and construction of the Llanwern solar farm, have established a precedent which dictates that any Ministerial decision not to approve the Wentlooge scheme would be vulnerable to legal challenge.

Given the determination of the renewable energy industry to exploit the economic advantages which sites on the Levels offer them, it is therefore not hyperbole to envisage that without some definitive action such as a temporary halt to major development, and under present arrangements, in the next 5-10 years we will see the complete transformation of this extraordinary environment into an energy park. Wales is one of the most nature-depleted countries in the world, and we all want the Gwent Levels to be a place where declines are reversed.

<u>A Positive Future for the Levels:</u>

The relentless pressure which the Levels are facing stands in stark contrast to the excellent work you and your Welsh Government and Senedd colleagues have been carrying out over the last few years, in conjunction with the charity sector, the Gwent Levels Working Group and local communities the length and breadth of the Levels. Your Ministerial Statements have had a real and lasting impact on momentum and direction of travel, whilst the Living Levels Partnership is a Wales-wide exemplar of cohesive work to achieve shared aims. The Gwent Levels National Natural Resource Management Area (NNRMA) delineation pursuant to Policy 9 of Future Wales, and your stated intention that a masterplan for the Levels is produced and adopted, are real ground breakers. All this work demonstrates what we in Wales can achieve in pursuit of the sustainable management of natural resources (SMNR) on a landscape scale.

Your Ministerial Statement concerning the results of the Biodiversity Deep Dive released last week is very timely, and we welcome the fact that it highlights the Gwent Levels as being specifically worthy of protection, and commits the Welsh Government to an enhanced level of protection for SSSIs via a review of Planning Policy Wales 11.

We therefore respectfully repeat our call for a halt on major development on the Gwent Levels. The halt we seek would be temporary in nature, but we believe it is necessary for the meaningful completion of the NNRMA work pursuant to Policy 9 of Future Wales, including the spatial masterplan and a comprehensive post-construction monitoring project.

As a result of this halt, we are hopeful that the big picture of a more positive future for the Gwent Levels NNRMA can be shared by all stakeholders working with a common purpose to protect and enhance this unique place in Wales.

Yn gywir iawn,

[redacted]

Catherine Linstrum & Diana Callaghan
(Joint chairs, FOGL)

Adam Taylor
(CEO Gwent Wildlife Trust)

Friends of The Gwent Levels

Ymddiriedolaeth Natur Gwent Wildlife Trust

ARUP

on behalf of
Welsh
Government

Llywodraeth Cymru
Welsh Government

Gwent Levels Post Construction Monitoring

part of the evidence base required for the Gwent Levels Future Wales: Policy 9 Pilot Project

Issue: 8 July 2024

This report takes into account the particular instructions and requirements of our client. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Ove Arup & Partners International Limited
63 St Thomas Street
Bristol
BS1 6JZ
United Kingdom
[redacted]

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List of Abbreviations

AGI	Above-ground Gas Installation
BEMP	Biodiversity Enhancement and Mitigation Plan
BERR	Business Enterprise and Regulatory Reform
CBI	Confederation of British Industry
CCW	Countryside Council for Wales
CEMP	Construction Environmental Management Plan
CIEEM	Chartered Institute for Ecology and Environmental Management
COs	Conservation Objectives
DCO	Development Consent Order
DECCA	Diversity, Extent, Condition, Connectivity and Adaptability
DNS	Development of National Significance
EcIA	Ecological Impact Assessment
EIA	Environmental Impact Assessment
EMS	European Marine Site
EPS	European Protected Species
ES	Environmental Statement
ESPG	Environmentally Sensitive Permanent Grasslands
FMfP	Flood Map for Planning
GIS	Green Infrastructure Statements
GLWG	Gwent Levels Working Group
GPP	Guidelines for Pollution Prevention
GWT	Gwent Wildlife Trust
HPI	Habitats of Principal Importance
IDD	Internal Drainage Ditch
LA	Local Authority
LDP	Local Development Plan
LEMP	Landscape and Ecology Management Plan
LPA	Local Planning Authority
NBB	Net Benefits for Biodiversity
NLCA	National Landscape Character Area
NNR	National Nature Reserve

NNRA	National Natural Resources Area
NRAP	Nature Recovery Action Plan
NREA	Nature Recovery Exemplar Area
NRW	Natural Resources Wales
NVC	National Vegetation Classification
OECMs	Other Effective Area-based Conservation Measures
PD	Permitted Development
PIs	Performance Indicators
PPW	Planning Policy Wales
PRoWs	Public Right of Ways
RAG	Red, Amber, Green
RSPB	Royal Society for the Protection of Birds
S106	Section 106 Agreements
SAB	Sustainable Drainage System (SuDS) Approving Body
SAC	Special Area of Conservation
SDP	Strategic Development Plan
SEP	Strategic Enhancement Plan
SINC	Sites of Importance for Nature Conservation
SMNR	Sustainable Management of Natural Resources
SMS	Site Management Statement
SoNaRR	State of Natural Resources Report
SPA	Special Protection Area
SPG	Supplementary Planning Guidance
SSSI	Sites of Special Scientific Interest
SuDS	Sustainable Drainage System
TAN	Technical Advice Note
TCFD	Taskforce on Climate-related Financial Disclosures
TNFD	Taskforce on Nature-related Financial Disclosures
WG	Welsh Government

Executive Summary

This report details the Post Construction Monitoring Study of large developments built within and adjacent to the Gwent Levels Sites of Special Scientific Interest (SSSIs).

Although the area is covered by a range of statutory and non-statutory designations relating to its biodiversity, landscape and historic landscape value it has over time been vulnerable to encroachment by development.

Due to multiple stresses, strengths and potentialities within the Levels, Policy 9 of Future Wales: The National Plan 2040[1] (the National Development Framework) identifies the Gwent Levels as one of nine National Natural Resources Areas (NNRA) in Wales. Welsh Government, working with Stakeholders, have committed to a Pilot Project to assist with the delivery of Policy 9. The Pilot Project looks at delivering additional planning guidance to assist the delivery of Policy 9 in the Gwent Levels. The outcomes from this Post Construction Monitoring Study are required as part of the evidence base for the Pilot Project. The recommendations from this Study will need further consideration as to how or if they could be taken forward. Work on the Pilot Project will feed into that consideration.

Aims and Objectives:

The key aims and objectives of this Post Construction Monitoring Study were to review an agreed list of substantial, already built, developments within the Gwent Levels, to:

- Firstly, assess whether biodiversity impacts, and those relating to the SSSIs features, were successfully identified, and avoided and/or mitigated; and
- Secondly, consider whether action and measures taken at the time could potentially be compatible with present day in relation to the objectives and the principles of Policy 9, to deliver net benefits for biodiversity (NBB). If not compatible or unlikely, to consider why this may be the case.

It is recognised that this second part is somewhat a retrospective assessment as some sites, when they were originally permitted, would have predated many or all of these policy requirements. Nevertheless, this retrospective assessment gives some insight into how they would potentially fare if being determined and monitored in relation to policies as they stand at the time of this Study. This part of the exercise is therefore intended as a means to gain insights and learn from what has happened previously and apply that learning for the future.

The outcomes of this Post Construction Monitoring Study will help inform whether specific actions (referred to in this document as Recommendations) are needed to ensure that biodiversity is preserved and enhanced, and net benefits are achieved for the future of the Gwent Levels. It was acknowledged that some of the recommended actions might be applicable at a wider level across Wales.

The Pilot Project, being undertaken by Welsh Government (WG) and involving stakeholders, recognises that any eventual guidance will take into account the objective and principles of the Sustainable Management of Natural Resources (SMNR) and may therefore need to go beyond traditional planning practice in order to address the multiple and interconnected challenges and opportunities facing the Gwent Levels. Additional planning guidance, when published, will compliment Future Wales and be applied alongside Planning Policy Wales (PPW) in strategic and local development plan preparation and in planning decisions made on the Levels. It will not repeat policy protections which already exist for the Levels. Rather, it will work within and compliment those policies.

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[1] Welsh Government (2021) *Future Wales: The National Plan 2040*. Available at: https://www.gov.wales/sites/default/files/publications/2021-02/future-wales-the-national-plan-2040.pdf. [Accessed January 2024].

The Methodology:

The delivery approach for this Post Construction Monitoring Study set out clear and defined stages, as shown in Figure 1 (Chapter 1), with each being guided and influenced by The Five Ways of Working of the Well-being of Future Generations Act 2015, with a collaborative approach and intent for co-creation. Part of the overall approach was for the methodology of the Study to be shaped and reviewed by a core Steering Group and a Stakeholder Group comprising key stakeholders relating to the Gwent Levels planning system. As part of this, two interactive Stakeholder Group workshops were conducted where the Stakeholder Group was encouraged to think of the long-term needs for nature recovery, focusing on challenges and limitations to achieving NBB within the planning system and any impactful changes required to overcome them.

The methodology focused on a criteria-based assessment aimed at evaluating the potential compatibility of built developments on the Gwent Levels with fulfilling the aims of Policy 9 and PPW. This was achieved by considering how well the developments maintained and enhanced the resilience of ecosystems through their response and contribution to Diversity, Extent, Condition, Connectivity and Adaptability, known as the DECCA Framework. This compatibility was considered both at the planning and determination (pre-construction) stages of development and the implementation and long-term delivery and management (post-construction) stages, to evaluate strengths and weaknesses. A set of DECCA-related criteria questions and a set of Planning System criteria questions were derived in consultation with the Stakeholder Group, for which the built developments were tested against.

In consultation with the Steering Group, potential 'sites' to be considered in this Study were identified. The sites were then sifted based on a number of factors, including whether there was sufficient data and documentation available to allow for a valid assessment. Sites were also put through a 'pilot testing' of the criteria-based assessment. As a result, five sites across the Gwent Levels were selected and put through the full appraisal. The first part of the appraisal consisted of a detailed desk top analysis, site visits and appropriate field appraisals.

The five sites were then tested against the criteria-based assessment which had been developed in discussion with Stakeholders. This part of the assessment allowed for general comparison of how the sites, when considered together, performed against the DECCA and Planning System criterion. The assessment at this stage also allowed for a comparison of each DECCA criterion individually and also for each of the Planning System criterion groups. Each assessment further identified the differences between results at the pre-construction and post-construction stages. From these various assessments, it was possible to determine broad trends in terms of potential compatibility.

Stakeholder Group workshops were held to discuss the delivery of NBB in the Gwent Levels and emerging trends from the results of the criteria-based assessment. The information gathered during these workshops are included in this report. These are, largely opinion-based and/or based on Stakeholder experiences. Although these have not necessarily transferred into direct recommendations in all cases, they do provide a valuable means of validation to the trends and recommendations which came out from the criteria-based assessment.

Assessment Results:

One of the most significant conclusions from the criteria-based assessment was that all sites collectively did better (scored higher) at pre-construction compared to their actual performance post-construction. The poorer performance in actually delivering NBB was typically due to a lack of successful implementation and delivery of mitigation, management and monitoring plans by the developer/landowner to mitigate any negative impacts and provide NBB to the Gwent Levels at construction and post construction stages. This compared to a generally good level of detail regarding proposed delivery of NBB produced and submitted by the applicant/developer at the 'pre-construction' planning application stage and/or to discharge planning conditions which is what was used to help justify the approval of the development in the first place.

The potential for successful compliance with Policy 9 was identified where developments in the Gwent Levels generally **performed well** based on the DECCA and Planning System assessment. However, often this good performance was linked to one or two particular aspects of DECCA rather than all aspects and/or stage of the Planning System. As such this piecemeal good performance would not necessarily have led to a holistic successful delivery of NBB for the SSSIs. Examples of good performance included:

- Developing proposals for ecological designs and habitat management and monitoring plans at the planning application stage. These demonstrate understanding of the potential requirements of maintaining and enhancing Diversity and Condition to achieve NBB. However, Condition and Diversity are only two of the five aspects of DECCA.
- The actual delivery of mitigation, management and monitoring associated with pollution prevention measures and water quality.
- The avoidance and protection of SSSI reens and ditches (both designated features of the Gwent Levels SSSIs) and implementation of buffers from development, demonstrating partial alignment with the step-wise approach.

The potential for failures to comply with Policy 9 and the resilience of ecosystems (DECCA) to achieve long-term NBB were identified within the assessment where developments in the Gwent Levels generally **performed poorly** based on the DECCA and Planning System assessment. Examples of poor performance include:

- Not developing proposed ecological designs and habitat management and monitoring plans which are 'fit for purpose' to achieve NBB through the application of all five aspects of DECCA. For example, lack of detail or requirements in relation to whether compensation or enhanced SSSI features will be functional to support SSSI features (i.e. hold sufficient water in ditches), and/or lack of detail or requirements in relation to supporting habitats for SSSI features such as the grasslands.
- Not developing management and monitoring plans which are targeted, long-term and adaptive.
- Planning conditions relating to long-term management and monitoring for biodiversity not being 'fit for purpose'.
- Failing to implement and deliver long-term management and monitoring for biodiversity, or in some cases the measures as set out in the management plan not working – not achieving what the set out to do.
- Not undertaking an audit trail of the implementation, management and monitoring of NBB.
- Inadequate ecological information being submitted for consideration at the planning application stage with details being deferred to be dealt with at a later date after the development has been approved. Planning conditions are used as the mechanism for submitting these details for approval at a later date.

Recommendations Going Forward:

From the trends and emerging key themes, recommendations were derived which are mainly described in the context of the Gwent Levels. These are recommendations only and further consideration will need to be given as to how, or if, they can be taken forward. Additionally, some of the recommendations have the potential to be applied in other areas in Wales or possibly even for the whole of Wales. This wider application would also need to be subject to further testing and investigation. Although some of the actions have the potential to be delivered in the short-term others may be longer term actions due to their time and resource implications.

The recommendations for further consideration are set out in full in Table 9 (Chapter 6). They are not in any order of priority or timebound, and the effort and impacts associated with implementing these recommendations have not formed part of this Study. As such, they remain recommendations for further consideration. Where next steps and further investigations have however been suggested, these are described to aid the decision-makers with how the recommendations could be further developed. It should be noted that:

- Any recommendations relating to future development proposals are made in the context of PPW: Chapter 6 which places a general presumption against development in SSSIs. PPW Chapter 6 does however acknowledge that there are some developments which would be permitted (as explained in PPW Chapter 6) and as such those developments would still benefit from improvements within the planning system; and
- The recommendations apply to the whole of the Gwent Levels and potentially areas which may affect the Levels. As such, not all parts are covered by SSSI status and the protection they are afforded and hence would also benefit from improvements within the planning system.

A high-level summary of some of the recommendations are listed below. This summary should be read in the context of further details provided in Table 9 and relative to the results and trends described in Chapter 6 of this Study for a full understanding. Recommendations range from measures relating to legislation, policy, regulation and guidance through to development of data management systems for planning, specifically on the Gwent Levels. Some could feed directly into the planning guidance currently being produced for the Gwent Levels. Others could be picked up as part of other workstreams. In no particular order of priority:

- Update the Gwent Levels SSSI's citations and Site Management Statements (SMSs).
- Strengthen legislation to support the delivery of NBB for the long-term.
- Further updates to PPW and Technical Advice Note (TAN) 5 to support the delivery of NBB for the long-term.
- Improved regulations and controls for NBB delivery, management, and monitoring, including:
    - Detailed delivery, management and monitoring plans for NBB considered to be part of the planning application rather than through a planning condition and/or commitments through a Section 106 Agreement (S106).
    - Planning condition standards and consistent wording for the security and delivery of NBB and adaptive long-term management and monitoring.
    - Introduction of NBB bonds/'non-performance bonds', levies, penalties or incentives into policy and regulation to improve delivery of NBB.
- That the planning guidance currently in preparation for the Gwent Levels should include guidance and requirements for NBB assessment and application.
- Implement a consistent data management system for Local Planning Authorities (LPAs) to undertake planning on the Gwent Levels.
- More resources in LPAs to monitor and enforce long-term NBB across the Gwent Levels.
- Corporate nature-based targets and other ways to incentivise developers to deliver successful NBB in the planning system.
- Accredited schemes and standardised approaches to delivery tools for biodiversity, for example Green Infrastructure Statements (GIS), across the Gwent Levels.
- Further protection for habitats that provide ecosystem resilience to Protected Areas and/or new nature conservation measures to avoid loss of nature networks.

Recommendations from this Study should now be further explored as part of the Pilot Project work for the Gwent Levels and other appropriate workstreams. Solutions are likely to need a multi-agency approach in many cases to help achieve the protection and recovery of nature ecosystems within the Gwent Levels and potentially elsewhere. The recommendations could potentially all have their relative role in driving better outcomes for biodiversity and nature recovery within the planning policy and economic development context, as well as wider contribution to secure a nature conscious and nature positive place.

1. Introduction and Approach

1.1 Introduction and Study Context

This report details the Post Construction Monitoring Study of built developments within the Gwent Levels which are within and adjacent to the suite of Sites of Special Scientific Interests (SSSIs).

The Gwent Levels, in South East Wales, is Wales' largest area of coastal and floodplain grazing marsh. It has the benefit of a number of statutory and non-statutory designations relating to its biodiversity, landscape and historic landscape value at the Wales, UK and European level which between them cover the vast majority of the Levels. It plays an important actual and potential role at a regional and national level in climate change adaptation and mitigation (flood storage and carbon sequestration). It is also important in providing supporting habitats to the Severn Estuary which is internationally and nationally designated as a Special Area of Conservation (SAC), Special Protection Area (SPA), Ramsar site and SSSI.

At the same time the Gwent Levels have been vulnerable to encroachment by development. This is largely due to its location being between the major cities of Cardiff and Newport, its topography being mostly flat, and having relatively good infrastructure and grid connectivity and capacity. Additionally, degradation of the Gwent Levels is occurring due to historical lack of appropriate land management as well as water pollution events which impact the ability of the SSSI units to achieve favourable SSSI conditions[2, 3]. Subsequently, the Gwent Levels SSSIs are reduced in terms of favourable condition and flood storage, contributing to an overall loss of biodiversity and ecosystem resilience, as well as contributing to reduced long-term climate resilience.

These multiple stresses, strengths and potentialities are the reason why Policy 9 of Future Wales: The National Plan 2040[4] (the National Development Framework) identifies the Gwent Levels as one of nine National Natural Resources Areas (NNRA) in Wales. The NNRA concept emanates from the Sustainable Management of Natural Resources (SMNR)[5] requirements of the Environment (Wales) Act 2016[6], and from the Five Ways of Working and the sustainable development principles set out in the Well-being of Future Generations (Wales) Act 2015[7], including *inter alia* the development of a sound evidence base, co-production, prevention, and the concept of ecological goods and services.

The Welsh Government (WG) and other public authorities in Wales have an obligation through the Section 6 Duty of the Environment (Wales) Act to have regard to conserving and enhancing biodiversity and promote the resilience of ecosystems where it is within the proper exercise of their function. Planning Policy Wales (PPW)[8] introduced a planning system response to the Section 6 Duty by setting out a framework for planning authorities to maintain and enhance biodiversity and promote the resilience of ecosystems in the exercise of their functions (providing a net benefit for biodiversity (NBB)) and calling for a proactive approach towards

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[2] Dr Kerry Murton, Kate Rodgers and Angela Hunt (April 2020) Conservation Objectives for the reen and field ditch habitat feature and aquatic plant features of the Gwent Levels SSSIs and Newport Wetlands SSSI. NRW Report.

[3] Dr Kerry Murton, Kate Rodgers and Angela Hunt (April 2020) The reen and field ditch habitat surveys undertaken on the Gwent Levels and Newport Wetlands SSSIs in 2010-2013. NRW Report.

[4] Welsh Government (2021) *Future Wales: The National Plan 2040*. Available at: https://www.gov.wales/sites/default/files/publications/2021-02/future-wales-the-national-plan-2040.pdf. [Accessed January 2024].

[5] Natural Resources Wales (2016) *Introducing Sustainable Management of Natural Resource.* Available at: https://naturalresources.wales/media/678063/introducing-smnr-booklet-english-final.pdf. [Accessed January 2024].

[6] Welsh Government (2016) the *Environment (Wales) Act 2016.*Wales.

[7] Welsh Government (2015) *Well-being of Future Generations (Wales) Act 2015: the essentials.* Available at: https://www.gov.wales/well-being-future-generations-act-essentials-html [Accessed January 2024].

[8] Welsh Government (February 2024) *Planning Policy Wales. Edition 12.* Wales. Available at: https://www.gov.wales/sites/default/files/publications/2024-02/planning-policy-wales-edition-12_1.pdf [Accessed January 2024].

facilitating the delivery of biodiversity and resilience outcomes by all those participating in the planning process.

In her Ministerial Statements ('Taking Action to Better Protect and Manage the Gwent Levels' on 1 July 2021[9] and an Oral Statement: Gwent Levels Nature Recovery Exemplar Areas on 14 June 2022[10]), the then Minister for Climate Change, Julie James MS, set out a commitment on the part of the WG to the preparation of a spatial masterplan of the Gwent Levels, working in conjunction with the Gwent Levels Working Group (GLWG), a multi-agency group including representatives from WG and relevant stakeholders across the Levels. A Pilot Project on Future Wales Policy 9 (and NNRA) has commenced to take this forward.

A key output from the Policy 9 and NNRA work will be the formulation and adoption, following a consultation process, of planning guidance to supplement Future Wales. The Pilot Project recognises that the guidance will take into account the principles of SMNR and will therefore need to go beyond traditional planning practice in order to address the multiple and interconnected challenges and opportunities facing the Gwent Levels. This additional guidance will compliment Future Wales and be applied alongside PPW in strategic and local development plan preparation and in planning decisions made on the Levels. It will not repeat policy protections which already exist for the Levels – rather it will work within and compliment those policies. In October 2023, WG published updated Chapter 6 policy of PPW, which included a strengthened approach to the protection of SSSIs, with increased clarity on the position for site management and exemptions for minor development necessary to maintain a 'living landscape'. Other development is considered unacceptable as a matter of principle. Exceptionally, a planned approach may be appropriate where necessary safeguards can be secured through a development plan. PPW makes clear that this could only happen if there is an agreed position in a development plan which indicates that the proposed development is acceptable in terms of its effect on the notified features of the SSSI. PPW however recognises that such circumstances are likely to be wholly exceptional. Existing policies and protections are explained in more detail in Chapter 2 of this post construction monitoring report.

The working hypothesis for the delineation of the NNRA for the purposes of this Post Construction Monitoring Study is the National Landscape Character Area (NLCA34), however, no firm decisions have been made at the time of writing as to what the final delineation will be for the Pilot Project itself.

As stated above, a key element which will underpin all the WG's work on the Policy 9 Pilot Project will be the need for evidence. It is important, in the context of the complexity and fragility of the Gwent Levels and its role as a NNRA, that a sound evidence base informs planning and wider land use decisions and the deployment of resources. This Post Construction Monitoring Study is a key strand in this evidence gathering imperative.

There have been no previous iterations of this Post Construction Monitoring Study. The Study's intentions are to better understand the evidence that can be gained from past development, within and adjacent to the Gwent Levels SSSIs and NNRA, in terms of ecological impact and mitigation, as well as implementation and monitoring of biodiversity safeguarding, enhancement and net benefits.

The purpose of this Study is to complement other on-going work in the NNRA, such as the Gwent Levels Strategic Enhancement Plan (SEP) work commissioned by the WG to help inform other elements of national policy and guidance, as appropriate. This Study is designed to form a starting point rather than end point on assessing post construction impacts and monitoring of development on or otherwise affecting the NNRA, and elsewhere. There will likely be an evaluation strand of the Pilot Project which will gather all learning

[9] Julie James, Minister for Climate Change (2021). *Written Statement: Taking Action to Better Protect and Manage the Gwent Levels.* Available at: https://www.gov.wales/written-statement-taking-action-better-protect-and-manage-gwent-levels [Accessed January 2024].

[10] James, J (2022). *Statement by the Minister for Climate Change: Gwent Levels / Nature Recovery Exemplar Areas.* Available at: https://record.senedd.wales/Plenary/12876#A72751. [Accessed January 2024].

and consider whether the overall approach developed for the Pilot Project could be applied elsewhere in Wales.

1.2 Study Aims and Objectives

The key aims and objectives of this Study are to review an agreed list of substantial, already built, developments (hereafter referred to as 'selected sites') within the Gwent Levels (within or adjacent to the SSSIs), to firstly assess how successfully biodiversity impacts, and those relating to the SSSIs features, were identified, and avoided and/or mitigated. Secondly, to consider whether action and measures taken at the time could now potentially be compatible with the objectives and the principles of Policy 9 and SMNR and the resilience of ecosystems (DECCA Framework, see section 2.1 below) to deliver net benefits for biodiversity (NBB), and if not, to consider why this may be the case. It is recognised that this second part is somewhat a retrospective assessment as many sites will predate some, if not all, of these policy requirements – nevertheless it gives some insight into how they would potentially fare if being determined and monitored in relation to policies as they stand at the time of this Study. The approach was intended as a means to gain insights and learn from what has happened previously and apply that learning for the future.

The review of the selected sites used a consistent and agreed assessment methodology, supported by site visits and appropriate site appraisals, utilising accepted biodiversity-related criteria to assess the degree to which the planning, construction and post construction operations of the development (including mitigation measures and their associated management and monitoring) achieved the intended result of removing or reducing to a trivial or inconsequential level adverse impacts on the Gwent Levels SSSIs (within the proposed NNRA) and their supporting ecosystems. Further to this, the assessment aimed to consider the different stages of the planning system, from pre-application to post construction monitoring, to evaluate strengths and weakness. Further details of the methodology are outlined in the section below and in Chapters 3 to 5.

From the onset, it was also recognised that older applications/sites were going to be assessed against today's policy, standards, guidance, and ecological knowledge relating to the Gwent Levels. It is recognised that this is somewhat a retrospective assessment as some sites, when they were originally permitted, would have predated many or all of these policy requirements. This was, however, factored into the assessment to allow for examination of trends, and determine generally where the sites had the potential to consistently perform well over time, where they would perform poorly, and where changes in policy, legislation, regulation and guidance may have impacted that performance.

The specific findings of this Study are required to form part of the evidence base for the Policy 9 Pilot Project and to potentially inform future action which may be useful, including revisions of PPW, Future Wales, prospective strategic development plans and the three local development plans of Cardiff, Newport and Monmouthshire, as appropriate.

In summary, this Study aimed to carry out a primarily desk-based review of built development across the Gwent Levels constructed since the early 1990s, supported by site visits and appropriate field appraisals, and deliver two key outputs:

- An assessment identifying whether and how impacts on the condition of the features within the relevant SSSIs were addressed in an acceptable way for an agreed list of development sites; and,
- As a consequence of the first part, to consider whether the development types identified could be considered compatible now with the aims of Policy 9 of Future Wales and the objectives and principles of SMNR and the resilience of ecosystems, by considering how well the development has responded to each of the DECCA attributes and emerging properties (as described in Section 2.1.10 below).

In relation to the second output above, the initial brief from WG aimed to select a range of sites that were representative of different development types built across the three Local Planning Authorities (LPAs) within the Gwent Levels to compare differences in impacts, mitigations and alignment with current policy, legislation and guidance. However, this comparison was not statistically viable due to temporal factors and sample size and became evident early on at the site selection stage of the project. See Chapter 3 for more detail on the Site Selection Process. Therefore, in terms of the second output above this ended up dealing with development in general rather than being able to reach conclusions based on specific development types.

1.3 Outline Methodology and Delivery Approach

At the onset of the project, a Steering Group was set-up including key advisors and leads from WG's department groups (including Climate Change and Rural Affairs, Property Infrastructure, and Planning Policy/Planning Directorate). Key advisors relating to planning, nature conservation and specifically relating to the Gwent Levels from Natural Resources Wales (NRW) and the Gwent Wildlife Trust (GWT) were also involved, particularly in the early design stages of the work.

A wider Stakeholder Group was then engaged including the above and Chief Planning Officers, Planning Officers, Biodiversity and Ecology Officers, Green Infrastructure and Landscape/Placemaking Officers from the three Local Authorities (LAs) of the Gwent Levels, being Cardiff, Newport and Monmouth, as well as Conservation and Planning Officers from NRW, GWT, Royal Society for the Protection of Birds (RSPB) and the Living Levels Project. Stakeholder workshops, consultation and reviews were held at key stages of the development of the Study, as demonstrated in Figure 1 below and further detailed in Chapter 5.

The outline methodology and delivery approach had clear and defined stages in undertaking the study, with each stage being guided and influenced by the Steering Group and Stakeholder Group, to ensure co-creation, collaboration and review, aligned with The Five Ways of Working of the Well-being of Future Generations Act[11]. Figure 1 below shows the outline methodology of the Study, showing the development of the methodology both through collaboration with the Steering and Stakeholder Groups but also through testing and application. These stages are summarised below and illustrated in Figure 1, with more details provided in Chapters 3 to 5.

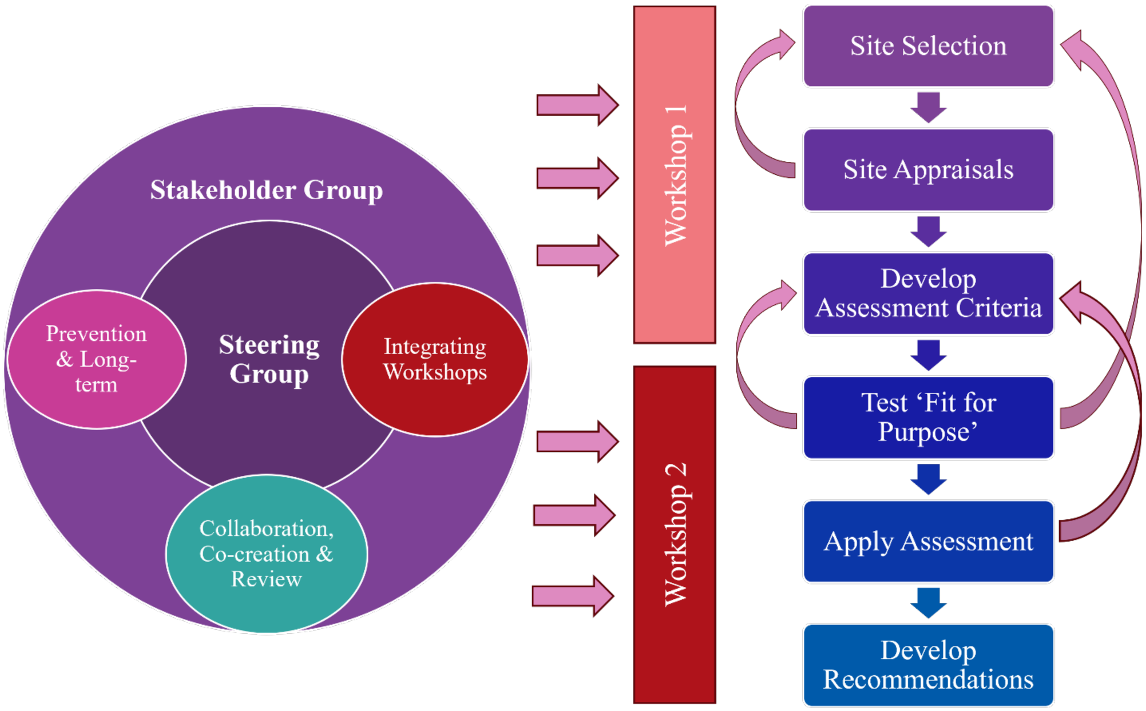

Figure 1: Outline methodology and delivery approach of defined stages of delivery with feedback loops of methodology development, all of which being co-developed collaboratively with the Steering and Stakeholder Groups.

[11] Future Generations Commissioner for Wales. Well-being of Future Generations (Wales) Act 2015. Available at: [redacted] [Accessed May 2024].

Stage 1: Site selection

As can be seen from Figure 1, this was an iterative process guided by the aims and objectives of the Study and refined by the Steering and Stakeholder Groups as well as the feedback from conducting the site appraisals and testing the 'fit for purpose' both from the site appraisals and the development of the assessment criteria. Through this process a preliminary list of 13 built developments was identified at the start of the Study (Appendix A.1), which was reduced to a short-list of seven sites, and then further refined through testing for 'fit for purpose' to the final five sites selected for the Study. This is further described in Chapter 3.

Stage 2: Site appraisals

These were conducted for the short-listed built developments. These included two elements, a) reviewing the planning documents relative to the ecological protection, mitigation and onward management and monitoring, and b) site survey visits. The site surveys followed standard methodologies of recording habitats, with bespoke survey sheets developed which were robust enough to rapidly assess the likely condition of the habitats and SSSIs features condition, as well as whether there was evidence of the proposed mitigation measures having been undertaken, including any management proposals. Through the site appraisals some sites were found to not be suitable to be progressed any further in this Post Construction Monitoring Study - the reasons for which are further explained in Chapter 3.

Stage 3: Develop Assessment Criteria

Assessment criteria were co-developed and reviewed through the Steering Group and Stakeholder Group (as shown in Figure 1 and described further in Chapter 5). These consisted of DECCA Framework criteria and Planning System criteria. The DECCA assessment criterions were circulated post Workshop 1 and a two-week consultation period offered to the Stakeholder Group for detailed comments. This part of the assessment was developed with the key aim to assess how successfully biodiversity and ecosystem resilience impacts were identified and addressed at pre-construction (planning stages) and at post-construction for the selected sites. The DECCA criteria were designed to be relative to the DECCA attributes and emerging properties (as described in Section 2.1.10 below), up-to-date standards, principles and best-practice guidance to ensure protection and enhancement of biodiversity, as well as specific principles and best-practice knowledge relating to the Gwent Levels SSSIs features. The Planning System criteria were derived from the interactive session in Workshop 1. Workshop 1 demonstrated the need for a separate set of criterions that could draw out differences between the stages of development planning and delivery in terms of the protection and enhancement to biodiversity and the Gwent Levels ecosystems. Post the workshop and based on discussions and data obtained during the interactive session, a set of planning process/system criterion were circulated, with a two-week period for members of the Stakeholder Group to comment. The DECCA Framework and Planning System criteria-based assessments were developed around a set of questions where the selected sites could be scored on a basis of strong, moderate or weak alignment with the criterion question being assessed. A confidence level was also applied to each of the criterion performance alignment scores, which is further described in Chapter 4.

Stage 4: Test 'Fit for purpose'

The criteria-based assessments and the short-listed seven sites were then tested for 'fit for purpose' against the Study's aims and objectives. Through this process, and in collaboration with the Steering Group and Stakeholder Group, the assessment criteria were reviewed, amended, and finalised. Similarly, the sites selected for the Study assessment were reviewed and finalised through this testing. Two sites were removed from the Study due to not aligning with the aims and objectives of the Study and/or did not have sufficient data to allow for a meaningful assessment to be made, further details are provided in Chapter 3. The review process is shown in Figure 1 as 'feedback loops' to both refinement of site selection and development of the assessment criteria.

Stage 5: Apply Assessment

The final five sites selected were then tested against the criteria-based assessment and relative performance alignment scores and confidence levels derived. The multiple variables across the different sites and sample size would not allow for a controlled statistical assessment or a comparison between different development types. Therefore, the sites were individually assessed, according to the DECCA and Planning System criterion questions, and the results presented collectively for development generally as means across the five selected sites. This enables analysis of the best and worst performance for the criterions at both pre-construction and post-construction stages, determined by evidence and site appraisals. The assessment methodology and data synthesis and analysis are further described in Chapter 4.

Stage 6: Develop Recommendations

Radar diagrams were used to represent the collective sites performance against the assessment criterion, allowing for the differences and trends to be visualised and analysed between the various criteria as well as the differences between pre-construction/planning stages compared to the post-construction/post-consent delivery stages (see Chapter 4 for results and analysis). Emerging themes and trends were discussed and further investigated with the Steering and Stakeholders Groups, which also made-up part of Workshop 2 (see Figure 1 and Chapter 5). From these trends, broad themes for recommendations were derived in consultation with the Steering and Stakeholder Groups and during interactive and collaborative activities within the workshops (see Chapter 5 for further description of the collaborative recommendation building exercises). Synthesis and analysis of both the criteria-based assessment data and the information, experiences and perspectives gathered from the stakeholder recommendation building exercises is provided in Chapter 5 and 6. Final recommendations are presented in Chapter 6 as suggested actions, both specific actions for the Gwent Levels and its unique biodiversity and environmental requirements, as well as actions that could be tested and/or are likely to be applicable in driving better outcomes for biodiversity and nature recovery within the planning policy and economic development context across the whole of Wales.

1.4 Structure and Delivery

Taking into account the stages described above, this Post Construction Monitoring report is set out as follows:

- **Chapter 2** sets out the baseline review of nature related policy in Wales which has influenced and shaped both statutory requirements and the planning landscape, as well as shaping major development decisions and bespoke mitigation advice over time. The baseline review also sets out the Gwent Levels in relation to historic features and land use, landscape character and land-based designations.
- **Chapter 3** describes the Study site selection process and methodology, providing details on the range of limiting factors and how sites were selected and considered 'fit for purpose'. This chapter describes the methodology and presents the results from the selected sites surveys and site appraisals conducted to inform the Study.
- **Chapter 4** presents the methodology and results from the criteria-based assessment, setting out how the sites performed against the DECCA and Planning System assessment criteria, considers performance at pre-construction and post-construction stages of the developments.
- **Chapter 5** sets out the collaborative stakeholder engagement and results from the interactive activities conducted at the two workshops. Although the workshops and stakeholder involvement was to refine the site selection (described in Chapter 3) and the assessment criteria (described in Chapter 4), the workshops also focused on targeted activities to draw out the groups thoughts to what they collectively and individually considered to be limiting factors and most impactful changes required for achieving NBB within the planning system of the Gwent Levels and beyond. The synthesis and analysis of the information and perspectives gathered during these interactive workshop sessions are presented in this chapter.
- **Chapter 6** pulls together the emerging themes from the criteria-based assessment data and the information and perspectives gathered from the stakeholder recommendation building exercises described in Chapters 3 to 5 and provides a clear set of recommendations and potential actions, which could be applied to the policy context and decision-making of the Gwent Levels going forward and possibly elsewhere in Wales.

2. Baseline Review of Nature Policy in Wales, the Gwent Levels Landscape and Major Development Decisions

This Chapter presents a baseline review of nature related policy and its evolution in Wales which has influenced and shaped both statutory requirements and the planning landscape relative to biodiversity safeguarding, mitigation, and enhancement. A baseline review is also presented summarising the history of the Gwent Levels, present day's landscape charter and nature-rated designations and protected areas, along with referencing some of the more major developments that have taken place on the Levels.

2.1 Key Policy and Statutory Requirements

2.1.1 The Environment (Wales) Act 2016

The Environment (Wales) Act 2016 was introduced to put in place the legislation needed to plan and manage Wales' natural resources in a sustainable and joined-up way and is intended to work alongside the Well-being of Future Generations (Wales) Act 2015. Part 1 of the Environment Act sets out Wales' approach to planning and managing natural resources at a national and local level with a general purpose linked to statutory 'principles of sustainable management of natural resources' defined within the Act. The objective of SMNR is to maintain and enhance the resilience of ecosystems and the benefits (ecosystem services) they provide, and in doing so meet the needs of present generations of people without compromising the ability of future generations to meet their needs, and contribute to the achievement of the well-being goals.

The Act amongst other things aims to build the resilience of Welsh ecosystems which in turns helps create jobs, supports livelihood and human well-being, adapt to the adverse impacts of climate change, and contribute towards sustainable development. The Act has duties and commitments to reverse the decline in biodiversity in Wales and increase the resilience of Welsh ecosystems. It requires all public authorities to "*seek to maintain and enhance biodiversity in the exercise of its functions in relation to Wales, and in so doing promote the resilience of ecosystems, so far as consistent with the proper exercise of those functions*". As set out in the letter from the Minister for Climate Change (December 2022)[12] "*in complying with the duty public authorities must take account of the resilience of ecosystems, in particular the following aspects (known as the DECCA Framework):*

- *diversity between and within ecosystems;*
- *the connections between and within ecosystems;*
- *the scale of ecosystems;*
- *the condition of ecosystems (including their structure and functioning); and,*
- *the adaptability of ecosystems.*

In relation to the duty public authorities must also have regard to:

- *the priority habitats and species list published under Section 7 of the Act;*
- *the State of Natural Resources Report (SoNaRR) published under Section 8;*
- *any Area Statement published under Section 11 for an area that includes all or part of an area in relation to which the authority exercises functions;*
- *to any guidance given to it by the Welsh Ministers*".

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[12] Welsh Government (2022) *COP15, Biodiversity Deep Dive, Section 6 Duty and the Planning System*. Available at: https://www.gov.wales/sites/default/files/publications/2022-12/cop15-biodiversity-deep-dive-section-6-duty-and-the-planning-system.pdf. [Accessed January 2024].

The Act also sets out the concept of the SMNR placing a specific duty on the regulatory and advisory body for issues relating to the environment in Wales, NRW, to ensure that the environment and natural resources of Wales are sustainably maintained, sustainably enhanced and sustainably used.

2.1.2 Future Wales: the National Plan 2040

Future Wales provides additional commitments for ensuring resilient location and design choices, reversing the decline in biodiversity, and increasing the resilience of ecosystems. Policy 9 confirms resilient ecological networks are vital for nature recovery and are defined as "*networks of habitat in good ecological condition linking protected sites and other biodiversity hotspots across the wider landscape, providing maximum benefit for biodiversity and well-being*". The Statement from the Minister for Climate Change of July 2022[10] announced that the Future Wales Policy 9 approach would be piloted on the Gwent Levels to pro-actively embed biodiversity considerations into planning policies within NNRA in Wales. Work on that Pilot Project has already commenced and the evidence from this Post Construction Monitoring Study will feed into that Pilot.

2.1.3 Well-being of Future Generations (Wales) Act

The Well-being of Future Generations Act 2015 focuses on improving the social, economic, environmental, and cultural well-being of Wales. To assist in the achievement of such improvements to well-being, seven well-being goals were created which set out a common vision for public bodies to work towards. Notably, this includes the Resilient Wales goal that strives for a nation which maintains and enhances biodiversity and the functioning of ecosystems to support social, economic, and ecological resilience.

The Well-being of Future Generations Act is a ground-breaking piece of legislation that requires public bodies in Wales to work better with others (including each other and communities) and take a more joined up, long-term approach so that their decisions have a positive impact on people living in the future as well as those living today. The Five Ways of Working of the Well-being of Future Generations Act explore what the ways of working might mean in practise to deliver the seven well-being goals, some of the barriers to implementation, their potential impact on the third sector, and some useful resources and support for further thinking. The Five Ways of Working are the principles that the public bodies listed in the Act must demonstrate in their decision making in order to show that they are taking into account the impact that they could have on people living their lives in Wales in the future as well as in the present. This is to show that they are acting in accordance with the sustainable development principle, defined as '*acting in a manner that seeks to ensure that the needs of the present are met without compromising the ability of future generations to meet their own needs*'. The Five Ways of Working are: Thinking for the Long-Term, Prevention, Integration, Collaboration and Involvement.

2.1.4 State of Natural Resources Report

The State of Natural Resources Report (SoNaRR) 2016[13] sets out the state of Wales' natural resources. It assesses the extent to which natural resources in Wales are being sustainably managed and recommends a proactive approach to building resilience. The report looks at how pressures on Wales' natural resources are resulting in risks and threats to long-term social, cultural, environmental and economic well-being, as set out in the Well-Being of Future Generations (Wales) Act 2015. The report looks at the key issues, as well as opportunities for integrated solutions that provide multiple benefits.

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[13] The State of Natural Resources Report (SoNaRR): Assessment of the Sustainable Management of Natural Resources. Technical Report. (2016). NRW. Wales. Available at: [redacted] Accessed January 2024].

The second SoNaRR report was published in 2020[14], assessing Wales' sustainable management of natural resources and sets out a range of opportunities for action. The Bridges to the Future section proposes a transformational approach for how Wales can bridge the gap between where it is now and where it needs to be to achieve a sustainable future. SoNaRR assesses sustainable management of natural resources (SMNR) against the four long-term aims of SMNR. These are: safeguarded and enhanced natural resources, resilient ecosystems, healthy places for people, and a regenerative economy. The report presents the best available evidence to support the assessment in eight cross-cutting theme chapters and eight broad ecosystem chapters. The key pressures, impacts and opportunities are summarised in the natural resource registers and can be explored using interactive infographics.

2.1.5 Natural Resources Policy

The Natural Resources Policy (2017)[15] sets out how as a nation, Wales will improve the management of natural resources, delivering against both economic and environmental objectives. This includes a focus on building ecosystem resilience by proactively developing resilient ecological networks, improve the condition of ecosystems, and reduce and better manage pressures and demands on ecosystems and natural resources.

2.1.6 Nature Recovery Action Plan for Wales

The Nature Recovery Action Plan (NRAP) (2020)[16] sets out the commitment to reversing the loss of biodiversity in Wales and objectives for action. This includes objectives to safeguard and improve the management of species and habitats of principal importance, and to increase the resilience of the natural environment through habitat creation, restoring degraded habitats, and tackling key pressures on species and habitats.

2.1.7 30 by 30

The Biodiversity Deep Dive conducted by the WG in support of the United Nations COP15 Biodiversity Summit centred its recommendations around the United Nations' commitment to deliver of the 30 by 30 target to protect, effectively and equitably manage 30% of land, freshwater and seas by 2030[17]. To support the delivery of 30 by 30, immediate actions include expanding and scaling up the Nature Networks Programme to improve the condition, connectivity and resilience of protected sites, focusing on active involvement of local communities and exploring opportunities to use Section 16 Land Management Agreements as match funding to enable additional sources of funding for nature recovery[18].

In the Minister for Climate Change Oral Statement 'Gwent Levels Nature Recovery Exemplar Areas' on 14th June 2022[10], the Minister stated that '*The Gwent Levels are an important part of the contribution to meeting this ambition* [30 by 30 target] *and the focus must now be on improving the condition of this protected area and its margins*'.

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[14] The Second State of Natural Resources Report (SoNaRR2020). NRW. Wales. Available at: [redacted] January 2024].

[15] Welsh Government (2017) *Natural Resources Policy.* Wales. Available at: https://www.gov.wales/sites/default/files/publications/2019-06/natural-resources-policy.pdf. [Accessed January 2024].

[16] Welsh Government (2020) The Nature Recovery Action Plan for Wales 2020-21. Available at: https://www.gov.wales/sites/default/files/publications/2020-10/nature-recovery-action-plan-wales-2020-2021.pdf [Accessed January 2024].

[17] Welsh Government (2022) *COP15, Biodiversity Deep Dive, Section 6 Duty and the Planning System.* Available at: https://www.gov.wales/sites/default/files/publications/2022-12/cop15-biodiversity-deep-dive-section-6-duty-and-the-planning-system.pdf. [Accessed January 2024].

[18] Welsh Government (2022) *Biodiversity deep dive: recommendations.* Available at: https://www.gov.wales/biodiversity-deep-dive-recommendations-html. [Accessed January 2024].

2.1.8 Ministerial Protection and Management of the Gwent Levels

Following the announcement of the Nature Emergency in June 2021, the WG provided a Written Statement relating to the protection and management of the Gwent Levels – 'Taking Action to Better Protect and Manage the Gwent Levels'[9] on 1 July 2021 and an Oral Statement 'Gwent Levels Nature Recovery Exemplar Areas'[5] on 14th June 2022. These included commitments to ensuring the Gwent Levels are better protected and managed, with additional action to maintain and enhance biodiversity and build resilient ecosystems.

In the Minister for Climate Change Written Statement issued in October 2022[10], the Minister reported on the findings of the 30 by 30 Biodiversity Deep Dive. The recommendations are a mixture of new actions that can be taken immediately, a scaling up and acceleration of existing schemes, and longer-term actions that will deliver benefits throughout this Senedd term and beyond. One such recommendation hinges around the need to transform our protected sites series so that it is better, bigger, and more effectively connected.

2.1.9 Planning Policy Wales

Planning Policy Wales[8] (PPW) responds to the Environment (Wales) Act Section 6 Duty by establishing a framework for planning authorities to deliver NBB. The Policy states that planning authorities must maintain and enhance biodiversity, meaning development should not cause any significant loss of habitats or populations of species, and must provide NBB. Specifically, this includes the application of the DECCA framework, taking reasonable steps to maintain and enhance biodiversity and ecosystem resilience through development, and the requirement that resilient ecological networks should be built. In October 2023, WG published updated Chapter 6 policy of PPW with immediate effect, which included a strengthened approach to the protection of SSSIs, with increased clarity on the position for site management and exemptions for minor development necessary to maintain a 'living landscape'. Other development is considered unacceptable as a matter of principle. Exceptionally, a planned approach may be appropriate where necessary safeguards can be secured through a development plan. PPW makes clear that this could only happen if there is an agreed position in a development plan which indicates that the proposed development is acceptable in terms of its effect on the notified features of the SSSI. PPW however recognises that such circumstances are likely to be wholly exceptional. Further amendments were provided, including further emphasise on the importance of NBB and the resilience of ecosystems, further clarity on the step-wise approach, the introduction of Green Infrastructure Strategies and strengthened protection for trees and woodlands. PPW Edition 12[8] was published in February 2024, capturing these changes to Chapter 6.

PPW (and Future Wales) also sets out how the planning system at a national, regional and local level can assist in delivering these requirements through Strategic Development Plans (SDPs) and Local Development Plans (LDPs). LDPs should set out a vision for how places are expected to change in land-use terms to accommodate development needs over the plan period. PPW is supplemented by a series of Technical Advice Notes (TANs), Welsh Government Circulars, and policy clarification letters, which together with PPW provide the national planning policy framework for Wales. TAN 5: Nature Conservation and Planning and TAN 15: Development and Flood Risk are of relevance to developing within the Gwent Levels, in relation to the SSSIs designation and high flood risk on the Levels. TAN 15 is currently being updated to focus more on a risk-based approach to decision making in response to climate change and achieving climate resilience. The new TAN 15 and associated new Flood Map for Planning (FMfP) now means that larger areas across Wales are considered to be in higher flood risk category. Consequently, in the future, there may be a greater number of instances where flood risk concerns prohibit development and re-development plans.

2.1.10 Welsh Government's Approach to Net Benefits for Biodiversity and Ecosystem Resilience

The definition of ecosystem resilience published in its SoNaRR in 2016[19], which is: "*the capacity of ecosystems to deal with disturbances, either by resisting them, recovering from them, or adapting to them,*

[19] Natural Resources Wales (2016) 'Chapter 4: Assessment of the Sustainable Management of Natural Resources' in *The State of Natural Resources Report (SoNaRR) 2016.*

whilst retaining their ability to deliver services and benefits now and in the future". Assessing resilience is difficult because ecosystems are complex and dynamic; responses to disturbances vary greatly in type, scale and duration, and many of the underlying mechanisms are not well understood. The DECCA Framework[20] has been developed by NRW to improve understanding of ecosystem resilience by using four ecosystem attributes and their emergent properties as proxies for resilience. Resilience arises from the interplay between the attributes, rather than from any one attribute in isolation.

The DECCA framework has four measurable attributes and emergent properties which are both aspects of ecosystem resilience[21]. This framework includes increasing **Diversity** of habitats and species on every level and scale to support complex interactions which is important for adaptation; increasing **Extent** of habitats (existing and new) through size and links of ecosystems; improved **Condition** of habitats through avoiding and mitigating pressures on ecosystems and increasing **Connectivity** by developing links between and within habitats to promote ecological networks. **Adaptability** is regarded as a product of the above four attributes which shows the recovery and resistance of habitats to pressures such as disturbances and climate change. These emergent properties show ecosystem resilience, which is not directly measurable but can be assessed through the ecosystem attributes of the framework and the emergent properties[22].

2.2 History of the Gwent Levels

2.2.1 Key Historic features

The Sea Wall

The Gwent Levels are situated approximately 7m above mean sea level[23]. The tidal range of the Severn Estuary is 14m, meaning at high tide large parts of the levels would be submerged under 1-2m of water a day. Therefore, a sea wall was constructed to prevent flooding.

The first sections of the sea wall were constructed around 100CE by Roman soldiers as sea defences. These defences were rebuilt and extended in the Middle Ages. Over the centuries, the wall has been repaired, modified and moved in land in response to rising sea levels. The existing wall is 35km in length. It dates from the medieval period and was rebuilt from 1953 to 1974.

Reens and Ditches

The reens and ditches characterise the Gwent Levels. They form a unique network of over 1500km of highly interconnected waterways that form field boundaries and connect ecosystems[24].

The reens and ditches are a hand-dug habitat, created primarily to drain the land of freshwater. Some of the features, such as the Percoed Reen, originate from the Roman era. However, most of the features are predominantly medieval or later in date.

The Gwent Levels are a naturally wet landscape resulting from underground springs, rainfall and run-off from surrounding upland areas. The creation of this network of reens and ditches allows for the control of water levels within the Levels and takes water off the land and out to sea, making it habitable for both people and livestock. Typically, rainwater is removed from fields along a network of ridge and furrows, or 'grips'.

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[20] Garret, H.M., and Ayling, S (2020). Ecosystem Resilience in a nutshell 1. What is ecosystem resilience? Natural Resources Wales. Bangor.

[21] CIEEM (2022) Welsh Government's Approach to Net Benefits for Biodiversity and the DECCA Framework in the Terrestrial Planning System. Available at: [redacted] [Accessed February 2024].

[22] Natural Resources Wales (2021) Terrestrial and freshwater Resilient Ecological Networks: a guide for practitioners in Wales. Available at: [redacted] [Accessed February 2024].

[23] Living Levels (2022) Sea Wall, Goldcliff. Available at: [redacted] [Accessed February 2024].

[24] Living Levels (2021) Reens, ditches and grips. Available at: [redacted] [Accessed February 2024].

Water then flows into field ditches that surround each field and out into a system of reens. The larger main reens take water down to the sea wall and discharge at intervals into the estuary through tidal flaps.

Reens, ditches and grips provide a significant wildlife corridor and home to rare aquatic flora and fauna[25], supporting SSSIs features and many European protected species (EPS).

Archaeology

The Gwent Levels is listed in the Register for Historic Landscapes in Wales[26]. It is an area of national importance and national significance in part due to its rich and archaeological and historic resource.

Agriculture on the Levels

The Gwent Levels are one of the largest areas of grazing marsh in Britain and has been used as productive agricultural land since the Romans[27]. Traditional agriculture has been declining over the last century as agricultural policy favours more intensive farming practices. This has resulted in the loss of semi-natural pastures and meadows for more improved grassland and arable production. Nevertheless, 'environmentally sensitive permanent grasslands' (ESPG)[28] still exist across the Levels which are both important within their own right and also as supporting habitats to species associated with the SSSIs.

Orchards were once a distinctive feature and integral part of the landscape and agriculture of the Gwent Levels[29]. The unique planting technique and landscape created traditional Welsh varieties of fruit trees and commercial fruit production.

2.3 Present Day Gwent Levels

2.3.1 Landscape Character

The Gwent Levels represents the largest and most significant example in Wales of a 'hand-crafted' landscape[30]. The landscape comprises an extensive area of low-lying drained agricultural land.

The Outstanding Historic Landscape of Gwent Levels, as cited in Part 2:1 of the Register of Landscapes, Parks and Gardens of Outstanding Historic Interest in Wales 1998, comprises two discrete and extensive areas of alluvial wetlands and intertidal mudflats situated on the north side of the Severn Estuary: Wentlooge Level and Caldicot Level. Wentlooge Level extends from Cardiff and the River Rhymney to the mouth of the River Usk. Caldicot Level, which extends between the River Usk and the bedrock promontory at Sudbrook.

2.3.2 Designated Sites

The designated sites within proximity to the selected developed sites being assessed, across the Gwent Levels, are shown on Figure 2 and summarised as below.

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[25] Pickup, T (2019) *The History of the Drainage of The Gwent Levels.* Living Levels Landscape Partnership

[26] Living Levels (unknown) Archaeology. Available at:[redacted]. [Accessed February 2024].

[27] Living Levels (2019) Unveiling the ancient history of the Gwent Level. Available at: https://www.livinglevels.org.uk/news/2019/8/19/unveiling-the-ancient-history-of-the-gwent-levels [Accessed February 2024].

[28] 'Environmentally sensitive permanent grasslands' (ESPG) are defined in the Common Agricultural Policy (CAP) with measures such as banning the ploughing or conversion with particular focus of those within Natura 2000 sites. Available at: [redacted] and [redacted] [Accessed February 2024].

[29] Living Levels (unknown) Orchards on the Levels. Available at: [redacted] [Accessed February 2024].

[30] Chris Blendford Associates (2017) Gwent Levels Landscape Character Assessment. CBA.

2.3.2.1 Gwent Levels SSSIs

The suite of the Gwent Levels SSSI units are described below. The special features for all of these SSSI units are:

- Reen and ditch habitats;
- Insects and other invertebrates (aquatic); and
- The shrill carder bee (*Bombus sylvarum*).

Although the grassland is not specifically listed as a feature of interest, it is necessary for the adult life stages of important invertebrates such as soldier flies which are part of the designation. Shrill carder bees also rely on large extents of species-rich grassland for foraging. The sympathetic management of the surrounding grassland is therefore fundamental for the survival of aquatic plants and invertebrates features which is why that land was included within the designated site boundaries at notification[2].

Additional biodiversity interest include protected species, such as dormice (*Muscardinus avellanarius*) and bats, that use the connective habitats.

The reens and ditches across these SSSI units support plant species and communities that are rare or absent in other levels systems. There are a series of Performance Indicators (PIs)[31, 32] that are used to determine the condition of the Gwent Levels SSSIs. These PIs are based upon the following:

- Extent of standing water with target set reflecting the overall extent of the feature within the SSSI identified at the time of notification;
- Presence of hedgerows alongside ditches (which cause overshading) within each 'field block'[33], whereby the PI of whether a field block is in favourable or unfavourable condition depends on the percentage of ditches within that field block being within the category 2, 2d, 3 or 4c[34], To be in favourable condition no more than 50% of the ditches must be within these categories, and over a whole SSSI at least 15% of ditches to be category 5 or 4a and 25% of ditches to be category 1 or 4b;
- Quantity of submerged flora within both main reens (60%+ have at least 50% of points with submerged flora) and internal drainage ditch (IDD) watercourses (50%+ have at least 50% of points with submerged flora); and
- Vegetation type and SSSI feature plant presence in the channel and margin of field ditches for IDD watercourses.

Factors that affect the condition include scrub encroachment, changing land practices, loss of field ditches through creation of larger fields and both point source and diffuse pollution.

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[31] Living Levels (2017) *Living Levels Landscape Partnership – Landscape Conservation Action Plan*

[32] Murton, K., Rodgers, K. & Hunt, A. (April 2020) Conservation Objectives for the reen and field ditch habitat feature and aquatic plant features of the Gwent Levels SSSIs and Newport Wetlands SSSI. NRW report.

[33] Countryside Commission for Wales (CCW) went through a process of dividing the SSSIs into units for ease of recording, reporting and management. Each main reen and IDD reen is a management unit in their own right. The blocks of land between the main reens were then assigned as 'field block' units. Field blocks contain numerous ditches and land within different ownerships but form a cohesive unit for the purposes of management.

[34] Ditches categories: 1: Hedge on one side of the ditch, 2: Hedges on two sides (double hedged) of the ditch, 3: No hedge alongside the ditch but the ditch appears to be dry, 4. Intermittent hedge (note this one is split into three sub categories), (4a intermittent/gappy hedge on one side, open on other, 4b intermittent hedge on both sides, 4c one side of ditch has an intermittent hedge, other side of ditch is hedged), 5: No hedge on either side of the ditch and the ditch appears to be holding water

Rumney and Peterstone SSSI

Rumney and Peterstone SSSI[35] supports a rich and important invertebrate fauna including nationally notable species such as marsh-flies (*Pherbellia brunnipes*) and the variable damselfly (*Coenagrion pulchellum*). The aquatic invertebrate fauna is also diverse, including nationally rare or notable species such as the water beetle (*Haliplus mucronatus*). The SSSI is important nationally for its snails and dragonflies which includes the species *Physa heterostropha* and *Brachytron pratense*, respectively. A total of 305 shrill carder bee were recorded at six sites within this SSSI unit during the surveys undertaken in 2003[41], resulting in this species being identified as a qualifying feature.

The maintenance of some reens provides suitable conditions for submerged plant species and open water emergent such as hairlike pondweed (*Potamogeton trichoides*) and arrowhead (*Sagittaria sagittifolia*).

Rumney and Peterstone SSSI failed the extent of water PI and the field ditch condition PI, having more than 50% of ditches shaded within identified field blocks, failed the condition of main reens PI but passed IDD channel submerged flora PI, based on the surveys conducted in 2010 to 2013 and reported in the 2020 report issued by NRW[3232]. Management objectives and requirements are summarised in the Rumney and Peterstone SSSI Site Management Statement (SMS)[36].

St Brides SSSI

St Brides SSSI[37] supports a rich invertebrate community with several nationally and locally notable marshland species such as the true fly (*Chrysogaster macquarti*) and the beetle (*Hydaticus transversalis)*. Shrill carder bee has been recorded from this SSSI and adjacent areas[38]. It is also the only SSSI across the Gwent Levels that supports the rare fly *Stenomicra cogani*.

An assemblage of plant species including the regionally notable grass vetchling (*Lathryus nissolia*) are found within St Brides SSSI.

The unit passed the PIs for the condition of main reens and IDD reens, focusing on quantity of submerged flora during the survey conducted between 2010 and 2013[31], however recent evidence provided directly from NRW stated that the monitoring in 2018 showed main and IDD reens now to be failing St Brides SSSI failed PIs for field ditches (related to shading), vegetation type in watercourses and extent of water[32]. Management objectives and requirements are summarised in the St Brides SSSI SMS[39].

Nash and Goldcliff SSSI

Nash and Goldcliff SSSI[40] has invertebrate interest as rare and notable species such as ornate brigadier soldier fly (*Odontomyia ornate*), common green colonel soldier fly (*Oplodontha viridula*) and diving beetle (*Hydaticus transversalis*) have been recorded. Additionally, shrill carder bee has been recorded within the SSSI; a total of 130 individuals in 2012[41].

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[35] Countryside Council for Wales (1993) *Site of Special Scientific Interest Citation: Gwent Levels – Rumney and Peterstone.* Available at: [redacted] [Accessed February 2024].

[36] GWENT LEVELS: RUMNEY AND PETERSTONE SITE OF SPECIAL SCIENTIFIC INTEREST: YOUR SPECIAL SITE AND ITS FUTURE (Confirmed SMS January 2008). Available at: [redacted] Accessed February 2024].

[37] Countryside Council for Wales (1991) *Site of Special Scientific Interest Citation: Gwent Levels – St Brides* Available at: [redacted] Accessed February 2024].

[38] Boyce, D.C (2021) Celtic Lakes, Wentlooge Level, Newport, Summary of Invertebrate Survey Results 2021.

[39] GWENT LEVELS: ST BRIDES SITE OF SPECIAL SCIENTIFIC INTEREST: YOUR SPECIAL SITE AND ITS FUTURE (Confirmed SMS January 2008). Available at: [redacted] [Accessed January 2024].

[40] Countryside Council for Wales (1987) *Site of Special Scientific Interest Citation: Gwent Levels – Nash and Goldcliff.* Available at: [redacted] [Accessed February 2024].

[41] Smith, M.N (2013) *The status and distribution of the Shrill Carder bee Bombus sylvarum on Gwent Levels- Rumney and Peterstone SSSI and Gwent Levels Nash and Goldcliff SSSI in 2012*. CWW Contract Science Report No. 1030. Countryside Council for Wales, Bangor

Nash and Goldlcliff SSSI failed all PIs relating to favourable SSSI condition during the 2010-2013 monitoring surveys[32], however recent evidence provided directly from NRW stated that the monitoring in 2022 showed main and IDD reens PI now to be passing. Management objectives and requirements are summarised in the Nash and Goldlcliff SSSI SMS[42].

Whitson SSSI

Whitson SSSI[43] area is of particular interest for its large number of nationally rare and notable invertebrate species including *Anthomyza bifasciata* and *Coptophlebia volucris* as well as the aquatic invertebrate great silver water beetle (*Hydrophilus piceus*). Small numbers of shrill carder bee were recorded in this area in 2010[44].

In relation to PIs, Whitson SSSI failed the field ditch condition (relating to shading) and extent of water, however passed the condition of main reens and IDD channel submerged flora during the survey conducted between 2010 and 2013[32]. The 2023 survey showed PI for main and IDD reens continuing to pass (evidence provided by NRW). Management objectives and requirements are summarised in the Whitson SSSI SMS[45].

Redwick and Llandevenny SSSI

The Redwick and Llandevenny SSSI[46] supports a rich assemblage of invertebrate species including *Chalcis sispes* a parasite of the Stratiomys fly larvae, the beetle *Scirtes orbicularis* and the drone fly *Pharhelophilus consimilis*. The reens and ditch systems also supports a range of aquatic invertebrates. Small numbers of shrill carder bee were recorded in this area in 2010[44].

The area also contains a number of nationally rare plant species including the rare whorled water-milfoil (*Myriophyllum verticillatum*) located in peaty ditches in the northern part of the site. The brackish water crowfoot has also been recorded and is associated with the ditches bordering the sea wall.

Redwick and Llandevenny SSSI failed the PIs relating to field ditches (relating to shading), extent of water , however passed the PIs relating to condition of main reens and IDD channel submerged flora during the 2010 to 2013 surveys[32]. More recent evidence provided directly from NRW stated that the monitoring in 2017 showed main and IDD reens continuing to pass. Management objectives and requirements are summarised in the Redwick and Llandevenny SSSI SMS[47].

Magor and Undy SSSI

Magor and Undy SSSI[48] supports a total of 43 nationally rare and notable invertebrate species including, and of particular interest, the silver colonel soldier fly (*Odontomyia argentata*) which is more or less confined to

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[42] GWENT LEVELS: NASH AND GOLDCLIFF SITE OF SPECIAL SCIENTIFIC INTEREST: YOUR SPECIAL SITE AND ITS FUTURE (Confirmed SMS January 2008). Available at: [redacted] [Accessed January 2024].

[43] Countryside Council for Wales (1988) *Site of Special Scientific Interest Citation: Gwent Levels – Whitson.* Available at: [redacted] Accessed February 2024].

[44] Smith, M.N (2010) *The status and distribution of the Shrill Carder bee Bombus sylvarum on the eastern Gwent Levels and within the Caerwent and Caldicot areas of Gwent in 2010.* CCW Contract Science Report No. 972. Countryside Council for Wales, Bangor

[45] GWENT LEVELS: WHITSON SITE OF SPECIAL SCIENTIFIC INTEREST: YOUR SPECIAL SITE AND ITS FUTURE (Confirmed SMS January 2008). Available at: [redacted] [Accessed January 2024].

[46] Countryside Council for Wales (1989) *Site of Special Scientific Interest Citation: Gwent Levels - Redwick and Llandevenny.* Available at: [redacted] February 2024].

[47] GWENT LEVELS: REDWICK AND LLANDEVENNY SITE OF SPECIAL SCIENTIFIC INTEREST: YOUR SPECIAL SITE AND ITS FUTURE (Confirmed SMS January 2008). Available at: [redacted] [Accessed January 2024].

[48] Countryside Council for Wales (1989) *Site of Special Scientific Interest Citation: Gwent Levels – Magor and Undy.* Available at: [redacted] [Accessed February 2024].

the Gwent and Somerset Levels, and the great silver beetle (*Hydrophilus piceus*). Shrill carder bee were recorded in this SSSI and adjacent areas in 2010[44].

Notable or rare aquatic plants such as hairlike pondweed (*Potamogeto trichodes*), Berchtold's pondweed (*Potamogeton berchtoldii*) and narrow-leaved water plantain (*Alisma lanceolatum*).

Magor and Undy SSSI failed all PIs of favourable SSSI condition during the 2010 to 2013 surveys[32], this was confirmed to be the same during the monitoring surveys in 2018 as provided directly from NRW. Management objectives and requirements are summarised in the Magor and Undy SSSI SMS[49].

Newport Wetlands SSSI

Newport Wetlands SSSI, designated in 2010, is part of the Newport Wetlands National Nature Reserve, which was constructed to meet the commitment by the UK Government to create "a substantial area of wetland habitat on the shores of the Severn Estuary" as part of the compensation for the loss of the Taf/Ely Estuary SSSI following the construction of the Cardiff Bay Barrage. Part of the reserve lies within the Severn Estuary SSSI.

This SSSI has a number of special features, over and above the features of the other Gwent Levels SSSI, including:

- Reen and ditch habitats
- Reedbeds
- Higher plants (including rootless duckweed (*Wolffia arrhiza*) and hairlike pondweed)
- Over-wintering birds (including nationally important numbers of shoveler (*Spatula clypeata*) and black-tailed godwit (*Limosa limosa*)
- Breeding birds (including nationally important breeding populations of Cetti's warbler (*Cettia cetti*) and water rail (*Rallus aquaticus*)
- Insects and other invertebrates (including the soldier fly, the great silver water-beetle and the shrill carder bee).

In relation to PIs, Newport Wetlands SSSI passed the IDD reens channel submerged flora during the surveys conducted between 2010 and 2013, (there are no Main reens) and was the only SSSI unit to pass the extent of water and field ditch (relating to shading) PIs, as reported in the 2020 NRW report[32]. The IDD reens channel submerged flora was however communicated by NRW to have passed during the 2023 monitoring surveys. Management objectives and requirements are summarised in the Newport Wetlands SSSI SMS[50].

2.3.2.2 *Other Statutory Designated Sites*

Other statutory designated sites within or within proximity to the Gwent Levels include the following, and as shown in Figure 2, are summarised below.

Severn Estuary European Marine Site

Severn Estuary, which lies immediately south of the Gwent Levels, is designated at an internationally/European level as a Ramsar site, SAC, SPA making up the European Marine Site (EMS), as well as a SSSI. The Severn Estuary SAC designation[51] covers important habitats (estuaries, mudflats, sandflats and Atlantic salt meadows) and species (sea lamprey (*Petromyzon marinus*), river lamprey

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[49] GWENT LEVELS: MAGOR AND UNDY SITE OF SPECIAL SCIENTIFIC INTEREST: YOUR SPECIAL SITE AND ITS FUTURE (Confirmed SMS January 2008). Available at: [redacted] [Accessed January 2024].

[50] NEWPORT WETLANDS SITE OF SPECIAL SCIENTIFIC INTEREST: YOUR SPECIAL SITE AND ITS FUTURE. Available at: [redacted] [Accessed January 2024].

[51] Natural Resources Wales (2009) Entry in the Register of European Sites for Wales – Severn Estuary.

(*Lampetra fluviatilis*) and twaite shad (*Alosa fallax*)). The SPA designation[52] covers important overwintering and migrant bird populations and the Ramsar site[53] designation covers a range of habitat, fish and bird features. At a national level, the Severn Estuary is also designated as a SSSI[54]. Important features include estuarine fauna, including vertebrate populations of considerable national interest and internationally important populations of wintering waterfowl and migratory fish.

The Gwent Levels is functionally linked to the Severn Estuary designations through both providing supporting habitats for essential life cycle processes of some of the features of the SPA, SAC and Ramsar site, and also through the direct hydrological connection between the reens and ditch network of the Gwent Levels that flows into the Estuary. Therefore, effects upon the Gwent Levels habitats and water quality could have an adverse effect on site integrity in view of the conservation objectives of the Severn Estuary designations, as described in case law on functional linkages to European sites[55].

River Usk SAC

The River Usk is one of the largest rivers in south Wales, and is designated for it riverine habitats as well as supporting populations of sea lamprey, river lamprey, brook lamprey (*Lampetra planeri*), twaite shad, Atlantic salmon (*Salmo salar*), bullhead (*Cottus gobio*) and otter (*Lutra lutra*).

Similar to the Severn Estuary as described above, the Gwent Levels habitats are intrinsically linked to the River Usk through both supporting habitats (such as the reen and ditch network) and also through hydrological connectivity. For example, the reen network and riparian habitats of the Gwent Level is known to support commuting otters which connects with the River Usk SAC, and so adverse impacts to these supporting habitats within the Gwent Levels could have an adverse effect on site integrity in view of the conservation objectives of the River Usk SAC.

Magor Marsh SSSI

Magor Marsh SSSI, designated in 1979, and GWT Reserve is the largest remnant of the formerly extensive fenlands on the Gwent Levels. The site supports a variety of submerged and emergent aquatic plants. There are areas of wet meadow and both willow (*Salix* sp.) and alder (*Alnus glutinosa*) carr (woodland) with an intersecting system of drainage ditches, reens and ponds. Important breeding ground for water and marsh birds.

2.3.2.3 *Non-statutory Designated Sites*

There are a total of 26 Sites of Importance for Nature Conservation (SINC) within a 1km buffer from the selected sites, as shown in Figure 2. The SINCs include: The River Rhymney, Cath Cobb Wood, Hendre Lake West, Hendre Road, Hendre Lake, Lamby Way, Wentloog Industrial Park, Rumney Great Wharf, Lamby Salt Marsh, Gwent Wetland Reserve, Julian’s Gout Land, Afon Ebbw River, LG Duffryn Site 1, LG Duffryn Site 2, Celtic Springs, Duffryn Pond, Upper Cottage Pond, Land at Barecroft Common, Barecroft Fields, Bowkett Field, Bluehouse Farm, Greenmoor Pool, Ridings Wood, Wilcrick Fort West, Spencer Works 3, Elver Pill Reen Grassland & Pond.

Great Traston Meadows is GWT Reserve is an example of grazing marsh, a traditional type of landscape on the Levels, part of which is within the Nash and Goldcliff SSSI unit. Notable for its grasslands, crossed by a system of reens and grips (drainage features). Great Traston Meadows is a good example of teamwork, with

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[52] Natural Resources Wales (1993) Severn Estuary SPA Citation.

[53] JNCC (1995) Information Sheet on Ramsar Wetlands - Severn Esturay. Available at https://jncc.gov.uk/jncc-assets/RIS/UK11081.pdf [Accessed February 2024].

[54] Countryside Council for Wales (1989) Site of Special Scientific Interest Citation: Severn Estuary. Available at [redacted] [Accessed February 2024].

[55] Chapman, C. & Tyldesley, D. (2016) Functional linkage: How areas that are functionally linked to European sites have been considered when they may be affected by plans and projects - a review of authoritative decisions. Natural England Commissioned Reports, Number 207. Available at: [redacted] [Accessed February 2024].

GWT working in partnership with the owner, Eastman Chemical Ltd, to manage the site for the benefit of people and wildlife.

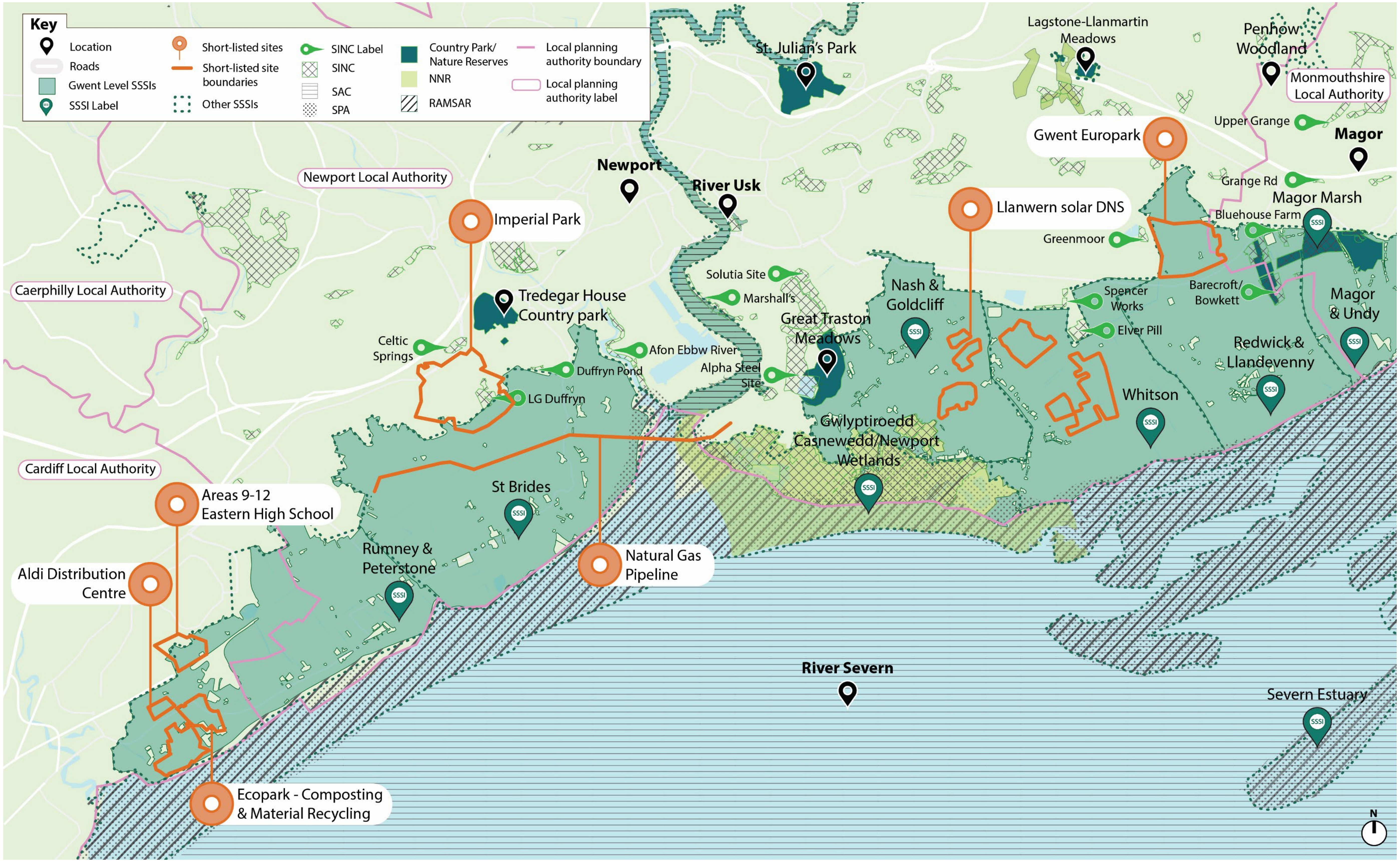

Figure 2: Short-listed sites and designated sites

2.4 Evolution of Welsh 'Nature-based' Policy and Major Development in the Gwent Levels

Wales has seen significant changes in its nature-based policy landscape over the last 40 years, which has influenced and shaped major development and planning decisions within the Gwent Levels. From the planning and development of the Llanwern steel works in the 1950s, before the Wildlife and Countryside Act 1981 and designation of the SSSIs, through to the 'green revolution' in Welsh Policy in the 2010s, sparked by the Well-being of Future Generations Act 2015 and leading to the Ministerial decision to not proceed with the M4 Relief Road, in part due to impacts to nature conservation, specifically the SSSIs (as shown in Figure 3 below).

Post the M4 decision, further commitment has been made by Welsh Ministers for the protection of the Gwent Levels, such as the Written Statement relating to the protection and management of the Gwent Levels – 'Taking Action to Better Protect and Manage the Gwent Levels'[9] on 1 July 2021 and an Oral Statement 'Gwent Levels Nature Recovery Exemplar Areas'[10] on 14 June 2022. These included commitments to ensuring the Gwent Levels are better protected and managed, with additional action to maintain and enhance biodiversity and build resilient ecosystems. In October 2023, PPW Chapter 6 was updated with immediate effect, which included the presumption against development within SSSIs, adding further protection to the Gwent Levels.

The policy efforts to protect degradation of the natural environment have influenced major development decisions on the Gwent Levels, as well as shaping implementation of bespoke development, mitigation and monitoring advice such as the guidance produced by NRW (and formally Countryside Council for Wales (CCW))[56, 57, 58, 59, 60] with specifics to support developments within and adjacent to the SSSIs to avoid, minimise and mitigate their environmental impacts (as shown in Figure 3 below). It is noted this guidance is old and outdated now and was not designed at the time to support large scale developments, rather to support at a local level for planners and developers.

Figure 3 below also shows the selected sites/developments for this Study, and the process for selecting these sites is described in Chapter 3.

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[56] CCW, Nature Conservation and Physical Developments in the Gwent Levels – The Current and Future Implications. Chapter 6: Conservation Guidelines for Development Proposals on the Gwent Levels, 1991.

[57] CCW, Interim Guidance Note One, General Guidance Monitoring of Physical Developments within the Gwent Levels SSSI. 1996.

[58] CCW, Interim Guidance Note Two, Flora Monitoring on the Gwent Levels SSSI. 1996.

[59] CCW, Interim Guidance Note Three, Invertebrate Monitoring on the Gwent Levels SSSI. 1996. Updated June 2004.

[60] CCW, Interim Guidance Note Four, Water Quality Monitoring on the Gwent Levels SSSI. 1996.

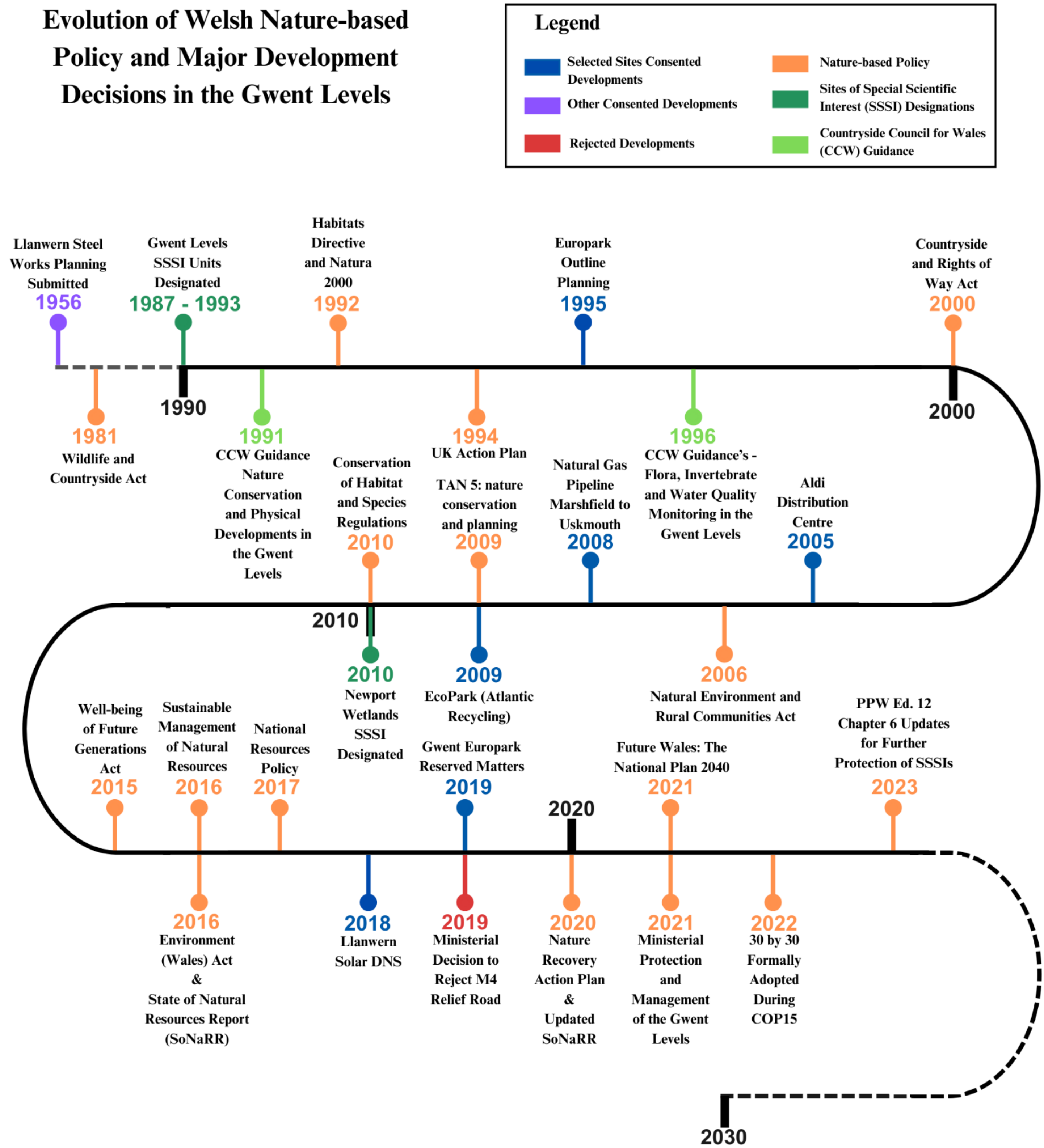

Figure 3: Evolution of Welsh 'nature-based' Policy and major development decisions in the Gwent Levels

3. Site Selection and Appraisals

3.1 Site Selection Process

In consultation with the Steering Group a preliminary list of sites to be considered in this Study was derived. The site sifting process was then determined by a range of limiting factors and whether the sites were 'fit for purpose', and a short-list established. This list was further refined through wider stakeholder engagement, which made-up part of Workshop 1 (see Chapter 5 for more details), and testing sites through a 'pilot test' of the criteria-based assessment.

The preliminary list of sites, which included 13 sites, was based on substantial, already built, development within or immediately adjacent to the Gwent Levels SSSIs and NNRA, since 1990. The list sought to contain development which were as broad and representative as possible of different substantial development types (housing, employment, infrastructure, renewable energy *etc*.) and cover the three LPA areas within the Gwent Levels. The first stage of the sifting process was determined by the 'sites' alignment with the key requirements to fulfil the aims and objectives of the Study, which was partly related to the level of documentation that could be obtained from the relevant Planning Portals, key stakeholders and also included visits to LPAs archives to take copies from paper documents. Key documents that were important to provide sufficient data to inform the assessment included Environmental Statements (ES) or Ecological Impact Assessment (EcIAs) and supporting survey information of the ecological baseline, development designs and proposals, habitat mitigation and management plans or landscape proposals, management and monitoring plans and any evidence of monitoring and onwards management reporting. Further to these, and for the assessment to be productive, evidence was required from Officer's Reports and Decision Notices, including any objections received and discharge of conditions. Absence of such information meant that meaningful assessment was not possible, and sites couldn't be taken any further in this Study.

Some of the older applications were deemed incompatible through this first sifting procedure. This was primarily due to the lack of key documents found, to allow for an assessment to be conducted. One of these sites was however retained on the shortlist at this stage, owing to its size and potential historical impacts on the Gwent Levels, this being the developments associated with Imperial Park in Newport (including planning application references: 96/0650/CD, 96/1033/CD, 96/1104/CD, 97/0436/CD, 97/0437/CD, 97/0052/CD, 98/0048/CD, 98/0109/CD, 98/0453/CD). It was discovered that the paper copy of the main ES and other relevant documents had been checked out of the Newport Local Authority archives but never returned. However, some documents, such as Notice of Decision for full and partial discharge of conditions (although no attached documents or reasons for discharge attached) and environmental and water quality monitoring reports dating back to the late 1990s and early 2000s, were found and so this site was short-listed for the next stage of the sifting process.

Through this first sift process, observations and recommendations were however recorded and have been captured in the Key Themes and Recommendation in Chapter 6. The short-list of seven developments was then discussed and agreed with the Steering Group and wider Stakeholder Group and formed part of the discussion in the first Stakeholder workshop (as detailed in Chapter 5 below). This initial short-list of seven sites/developments, as shown on Figure 2 above, met the brief in that they covered all three local planning authorities, were representative of different substantial development types, and were located within or immediately adjacent to the SSSIs and NNRA. Furthermore, and for added value to the assessment, the seven short-listed sites/developments covered a temporal range, dating from before and during major policy and legislative changes and drivers relating to the environment and natural resources, such as the Environment (Wales) Act 2016, Future Wales, CCW guidance of development in the Gwent Levels, and the recent planning policy relating to ecosystem resilience (and DECCA) and Ministerial drive for protection and management of the Gwent Levels. Additionally, the seven short-listed sites/developments also covered different planning application types, outline, reserved matter and full, which also allows for comparisons of effectiveness of ecological protective measures and enhancements between these types of consenting routes. The short-listed sites are shown in Figure 3 alongside the key Welsh policies, legislation and guidance.

This initial short-list of seven sites/developments were then surveyed by experienced ecologists with both extensive knowledge of planning requirements and specifics relating to the Gwent Levels SSSIs features and functions, and the current mitigations required by NRW to safeguard those features. The methodology of the field surveys is described below in section 3.2.

Once data was gathered from both the survey visits and planning documents, the next stage of the site selection process was to test the seven selected developments/sites through a pilot version of the criteria-based assessment, using the DECCA criteria, as further detailed in Chapter 4. This process eliminated the Imperial Park development due to lack of key documents required to productively apply the criteria-based assessment. A second development was eliminated due to being located outside of the SSSIs and NNRA, being on previously developed land and having limited potential impacts to the SSSIs, and therefore minimal mitigation, management and monitoring requirements when it was permitted. This development, being Eastern High School in the Rumney area of Cardiff (planning application: 15/02513/MJR) was also first thought to be linked to the Area 9 -12 outline planning application (planning application: 06/00524/E), which although has not all been built does lie within a significant area of the Rumney and Peterstone SSSI unit. However, through the sifting process, the school application was discovered not to be linked to the Area 9 - 12 application, and that although the outline planning was granted in 2006, all matters were reserved and a condition on the planning decision required reserved matter applications to be submitted within three years of the permission at which time the permission would and has expired. For these reasons, both the Area 9 – 12 outline planning and the Eastern High School development were omitted from the site selection.

The remaining five sites 'fit for purpose' for the application of the criteria-based assessment from the site selection process are shown on Figure 3 and included:

- Ecopark Composting and Material Recycling Facilities (Atlantic Recycling) (planning application: 08/00626/E), consented on 29th October 2009, and located in Rumney and Peterstone SSSI unit and within Cardiff planning authority.
- Aldi Distribution Centre (planning application: 04/01109/E) consented on 26th January 2005 and further extended in 2009 due to the plans being put on hold by Aldi. The proposed use has not significantly changed from the previously granted permissions when the application was resubmitted in 2014 (planning application: 14/01464/DCO (Development Consent Order)) and a decision granted in September 2014. The Aldi Distribution Centre is located in Rumney and Peterstone SSSI unit and within Cardiff planning authority.
- Natural Gas Pipeline Marshfield to Uskmouth (planning application: Department for Business Enterprise and Regulatory Reform (BERR) reference number 01.08.04.07/13C), consented on 3rd March 2008 and located in St Brides SSSI unit and within Newport planning authority.
- Llanwern Solar Development of National Significance (DNS) (planning application: 18/0198), consented on 8th November 2018, and located within both Whitson SSSI unit and Nash and Goldcliff SSSI unit, within Newport planning authority.
- Gwent Europark (planning application: 18/1234), consented in 2019 as a reserve matters planning application to the wider 1995 Europark outline planning application (planning application: 92/0875, granted on 25th May 1995). Located in Redwick and Llandevenny SSSI unit of the Gwent Levels, with the western area of the application being within Newport planning authority and the eastern most area being with Monmouth planning authority.

These sites are further detailed in the Selected Sites Appraisal (section 3.3) and were taken forward to the criteria-based assessment described in Chapter 4.

3.2 Site Appraisal Methodology

A field survey methodology was developed which was robust enough to rapidly assess the likely condition of the habitats and SSSIs features condition within the sites, as well as whether there was evidence of the proposed mitigation measures had been undertaken, including any management proposals.

To do this, firstly all relevant documents for the sites were reviewed, including baseline habitat and species reports and ecological assessments, scheme designs and mitigation/landscape designs, proposed habitat management and monitoring plans, and any management and monitoring reports that were available. This allowed for conditions present at the site to be tested against those proposed and committed to through the planning applications and associated conditions.

Survey sheets were designed to rapidly assess the habitats and SSSIs key features, both within the proposed mitigation areas and those surrounding, where relevant. The field surveys followed Phase 1 Habitat Survey[61] methodology which is a standardised system for classifying and mapping habitats, providing a relatively rapid system to record semi-natural vegetation and other habitats. The template survey sheet is provided in Appendix B.1, but included recording the extent and condition of each habitat type, suitability for key species relating to the SSSIs and protected species, with more details being recorded relative to SSSIs features (reens/ditches and shrill carder bee habitat) such as water levels and quality, evidence of nutrient enrichment, notable plant species, presence of hedgerows and/or shading of ditches, connectivity and suitability to support shrill carder bee.

The site visits to the five short-listed sites were conducted on 4th and 5th September 2023. Access was granted for a number of the sites, including Gwent Europark, Ecopark Composting and Material Recycling Facility (Atlantic) and Aldi Distribution Centre, which allowed for the surveyors to walk around the sites to conduct a full appraisal. Surveys for Llanwern Solar DNS and the Natural Gas Pipeline utilised Public Right of Ways (PRoWs) and roads to conduct the site appraisals. This was only limiting for the Natural Gas Pipeline where only a few key vantage points of the pipeline route were available, all others provided sufficient views to conduct appraisals.

The results from the field survey appraisal and from the initial review of relevant planning documents is provided below for each of the five selected sites.

3.3 Selected Sites Appraisal

The section appraises each of the five selected sites based on the field survey visits and the initial review of relevant planning documents, as detailed above.

3.3.1 EcoPark Composting and Material Recycling Facilities (Atlantic Recycling)

EcoPark Composting and Material Recycling Facilities, also known as Atlantic Recycling, was granted planning permission in October 2009. This was for the erection of an EcoPark to support effective waste management and environmentally efficient recycling across south Wales. It comprised of a composting facility and a material recycling facility.

According to the areas calculated from the site boundaries in Figure 4, the total area of EcoPark is approximately 47 hectares (ha) which comprises Atlantic Recycling (11.6ha) and Neal Soils Suppliers Ltd (35.6ha). The site is situated to the south of St. Mellons and southeast of Rumney. At its closest location the site is approximately 33m north from the Severn Estuary EMS, which comprises the SAC, SPA, and Ramsar site. The site lies wholly within one of the Rumney and Peterstone SSSI unit, and within the NNRA on the Wentloog Levels.

Prior to this application, the site was used by Neal Soil Suppliers Ltd to market and dispose of surplus topsoil from local development projects. Historically, the site comprised predominantly arable and pastoral land. Fields were, and are still, bounded by hedgerows and a series of drainage ditches/reens.

The main documents used for the appraisal and later the assessment in Chapter 4 below, included the Decision Notice and Planning Conditions, Outline Construction Environmental Management Plan for the Atlantic EcoPark (2013) Surface Water Management Plan - Protection of the Reens (2007), Field Ditch Management Schedule (2014), Five Year Habitat Management Programmes and a wealth of Monitoring Reports for ecological features, species and water quality and the Environmental and Management Annual Review (2020).

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[61] JNCC, (2010), Handbook for Phase 1 habitat survey – a technique for environmental audit, JNCC, Peterborough, ISBN 0 86139 636 7.

The development did require one reen to be infilled and a replacement reen, that was of similar proportions to the reen lost, and to be connected to the existing reen network. The quantities, in terms of meters lost and created, and parameters, in terms of location and cross-sections, relating to the reen to be infilled and a replacement reen were however not located from within the planning documents searched for on the planning portal. The Surface Water Management Plan outlines the maintenance and monitoring to be undertaken to ensure that the reens located within the site are protected. Furthermore, proposed maintenance, management and mitigation measures were required and secured by planning condition to ensure that no harm to the SSSI occurred.

A sample of the ditches and grasslands within the Atlantic site were surveyed as shown on Figure 4, favouring areas where works was not being carried out the day of the survey on 5th September 2023, for health and safety reasons. However, the areas surveyed represented a reasonable snapshot of the type of mitigation that was designed for the scheme at planning and the evidence of the implementation and management of the mitigation. Furthermore, the Management Schedules were developed for both sites, and were obtained for all areas surveyed. The ditch numbering has been taken from the Field Ditch Management Schedule (March 2014) to allow for comparison to management plans and monitoring reports produced for the scheme. Where a ditch or a reen was not numbered within the Schedule, meaning it does not form part of the management and monitoring plans, a letter has been used, such as Reen X (RX, Figure 4).

Ditch 4 provides an example where an appropriated sized buffer has been applied to the retained and protected ditches with fencing and/or posts to mark out the buffer, and evidence of some level of historic grassland management as grassland and flower species present with no evidence of scrub encroachment. The buffer appeared to be at least 7m as per NRW guidance, however in the Buffer Zone Plan provided within the Surface Water Management Plan - Protection of the Reens (Sept 2007) shows these buffers were proposed to be 10m. Due to the close proximity of works and vehicle movements, these grasslands, and likely the associated ditches, are however suffering from a covering of dust/soils which will be impacting the plant growth and the ditch water quality, although noting the site visit was undertaken during a dry hot summer period in September 2023. Ditch 4 also shows that hedgerow management may not have been conducted or enforced during the management plan period, as the trees of the hedgerow have grown tall (on the south and east side of the ditch) and as consequent is causing shading of the ditch. Hedgerow management through cutting is proposed in the Field Ditch Management Schedule (2014) for this hedgerow on two-year rotation (i.e. every two years). The ditch shows indication that management in terms of re-casting and/or cutting back of bank side/in channel vegetation had not been undertaken in recent years, due to the ditch being encroached by reeds (*Phragmites australis*), tall herb species and some scrub. The Biodiversity Enhancement and Mitigation Plan (BEMP) specifies periodic casting of channels on a rotation of seven to ten years, frequent cutting of bankside vegetation and ongoing management of adjoining scrub alongside the ongoing implementation of environmental protection measures around operational areas. Although the relevant report demonstrating when this ditch was last re-cast and bank vegetation cleared was not found, ditches vegetation can quickly regenerate.

Reen X (RX, Pil Melyn Reen on Figure 4) provides an example where a buffer has been applied to only one side of the SSSI feature and/or the full 12.5m buffer for reens (7m for ditches) has not been fully designed and/or enforced. However, Newton Road which is adjacent to this reen was there before construction works. The reen lacked aquatic species and in places was choked with reeds which suggests a lack of recent casting of this reen, which is the responsibility of NRW. The reen runs close to the access road (Newton Road) to the site and as such the vegetation surrounding the ditch was covered with dust, and the reen had evidence of pollution with algae blooms and litter. Reen X connects to a Ditch X under a culvert which continues northward along the edge of Newton Road toward the entrance of the site from Wentloog Avenue. Ditch X and Ditch 10, which run west from Reen 1 (see Figure 4), both have a buffer (approximately 7m wide) on only one side of the ditch, with a hedgerow on the other side (on the eastern side of Ditch X and southern side of Ditch 10), and the ditches are being choked by reed and scrub growth; indicating casting of these ditches has not taken place over the last few years, and Ditch 10 is heavily shaded by the hedgerow which has grown tall and thick.

Ditch 6 and 7 provide examples on the site where the 7m buffer to ditches (which should be 10m in line with the Buffer Zone Plan) has not been maintained, and possibly nor has the casting of the ditch in accordance with the BEMP and appropriate Five Year Habitat Management Programme. Ditch 6 had piles of soil/earth encroaching into the southern section of ditches, spilling over the wooden posts that had been put in place to mark the ditch. The remaining of Ditch 6 as it moves north and then west around the earth pile in the field area and Ditch 7, had scrub developing within the ditch, predominantly willow species, as well as being fully encroached by reeds. This shows that these ditches have not been managed by re-casting or frequent cutting of bankside vegetation for a number of years. The grassland buffers have transitioned into tall ruderal, rough grassland with rushes and sedges, and have sapling willows growing in places, which suggests these have not maintained the three-year rotational cutting regime of the grassland buffers, as proposed in the Five Year Habitat Management Programmes. There was also no sign of the hedgerow on the west and north of Ditch 6 being managed as the trees have grown tall and are encroaching into the ditch causing shading, however it appears from plans that these hedgerows are not in the control of the site/management plans, i.e. not geographically covered by the planning permission or therefore the management plan. Ditch 6 should have been recast in 2022 and the grassland cut in 2021, and Ditch 7 should have been recast in 2017 and the grassland cut in 2021, as proposed in the Management Programmes.

Ditch 8, as well as Ditch 14, provides examples on the site where a triple ditch system has been provided as part of the mitigation for the impact to ditches. In these locations ditches were created on the edge of the grassland buffer either side of retained and protected ditch feature. This system has worked well in that the retained ditch and the grassland buffers are fully protected from any encroachment of works and vehicles. The grassland buffers (approximately 10m) surrounding the retained ditch were of good condition semi-improved grassland with no scrub encroachment and a good abundance of flowering species, including those which support carder bee species such as red clover (*Trifolium pratense*), knapweed (*Centaurea*), meadow vetchling (*Lathyrus pratensis*) and tufted vetch (*Vicia cracca*). A relatively high abundance of carder bee species (mostly common (*Bombus pascuorum*) and brown-banded carder bee (*Bombus humilis*)) as well as other bee species were recorded within these grasslands. Shrill carder bee was not recorded; however, it is likely these species may have been missed during a quick walkover, as the grassland species present were suitable to support foraging shrill carder bee which are known to be present in the local area. The grassland condition suggests that the three-year rotation of grassland cutting has been conducted.

The external ditches of these triple ditch systems were mostly dry during the survey which could be due to the reed encroachment and sediment build-up in the ditches as these ditches are possibly unmanaged, or possibly due to water availability, which could be a factor of creating three ditches in a location which historically only supported one. The retained ditches (D8 and D14, Figure 4) in the middle of the triple ditch system were holding water in places, although common reeds were present throughout the ditches. Ditch 8 was recorded as being recast in 2019, no date was found in the available reports for Ditch 14.

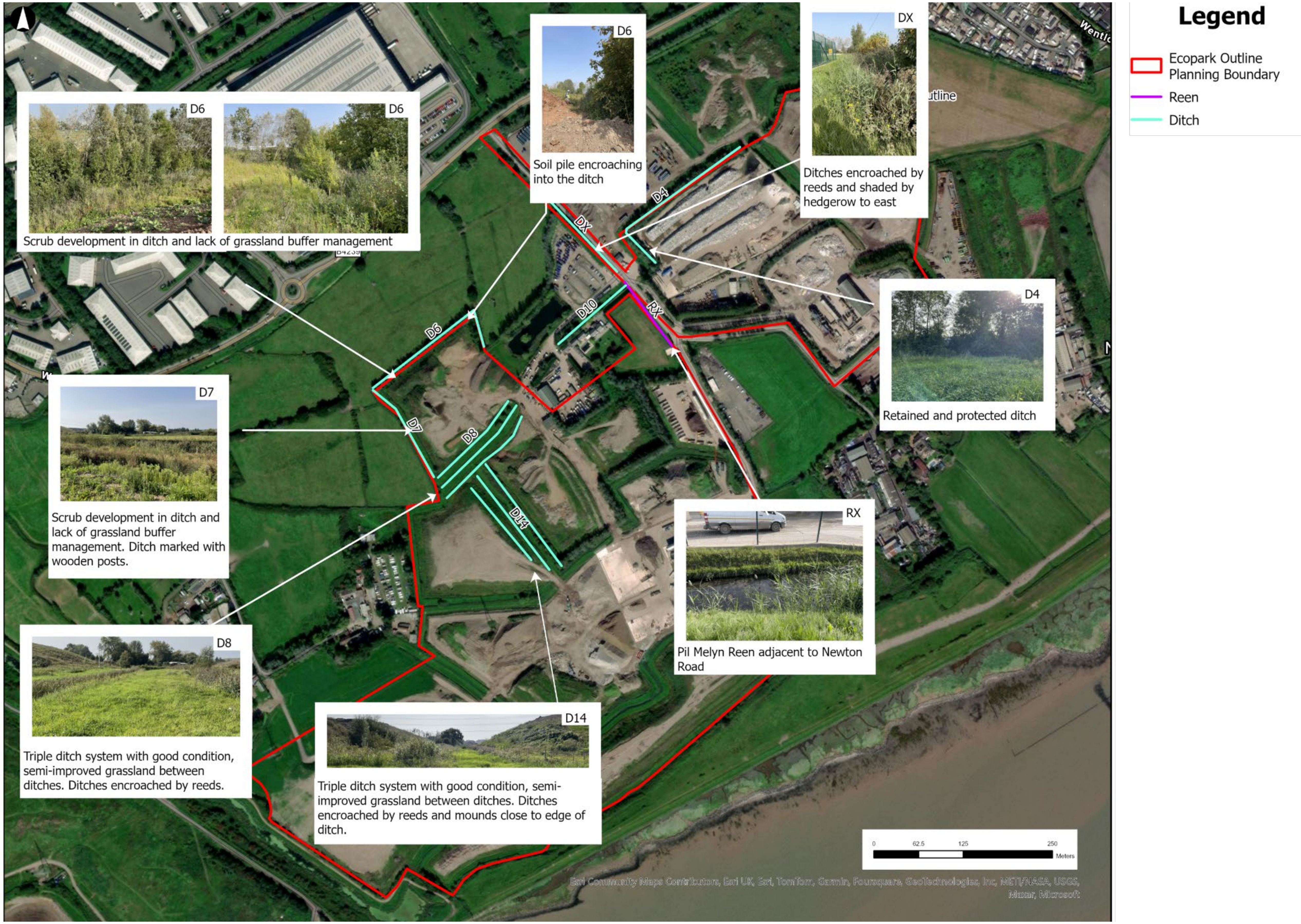

Figure 4: Surveyed ditches and reens within Ecopark – Composting & Material Recycling

3.3.2 Aldi Distribution Centre

Aldi Distribution Centre was first granted planning permission in January 2005 and then the resubmitted application granted planning in September 2014. This was for the erection of a warehouse to be used as a central distribution hub for South Wales. It comprised associated offices, car park, service areas, ancillary buildings and landscaping, as well as vehicle and pedestrian access. According to the area calculated from the site boundary in Figure 5, the site covers approximately 11.4ha. The site is located to the northeast of Cardiff City, approximately 920m north of the Severn Estuary EMS. The site lies wholly within one of the Gwent Levels SSSI units, Rumney and Peterstone, and within the NNRA on the Wentloog Levels.

Pre-construction, the site comprised a majority of mosaic habitat, both bare ground with ephemeral vegetation growth and tall ruderal vegetation were dominant under scattered scrub. Various areas of swamp habitat were also scattered throughout. The site was bounded by native rich hedgerows on three sides.

The main documents used for the appraisal and later the assessment in Chapter 4 below, included the Decision Notice and Planning Conditions, Ecological Appraisal (2014), Protected Species Survey (2014), Aquatic Monitoring Report (2014), Reen Management Plan (2016), Landscape Management Plan (2015), Sampling Strategy (2014) and Post Construction Monitoring Report (2016- 2017). No reports post 2017 were found on the planning portal under the application reference, although habitat and reen management was intended over a ten-year period and beyond as prescribed in the Landscape Management Plan (February 2015) produced for the scheme.

Works under the previous enabling works planning permission (07/007/E) within this site pre-dates the Aldi Distribution Centre planning permission in September 2014 (14/01464/DCO). The enabling works application resulted in the loss and realignment of the reen, as evident from viewing historical reen network mapping (as provided by NRW). Due to this enabling work being conducted at the site, the Aldi Distribution Centre application did not require the realigned of reens or ditches, and although there is reference to approximately 100m of watercourse to be lost to the current proposed development in a letter from CCW relating to the planning application, the application reports that '*the system to look and function in the same way post-construction*' as to the baseline reported in the Aldi planning application. Maintenance and mitigation measures were however required and secured by planning conditions to ensure that no harm to the SSSI occurred, which included management and maintenance of the reen and ditch features within the site. The management and maintenance prescribed for the previous enabling works application was not found to be mentioned or considered within this application, despite the requirements of condition 3 of 07/0772/E around the function and management of the reen to support SSSI features.

Results from the Extended Phase 1 Habitat Survey, undertaken on 22nd November 2013 and described in the Ecological Appraisal (2014), suggested that aquatic habitat on site was generally considered to be poor and did not reflect the reen habitats of the Gwent levels SSSIs, as they had not historically been managed and so have become heavily vegetated. However, this should have been classed as a temporary state within the ecological assessment, and a future baseline should have been considered that did not precluded the aquatic habitats (reens and ditches) being bought back to favourable condition through appropriate management.

The field survey site visit was conducted on 5th September 2023, in which the perimeter ditch was surveyed (as shown on Figure 5) that was included in the mitigation and management plan. The reens/ditches all have a buffer from them towards the development, with a permanent fence demarking the edge and prohibiting access. The grassland buffer was mostly approximately 7m in width (which corresponds to that proposed within the planning application) and the grasslands within these buffers showed signs that they had been managed in recent years as they lacked scrub encroachment, although they were all tall and uncut during survey in early September. The grasslands contained flower species suitable for shrill carder, such as tufted vetch, meadow vetchling, white melilot (*Melilotus albus*), willowherb species, creeping thistle (*Cirsium arvense*), as well as other flowering plants such as bristly oxtongue (*Helminthotheca echioides*), redshank (*Persicaria maculosa*), wild carrot (*Daucus carota*), meadow buttercup (*Ranunculus acris*), ox-eye daisy (*Leucanthemum vulgare*) and hogweed (*Heracleum sphondylium*). Ditch 2 also had an abundance of common fleabane (*Pulicaria dysenterica*) within the grassland buffer. All grassland buffers also have common reeds present in some areas which have moved into the grasslands from the ditches.

All watercourse (reen and ditches) within the site show evidence of limited ditch management for a number of years, with mature scrub developed on the development side of the ditch since being re-profiled (re-casted) during construction in 2015 and as set out in the Reen Mitigation Scheme (November 2014). Scrub development was predominantly willow species grown to heights of approximately 4m in places. The scrub lined the edge of the ditch which prevented the ability to re-cast the ditch or perform any type of ditch management, as well as causing shading of the ditch. The Landscape Management Plan (February 2015) produced for the scheme, provides management prescriptions, including for the ditches, over the intended ten-year period and beyond. The management schedule shows that maintenance to the top of the bank and grassland buffer through mowing grass, de-weeding and flailing bankside vegetation and cutting, de-weeding and removing aquatic vegetation from within the ditches should have occurred every year during the ten-year schedule.

All reens/ditches also had a historic mature hedgerow on the other side of the ditch on the edge of the development boundary, also showing lack of any management with branches overhanging int the ditch and causing shading. Ditch 1a and 2 were also encroached and full of common reed and appeared dry in places. Ditch 1b was wider and held water with duckweed (*Lemna* sp.) visible across the surface of the water.

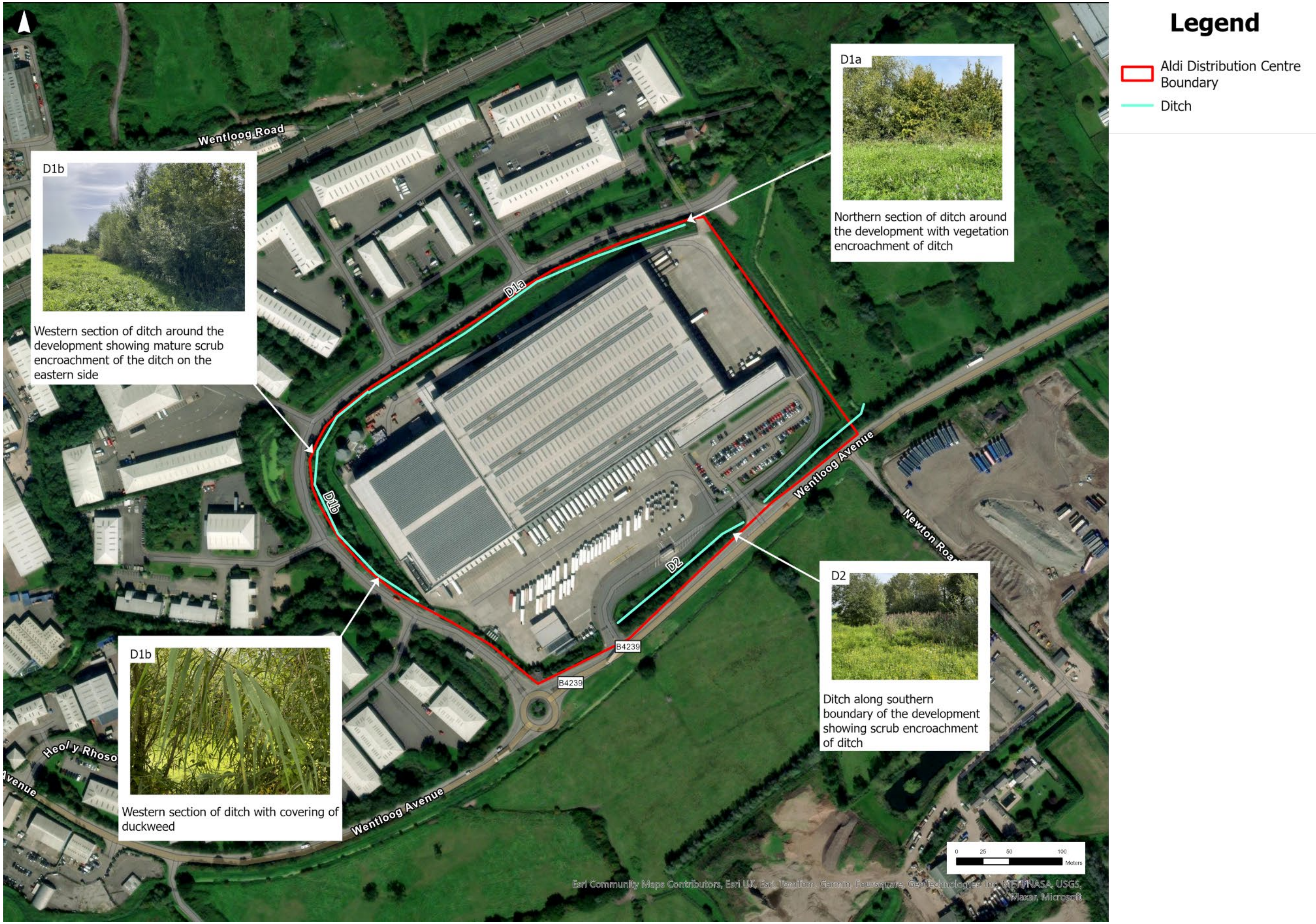

Figure 5: Ditches within Aldi distribution centre site

3.3.3 Natural Gas Pipeline

The natural gas pipeline was granted planning permission in March 2008. It comprised a 6.3km (according to the length on Figure 2) long steel high pressure gas pipeline between Marshfield above-ground gas installation (AGI) and the Uskmouth Power Site near Newport. The pipeline is located to the south of Newport City Centre and to the east of Marshfield. Part of the gas pipeline runs though the Severn Estuary EMS. The pipeline was constructed though the St Brides SSSI on the Wentloog Levels, and due to the sensitive nature of the SSSI, approximately 90% of the pipeline was installed by a horizontal directional drill, which is a non-open cut method that ensured minimum disturbance to the SSSI.

The main documents used for the appraisal and later the assessment in Chapter 4 below, included the Decision Notice and Planning Conditions, Environmental Statement appendices relating to ecological surveys (2006), Environmental Management Plan (2008), Project Restoration Plan (2009) and Water Quality Monitoring reports pre- (2007), during (2008 - 2009) and post-construction (2010 - 2011).

A total of 12 ditches/reens were directly affected by the development works during construction phase due to temporary access road installation. All of the affected ditches/reens were reinstated to original condition on completion of pipeline construction. Ditch/reen maintenance and mitigation measures were required and secured by planning conditions to ensure that no harm to the SSSI occurred.

As mentioned above, the site visit survey for the Natural Gas Pipeline on the 5th September 2023 was limiting as only a few key vantage points of the pipeline route were available, from PRoWs and roads that crossed the route. Hawse Lane bridge over the main trainline provided good views of the route, which was completed indiscernible in the landscape owing to the method of construction being directional drilling. Evidence was also sought form Pont Estyll Lane and Lighthouse Road, and associated unnamed tracks and minor roads that lead off these towards locations where the pipeline crosses the landscape. Similarly, the location of the pipeline was undetectable apart from the roadside markers showing its location, showing that either habitats had been retained through directional drilling and/or reinstated to main connectivity within the landscape and as such there is now no visible evidence on the ground as to where the gas main is located. For these reasons, no site survey map or photographs are included for this site.

3.3.4 Llanwern Solar Farm – Development of National Significance (DNS)

Llanwern Solar Farm was granted planning permission in November 2018, built in 2020. This was for the erection of a solar farm energy hub generating 49.9MW net installed generating capacity. It comprised ground mounted solar panels, 200 battery storage container units, underground caballing, grid connection hub, associated infrastructure, landscaping and environmental enhancements, for a temporary period of 30 years.

According to the Landscape and Ecology Management Plan (LEMP) (2018), the site covers approximately 145ha to the north, west and south-east of Whitson, approximately 0.9-3km from the Severn Estuary and is located on the Caldicot Levels. The site lies wholly within two SSSI units, Whitson SSSI to the east of Whitson Common Road, and Nash and Goldcliff SSSI to the west of Whitson Common Road. The site also lies wholly within the NNRA and on the Caldicot Levels.

According to the LEMP in 2018[62], pre-construction the site comprised predominantly low-lying coastal and floodplain grazing marsh of improved grassland and semi-improved neutral grassland with rush pasture. Some of the more flower-rich grasslands recorded the presence of shrill carder bee, breeding lapwing (*Vanellus vanellus*) and common crane (*Grus grus*) were recorded within the site. Fields were bounded by hedgerows with scattered trees, reens and ditches. All hedgerows were considered to be Habitats of Principal Importance (HPI) under Section 7 of the Environment (Wales) act. However, the growth of hedgerows on both sides of the ditches and reens meant many had not been managed in recent years, leading them to become over-shaded, silted and dry or partially dry in some cases. The reens and wetter ditches within the site recorded presence of SSSIs flora and invertebrates, as well as presence of water vole (*Arvicola amphibius*).

The main documents used for the appraisal and later the assessment in Chapter 4 below, included the Officers Report (2018), Decision Notice and Planning Conditions, Landscape and Ecological Management Plan (2018), Lapwing Management Plan (2019), Common Crane Mitigation Plan (2019), Llanwern Solar Ecological Monitoring and Review - Year 1 (2022) and Year 2 (2023), Aquatic Invertebrate Monitoring (2022) and Surface Water Monitoring Quarterly Report (2023).

The Llanwern Solar Ecological Monitoring and Review - Year 3 (2024) and the Terrestrial Invertebrate Monitoring (2023) reports were uploaded to the planning portal towards the end of this Study, under the planning application 24/0293. This was after the final criteria-based assessment on the selected sites had been undertaken, and as such the data provided within these monitoring report for Llanwern Solar Farm were not included in the criteria-based assessment. However, the Year 3 monitoring reports have been reviewed and evaluated against the assessment to ensure no significant deviation from the results and have been included in the site appraisal presented here. Furthermore, the Year 3 reports have been reviewed with the lens to refine and verify emerging trends and recommendations.

The Year 3 Ecological Monitoring and Review report concludes that considering all monitoring objectives, it is unlikely for the objectives to be met within the timescales set and therefore there is a need to implement specific contingency methods. This has also stimulated an adaptive management approach to ensure objectives are achieved. For example, the monitoring on the Off-Site Lapwing Compensation Area shows no breeding lapwing present and a decrease in lapwing compared to the baseline. Therefore, adaptive management, according to the Monitoring and Contingency Plan, is being implemented on the fields that constitutes the Off-Site Lapwing Mitigation Area, with the possibility of extending this area. This adaptive management approach will try to achieve the short-term objects by Year 5. Contingency requirements are also applicable to other ecological features, such as bats. Only one bat box was found to be occupied during monitoring (2023) and therefore, bat boxes are planned to be reposition and further monitoring is recommended through to Year 10. Additional monitoring years will give insight into the potential decreases of bat abundance in the array fields post-construction.

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[62] Green Ecology (2018) Llanwern Solar, Whitson, Newport, Wales. Landscape and Ecology Management Plan (2018).

The Ecological Monitoring Review – Year 3 reports that herbicide had been used in 2023 to control spear thistle (*Cirsium vulgare*) in the retained grassland in array area 1. Consequently, this has reduced available habitat for shrill carder bee and therefore, the report advises this to be stopped. Additionally, this is reflected in the Terrestrial Invertebrate Monitoring report as populations of both brown-banded bee (*Bombus humilis*) and shrill carder bee have declined significantly since the baseline survey in 2017. During the baseline survey, spear thistle was identified as the most important nectar/pollen source for shrill carder bee which remains the preferred source in 2023. Therefore, spear thistle should be retained where it is not interfering with the solar panels, such as field boundaries, to ensure sufficient forage for shrill carder bee.

The Year 3 monitoring reports emphasise the requirement for adaptive management techniques and contingency requirements to ensure progress of short-term objectives and future actions during post-development.

Furthermore, both of the Year 3 monitoring reports were uploaded to Newport's Planning Portal attached to the 24/0293 planning reference, comprising reports associated to the discharge of conditions (i.e. 'Further partial discharge of condition 14 (ecological monitoring) of planning permission 18/1201'). This different planning reference and thus location on the planning portal to the initial Llanwern Solar Farm DNS planning application: 18/0198, makes an audit trail of management and monitoring delivery challenging. This is further discussed in Chapter 6.

The development did not require any of the reens or ditches within the application site to be obstructed or filled in, thus allowing the system to look and function in the same way post-construction. The proposed maintenance, management and mitigation measures set out in the LEMP and secured by planning condition meant that no harm to the SSSIs where the development was located were anticipated within the assessment.

The site visit survey was conducted from the roads and PRoWs network surrounding the areas proposed for ecological mitigation on 4th September 2023, as access was not secured to enter the internal areas of the solar farm. Access to all areas of the solar farm was not considered essential to gather data relating to the biodiversity protected, mitigation and compensation as decided within the LEMP (2018) and any supporting documents and monitoring reports. The fields and ditches surveyed as shown on Figure 6.

Fields F1, F3, F5 and F8, and fields in-between east of the road are mapped as proposed hay management and crane survey area on the Ecological Monitoring Plan within the Ecological Monitoring and Review reports Year 1 (2022), Year 2 (2023) and Year 3 (2024). At the time of survey in early September 2023, all but F8 appeared to have been cut for hay earlier in the year with arising removed and evidence of re-growth in fields. The Ecological Monitoring and Review Year 3 (2024) states that these fields are now well-established with six species of grasses and 15 forbs identified in the sward which has a height of around 500mm. Pockets of knapweed were identified within these fields, which supports carder bees, observed to be foraging in this area. Additionally, the banks of the reens, adjacent to the fields, support diverse flora for invertebrates.

Field F2 is also mapped for hay management and crane management on the Ecological Monitoring Plan. This field had only recently been cut on 1st September (personal communication with tenant famer), with arising still drying within field.

Fields F4 and F7 are mapped as proposed new wildflower planting for shrill carder bee. Both fields appear to lack species and structural diversity and flora species, with dominance of meadow grasses. These grasslands appear to be of improved or poor semi-improved nature. Herbicide treatment was thought to have been used before re-seeding in 40m strips within these fields, which could have impacted the establishment of a species-rich sward (personal communication with tenant famer). Seeding on a mosaic pattern was agreed within the management plan.

Fields F9, F10, F11 and F12 are mapped as the lapwing surveys area which appear to be dominated by grass species, possible rye-grass. Field F13 appear to be mapped as proposed new wildflower planting on the Ecological Monitoring Plan, although this map is hard to determine type of habitat management and monitoring due to multiple layers. The field, however, does not show evidence of any type of management and the poor semi-improved grassland was being grazed by horses at the time of survey.

Reens D1 (Bowleaze Reen), D2 and D4 (Parish Reen (Drain)), and D3 (Crabtree Reen) are mostly unshaded and show signs of being managed to be open reens by NRW. All have frogbit present as SSSI species and are covered with a duckweed species.

Ditch D5 and D6 are ditches that feed into Chapel Reen which run adjacent to Chapel Road. The hedgerows along these ditches are mapped on the Ecological Monitoring Plans for double hedgerow to be reduced. There is only hedgerow present on the northern side of these ditches, which suggests that a hedgerow from the southern side has been removed. However, both ditches are choked with reeds causing shading to the ditch and the hedgerow remain on the northern side is also encroaching into the ditches. Ditch D7 and D8 were similarly choked with vegetation causing shading of the ditch.

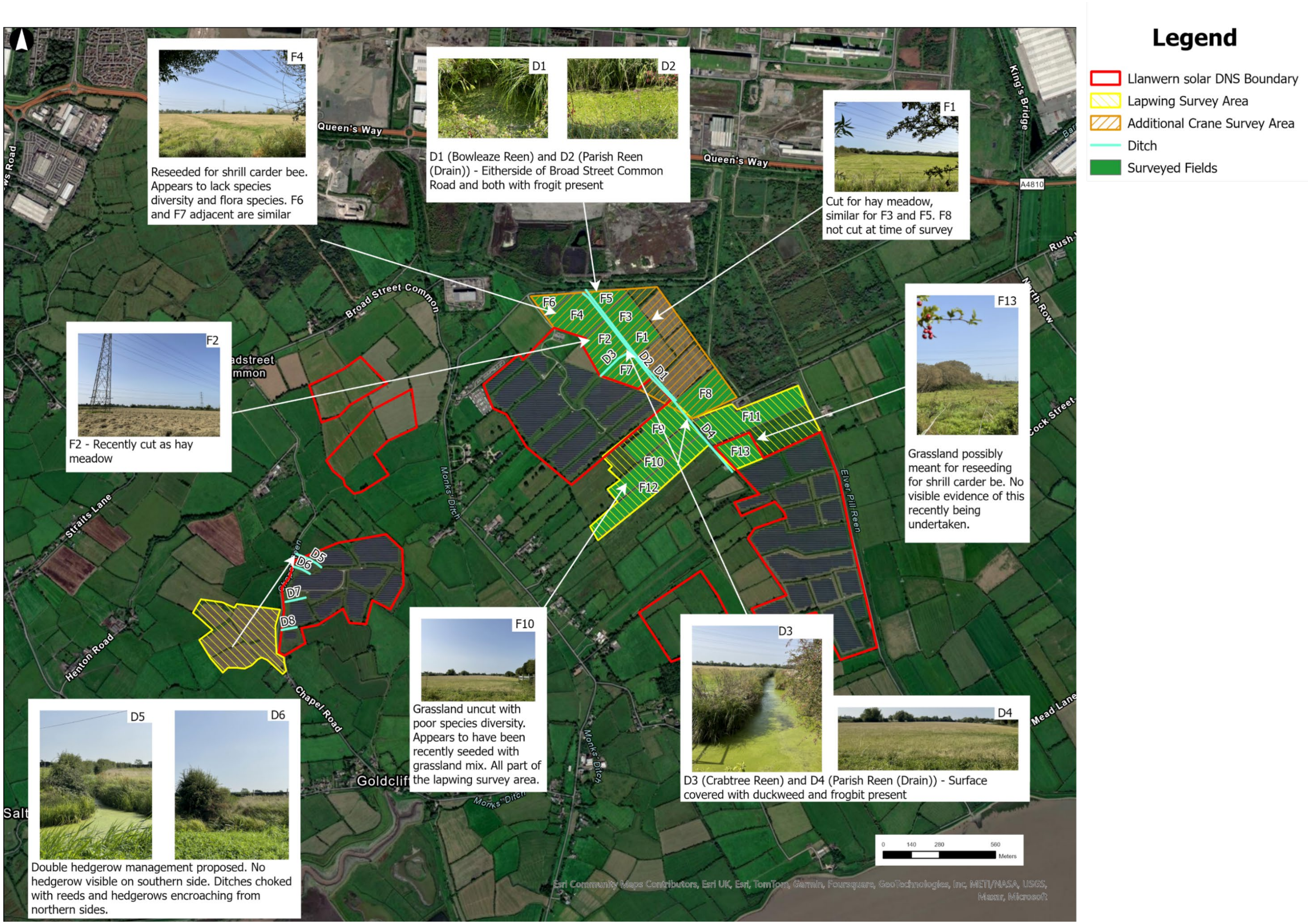

Figure 6: Surveyed ditches and fields within Llanwern solar farm

3.3.5 Gwent Europark

Gwent Europark reserved matters application (18/1234) was granted permission in March 2019 for the erection of warehouse for stage pallets, associated infrastructure, storage, offices, gatehouse and parking areas, with an additional reserved matters application (22/0349) being approved in November 2022 for a variation of 18/1234 relating to access, appearance, landscaping and layout. The outline planning permission (92/0875) was granted in May 1995 for the development of land for Class B8 (distribution) on previously undeveloped land east of Llanwern Steel Works. Following this, reserved matters planning permissions were granted relating to landscaping and the access road and roundabout on Llandevenny Road in late 1995 (95/1038 and 95/0721, respectively). The outline planning permission was subsequently renewed twice to extend the timeframes for the submission of reserved matters by virtue of planning permission 99/0800 in August 1999 and 02/0783 in August 2002. The operational outline planning permission, therefore, is 02/0783 granted subject to conditions. Subsequently a reserved matters application relating to the Gwent Europark site was submitted pursuant to planning permission 02/0783 for the erection of a B8 distribution facility with associated two-storey offices, single storey gatehouse and vehicle maintenance unit (07/0743). This application was approved in September 2007. A further reserved matters (19/0122) was approved for an industrial building in August 2019.

The Gwent Europark being appraised here, therefore forms part of the Europark Industrial Estate and is flanked by the Tesco distribution centre to the south and Wilkinson distribution centre to the west. Beyond this and to the west is the former Llanwern Steel Works.

The Gwent Europark application (18/1234) site covers approximately 23ha, forming part of the outline planning application area, covering approximately 86ha. This site is currently being built out under the relevant phases of the development, with ‘Phase 1’ to the west of the development being complete and only mitigation features, vegetation clearance and ground works taking place on the ‘Later Phases’ to the east (as shown in Figure 1-2 Indicative Site Layout in the Biodiversity Management Plan (2020). The site is approximately 2.9km from the Severn Estuary EMS, and the site lies wholly within one SSSI unit, Redwick and Llandevenny SSSI, the NNRA and is within the Caldicot Levels.

Pre-construction, the site comprised predominantly low-lying coastal and floodplain grazing marsh of semi-improved neutral grassland with large areas of dense and scattered scrub, with a network of reens and ditches within and surrounding the site, including the Waundeiland Reen through the centre of the site, which has now been realigned as part of the mitigation, using an existing ditch to the east, with associated widening and deepening to accommodate the water levels and volumes required (the loss of field ditch was not however compensated for).

The main documents used for the appraisal and later the assessment in Chapter 4 below, included the Preliminary Ecological Appraisal (2020), Biodiversity Management Plan (2020), Detailed Planting Scheme and Management Plan (2019), Ditch and Reen Environmental Baseline and Monitoring Plan (2020), Surface Water Quality Monitoring (2020), Drainage Strategy (2019), landscape plans (2019 - 2022) and Swale /Ditches Setting Out Plan (2020), and various letters from NRW and LPA stating their concern regarding inadequate information and the impact upon designated sites and protected species.

Within these documents, the proposals of the site set out that external reens were to be avoided and 7m grass buffer maintained (as per outline planning - not the 12.5m NRW requirement now). One reen infilled and the water diverted to the eastern ditch (as per outline planning) and ditch enlarged, and all the internal site ditches infilled. Significant area of semi-improved grassland and scrub lost with minimal mitigation and compensation proposed in the application (likely linked to the outline permission). Swales were proposed and have been implemented, including a 12m wide length in the centre of the site and a smaller one to the south and west of the hardstanding area for the warehouse and storage as shown in Figure 7.

The site visit survey to Gwent Europark was conducted on 4th September 2023. The creation of the 12m wide ditch in the centre of the site (Ditch D1 on Figure 7) was recorded to be holding water and with marginal and aquatic plants present, including bulrush (*Typha latifolia*), reeds and amphibious bistort (*Persicaria amphibia*); presence of SSSI species was not observed. The new ditch feature is connected to the reen network through culverts and sluices (personnel communication with site personnel).

The development has diverted the Waundeliland Reen into the ditch to the east of its original location (D2 on Figure 7), as agreed in the outline planning application, which was covered in duckweed but with signs of management and hedgerow only on eastern side. The new attenuation ponds, which had low water levels at the time of survey with minimal marginal and aquatic species present, also drains into D2.

Ditch D3, which has now become a dead-end ditch with the diversion of Waundeliland Reen appeared to be dry at the time of surveys and fully shaded by scrub encroachment. Ditch D3 ditch may have been infilled during the earthworks phase of the development as agreed within the outline and reserved matters applications and subsequently overgrown with scrub. The field F1 south of this ditch had been recently cut of hay with arising still present on site.

The newly created ditch/swale (D4 on Figure 7) that runs around the new hardstanding platform with temporary buildings and storage areas, has limited buffer from the hardstanding area and the sites fencing. This buffer is shown to be 3.2m on the Swales/Ditches Setting Out Plan Phase 1 & 2 Construction Works (Drawing 19045-507), however due to vegetation growth, it was hard to determine whether this buffer width was maintained in all locations. The ditch was completely choked and over-grown with vegetation, including willow and other scrub species starting to grow; other species present include bulrush, willow herb species (*Epilobium spp.*) and purple loosestrife (*Lythrum salicaria*). The ditch was holding limited water and was mostly overshaded by the vegetation growth. Due to the location of the fence and the hardstanding and buildings, there doesn’t appear the ability to re-cast the ditch. There was no evidence of management of the ditches/swales, although the Operation and Maintenance Requirements – Swales and Basins Features schedule proposed management of vegetation monthly for the first year and then as required, and sediment removal from swale/basin every five years, or as required.

Grassland buffers have been maintained from the surrounding reens, including Bareland Street Reen and Wilcrick Moor Reen, where buffers appear to be approximately 7m in width from the fence line, which is consistent with the Drawing 19045-507 and as agreed through the outline planning application. The grassland had some species diversity and showed signs of being manged from scrub encroachment.

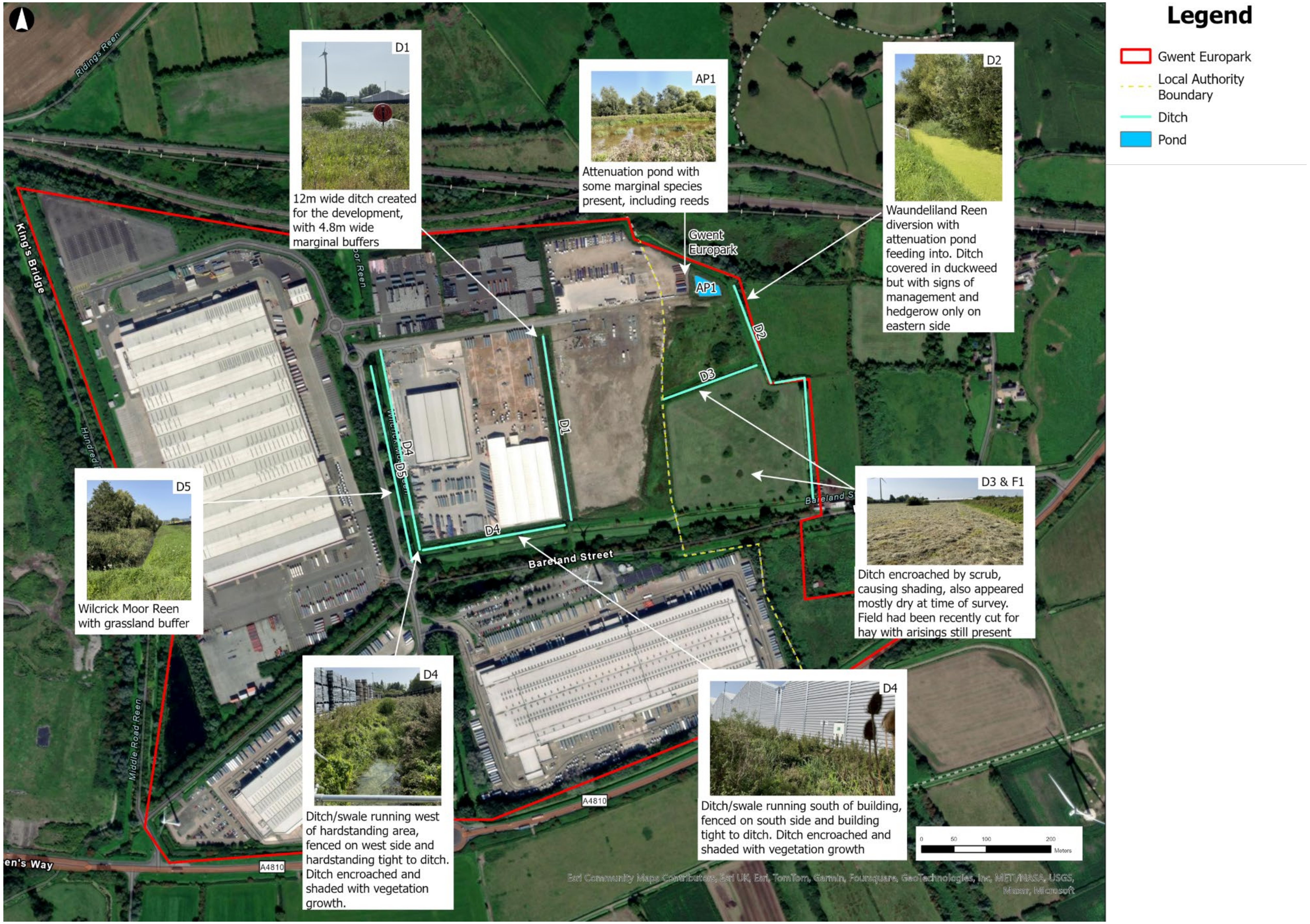

Figure 7: Surveyed fields, ditches and ponds within Gwent Europark site

4. Criteria-based Assessment

This chapter describes the methodology used to develop the criteria-based assessment with the key aim to assess how biodiversity and ecosystem resilience impacts were identified and addressed at pre-construction (planning stages) and at post-construction for the selected sites. The methodology considers whether actions and measures taken can be considered compatible with fulfilling the aims and objectives of Policy 9 of Future Wales and SMNR, with particular focus on the features within the SSSIs and ecosystem resilience (DECCA), and the delivery of NBB, and if not, to consider why this may be the case. Further criteria-based assessment was developed with the additional aim to evaluate the relative strengths and weaknesses within the planning system and the different stages of the planning process, from pre-application advice to delivering post-construction management and monitoring.

Again, it is important to stress that it is recognised that this criteria-based assessment is somewhat retrospective as some of the sites, when they were originally permitted, would have predated many or all of these policy requirements. Nevertheless, this retrospective assessment gives some useful insight into how they would potentially fare if being determined and monitored in relation to policies as they stand at the time of this Study. This part of the exercise is therefore intended as a means to gain insights and learn from what has happened previously and apply that learning for the future.

The assessment criteria were co-developed with the Steering Group and refined through the stakeholder engagement. The Stakeholder Group provided a firmer understanding of the Planning System criteria which were influenced and formed part of the interactive Workshop 1, as described in Chapter 5.

This chapter then provides the results from the criteria-based assessments, both through the lens of the DECCA framework and the Planning System criteria.

4.1 Methodology

4.1.1 The DECCA Assessment

The main objective in developing a DECCA criteria-based assessment was to assess the degree to which the selected developments, proposed and/or achieved protection and enhancement of the Gwent Levels SSSIs features, as well as the wider local biodiversity interest and supporting ecosystems in line with the approach set out in PPW. In doing so, the assessment also aimed to determine whether the varying development types, of the selected sites, could potentially be considered compatible with the aims of Policy 9 of Future Wales and the objectives and principles of SMNR and the resilience of ecosystems (DECCA), by considering how well the development has responded to each of the DECCA attributes and emerging properties.

A preliminary list of questions was collaboratively derived within the Steering Group for each of the DECCA criterion groups. The questions under each DECCA criterion group had to be relative to the DECCA attribute (Diversity, Extent, Condition and Connectivity) or emergent properties (taken as Adaptability, but also considering recovery and resilience) for which they were being developed. They were also defined by current Welsh policy requirements, up-to-date standards, principles and best-practice guidance to ensure protection and enhancement of biodiversity, as well as specific principles and best-practice knowledge relating to the Gwent Levels SSSIs features.

Further refinement of the DECCA criterion questions sought to be able to apply the questions for both pre-construction (planning stages of the development) and post-construction stages (including construction mitigation and obligations, as well as longer-term habitat and species management and monitoring). Additionally, each DECCA criterion group needed to cover aspects specific to terrestrial and aquatic habitats, both specific to the SSSIs and wider consideration for net benefits of biodiversity, as well as protected and notable species.

The preliminary list of questions was later refined through working with the Stakeholder Group, as well as a testing whether the questions were ‘fit for purpose’ by running two different sites through the assessment, as shown in Figure 1 in Chapter 1. Through this process the preliminary assessment questions were revised and concentrated into five questions per DECCA criterion group, as shown in Table 1 below.

4.1.2 Planning System Assessment

The main objective in developing the Planning System criteria-based assessment was to draw out differences between the stages of development planning and delivery in terms of the protection and enhancement to biodiversity and the Gwent Levels ecosystems. Using a similar approach to the DECCA Framework assessment, questions were derived which sought to enquire how well the developments/selected sites performed against stage of the planning system.

The questions principally needed to cover the following stages:

- Pre-application and planning application stage, relating to consultation, assessment and design relating to net benefit for biodiversity and application of the step-wise approach[63] (pre-construction stage);
- Planning regulation and determination stage, relating to the planning balance and evidence of the weighting of biodiversity, as well as planning regulation efficiency through planning conditions and/or Section 106 Agreements (S106) (pre-construction stage); and
- Post planning regulation stage, relating to the efficiency of the discharge of conditions and implementation of mitigation and enhancement measures, including long-term management and monitoring (post-construction stage).

A list of questions was derived using these principles within the Steering Group, and further refined through working with the Stakeholder Group, as well as testing whether 'fit for purpose' by running sites through the assessment questions. Through this process the planning system assessment questions were revised and concentrated into seven questions and three planning stages: 'planning application', 'planning regulations & determination', and 'post-planning regulations', as shown in Table 1 below. For the purposes of displaying the results later on in this chapter questions 1 –5 are grouped together and are referred to as the pre-construction stages whereas those relating to questions 6 - 7 are grouped together and referred to as the post-construction stage.

4.1.3 Assessment Application

Each of the selected sites (built developments) were assessed in terms of how well they perform against each of the criterion questions within the DECCA and the Planning System assessments, both at pre-construction and post-construction stages. The performance was determined as to whether the developments had strong, moderate or weak alignment with the criterion question being assessed. The evidence to determine performance against the criterion questions was gained from the key documents relating to planning and post-construction monitoring and management, and as identified in the individual Selected Sites Appraisal in section 3.3 above, the observations recorded from the Site Appraisal Methodology, as described in section 3.2 above, as well as evidence gained from the Stakeholder Group.

The results of the DECCA assessment and the Planning System assessment have been presented collectively, bringing together, and averaging the results from each of the criterion questions, for both the pre-construction and the post-construction stages, to provide the mean result across all the five selected sites. Radar diagrams have been used to represent the collective sites performance against the criterion, these are presented and analysed in Section 4.2 below.

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[63] First priority is to avoids damage to biodiversity, when all locational, siting and design options for avoiding damage have been exhausted, the proposed development must seek to minimise the impact on biodiversity and ecosystems. Where, after measures to minimise impact, biodiversity and ecosystems could still be damaged, or lost through residual impacts, the proposed development should mitigate that damage. Mitigation measures must be put in place to limit the negative effects of a development. As a last resort when all other steps are exhausted, off-site compensation for unavoidable damage must be provided. Each stage of the step-wise approach must be accompanied by a long-term management plan of agreed and appropriate avoidance, minimisation, mitigation/restoration and compensation measures alongside the agreed enhancement measures.

The values on these diagrams are informed by scores assigned to the performance alignment with criterion questions which ranged between a score of 3 for strong alignment to a score of 1 for weak alignment, as described below:

- A score of 3 was provided for strong alignment: Strong alignment was assigned where there was clear evidence that key elements within the criteria question had successfully been addressed;
- A score of 2 was provided for moderate alignment: Moderate alignment was assigned where evidence showed that some of the elements of the question was achieved; and,
- A score of 1 was provided for weak alignment: Weak alignment was assigned when there was a clear lack of evidence to support key elements within the question, not because the documentation was not found but due to evidence indicating lack of alignment/elements being addressed.

As such, the minimum average/mean score across a criterion for all five sites could be 1, with a maximum of 3.

Due to the difficulties experienced in locating key documentation from relevant planning portals (see section 4.1.4 Limitations and Assumptions, below), a confidence level was applied to each of the criterion performance alignment scores. The confidence level was based on a 'RAG' system, with:

- 'Red' meaning there was a lack of evidence located/found on the planning portal however it could not be ruled out that some elements of the criterion questions were addressed just evidence was not available. In this circumstance, a moderate alignment was applied to the criterion question due to the confidence level being low.
- 'Amber' confidence level was applied when there was enough evidence to determine the alignment, however not all documents were readily available/found on the planning portal. In this circumstance, the alignment score remained the same, however analysis was undertaken to determine trends where criteria repeatedly scored an amber confidence level, indicating where documentation and data was lacking. This analysis was used to inform results in Section 4.2 below.
- 'Green' confidence level was applied when there was a wealth of evidence found to support the selection of the alignment (strong to weak) to the criterion question.

In addition, it is recognised that the DECCA assessment was developed considering the aims of Policy 9 and the objectives and principles of SMNR and the resilience of ecosystems, as well as using today's standards, guidance and ecological knowledge relating to the Gwent Levels. As such, it was expected that some of the older applications were unlikely to have 'strong' alignment with all criteria. However, this was a factor of the assessment, in that the assessment allows for both general comparison of how well the sites performed against the DECCA criterion, as well as allowing for a more detailed comparison within each DECCA criterion group to determine trends, and where the sites consistently perform well, over time, where they perform poorly, and where changes in policy, legislation, regulation and guidance may have impacted that performance.

The radar diagrams as such are based on the mean scores, and are scaled 1 to 1.66 for weak alignment (within the centre area of the radar), 1.67 to 2.33 for moderate alignment (middle area of the radar) and 2.34 to 3 for strong alignment (outer area of the radar).

Although the criterion questions are not directly dependent on each other to achieve their relative alignment, they are connected in so far as being all defined around the attributes and emerging properties of DECCA, or the Planning System stages in succession, and for this reason the connective lines between the scores are represented on the radar diagrams. In doing this, the differences can be seen between the various criteria and their groups, as well as the difference between alignment at pre-construction and post-construction stages, which are represented as two sperate connected lines within the radar graphs.

Table 1: Criteria-based DECCA and Planning System Assessment ***(indicating Pre-construction and Post-construction stages)***

Criterion Group	Criterion	Habitat Feature	Qualitative Criterion Assessment Questions
Diversity	D1	All Habitats (SSSIs)	Have the appropriate ecological surveys been undertaken to survey and determine the diversity of species and habitats relevant to the SSSIs and to inform relative impacts, mitigation/compensation, management, and monitoring (*e.g.* National Vegetation Classification (NVC) surveys, Aquatic Flora surveys of reens and ditches, Aquatic and Terrestrial Invertebrate surveys, including for shrill carder bee)? *(Pre-construction)* Have these been repeated for monitoring purposes? *(Post-Construction)*
	D2	All Habitats	Have habitats with moderate to high diversity been avoided? Where this has not been achieved, does mitigation/compensation create 'like for like' or an improved same ecosystem habitat (i.e. grassland, woodland, wetland *etc.*) with greater diversity? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	D3	All Habitats	Is there evidence provided to support the suitability of the proposed habitats and species mixes in terms of the local context, SSSIs features and species, soils, topography, etc.? *(Pre-construction)* Have these species mixes been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	D4	All Habitats	Have appropriate habitat enhancement and creation techniques been provided, with reference to guidance and/or approval by NRW and/or LPA? *(Pre-construction)* Have these techniques been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	D5	Protected & Notable Species	Have appropriate species surveys been undertaken to develop an understanding of population dynamics and carrying capacities of protected and notable species (other than SSSIs species) to inform mitigation strategies to maintain or enhance the species diversity of the local area/site? *(Pre-construction)* Have the mitigation strategies for species been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
Extent	E1	Terrestrial Habitats	Where development results in the loss of medium to high value terrestrial habitats (such as semi-improved grasslands, wetlands or semi-natural woodland and hedgerows), does mitigation and/or compensation replace these habitats to an equal or greater extent? Where habitats are enhanced as part of the mitigation and/or compensation, have the habitat calculations/assessments taken account of the value of the existing habitat to be enhanced, and is this considered in the calculations/assessment to achieve net benefits in terms of relative extent? (For example, enhancing an existing grassland is not increasing the extent of this ecosystem, whereas creating or restoring completely lost habitat, such as arable to grasslands, is increasing extent). *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	E2	Aquatic Habitats	Have all ditches and reens been avoided? Where ditches (dry or wet) and/or reens are lost as part of development, does mitigation or compensation replace these waterbodies to an equal or greater extent? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	E3	Aquatic Habitats	Where new ditches and reens have been proposed and/or enhancements to existing ditches and reens are proposed, has NRW guidance been followed for cross-sections, slope gradients, inclusion of berms, and surface area of ditch or reen been considered to maintain the extent of the wetland habitat? (Note: it is the landowner's responsibility to manage ditches in compliance with the Conservation Objectives of the SSSIs, as such even if a development is not impacting the reens and ditches there should commitments to enhance the ditch conditions) *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	E4	Aquatic Habitats	Where new ditches and reens have been proposed and/or enhancements to existing ditches and reens are proposed, has the design demonstrated and/or proven water retention during the summer months, and that the depth of water is sufficient to ensure that SSSIs features can prevail? (For example, new sluices may be required to hold back water and a preferred summer water level of 0.30 – 1.25m (average 0.40m) for ditches and 0.60 – 2.0m (average 1.25m) for larger reens) *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	E5	Protected & Notable Species	Have appropriate extents of protected and notable species habitat been proposed that will maintain favourable conservation status for protected species and/or maintain or enhance species ranges in the local area? Has this been evidenced on how this will be achieved? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
Condition	C1	All Habitats (SSSIs)	Have the appropriate SSSIs condition assessments been undertaken to inform baseline, scheme designs and/or mitigation, compensation and/or enhancement of SSSI features, to achieve an overall improvement in SSSIs condition? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	C2	All Habitats	Has a monitoring and management strategy been developed for both retained, enhanced and created habitats that provides clear targets for habitat condition (including relevant to Conservation Objectives of protected sites), and outlines actions to be undertaken if condition is not achieved within set timescales? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	C3	Aquatic Habitats	Where a development could result in the pollution of ditches and reens, direct or indirect, are sufficient measures in place to prevent a decline of water quality within the ditch and reen network? Has water quality sampling taken place pre-construction, during construction and post-construction to evidence these measures are sufficient? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	C4	Aquatic Habitats	Have sufficient buffers been proposed around all ditches and reens (existing and proposed) which also ensure no overshading from trees, shrubs or buildings of the ditch or reen feature? (For example, no development within 12.5m for reens and 7m for ditches as per NRW guidance and maintaining open unshaded reens and ditches) *(Pre-construction)* Has this been enforced, implemented, managed, and monitored or evidenced on the site? *(Post-construction)*
	C5	Protected & Notable Species	Has the condition of protected and notable species habitats been assessed, and conditions improvement clearly stated and evaluated when demonstrating net benefits? *(Pre-construction)* Have these condition improvements been evidenced, enforced, implemented, and monitored on the site? *(Post-construction)*
	Co1	All Habitats	Have the development proposals demonstrated that designs have been incorporated to avoid and minimise impacts to ecological functional networks and connectivity? Where this is not been possible, has mitigation and/or compensation been provided which clearly demonstrates the maintenance and/or enhancement of ecological functional networks and connectivity, which includes links between and within habitats in the form of physical corridors or stepping-stones of the same or related vegetation types? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	Co2	All Habitats	Has the development adequately considered in-combination effects relating to other potential negative impacts to biodiversity and the SSSIs? *(Pre-construction)* Have any potential cumulative impacts been monitored or considered post-construction? *(Post-construction)*
	Co3	Aquatic Habitats	Have reens and field ditches been avoided and no impact to connectivity demonstrated? If replacement and/or enhancement reens/field ditches are proposed, are these onsite and/or within the same SSSI unit, maintaining connectivity of wet reens/field ditches within the SSSI unit? *(Pre-construction)*

Criterion Group	Criterion	Habitat Feature	Qualitative Criterion Assessment Questions
Connectivity			Has this been enforced, implemented, and monitored or evidenced on the site for the success of the connective habitat? *(Post-construction)*
	Co4	Aquatic Habitats	Where new and/or enhanced ditches and reens have been proposed, has the design demonstrate and/or proven that the water required to fill the new and/or enhanced ditches will not negatively impact the water movement, connectivity and availability of the existing reen network and its water level management? Have water modelling/calculations been conducted to demonstrate this? *(Pre-construction)* Has this been enforced, implemented, and monitored for potential impacts on the site? *(Post-construction)*
	Co5	Protected & Notable Species	Have appropriate species and habitat surveys been undertaken to inform a mitigation strategy that provides suitable ecological functional networks to the relative distance a species can move to feed, breed and complete life cycles that may need different environments? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
Adaptability (Recovery & Resistance)	A1	All Habitats	Is adequate evidence provided to demonstrate alignment with the stepwise approach (avoid, minimise, mitigate, compensate)? *(Pre-construction)* Has this been enforced, implemented, and evidenced on the site? *(Post-construction)*
	A2	All Habitats	Have the proposals demonstrated sufficient understanding of local environmental aspects, understanding place, when developing mitigation and compensation strategies (such as topography, landscape character, geology and soil, water resources, the role of protected areas) to prove the long-term viability of proposals? *(Pre-construction)* Has this been enforced, implemented, and evidenced on the site? *(Post-construction)*
	A3	All Habitats	Has sufficient consideration of the potential impacts of climate change (*e.g.*, on rainfall and temperature) been included when developing mitigation and compensation proposals, such as when determining seed mixes, when designing ditches and reens to hold water during summer months resilient to climate change predictions, when considering post-construction management and monitoring and considering the need for adaptive plans due to climate change? on rainfall and temperature) been included when developing mitigation and compensation proposals, such as when determining seed mixes, when designing ditches and reens to hold water during summer months resilient to climate change predictions, when considering time frames for post-construction management and monitoring and considering the need for adaptive plans due to climate change? *(Pre-construction)* Has this been enforced, implemented, monitored and evidenced on the site? *(Post-construction)*
	A4	All Habitats	Does the proposed habitat management and monitoring strategy cover a sufficient period of time appropriate to the scale of the development and habitat types to ensure the habitats achieve target conditions and evidence mechanisms are in place to adapt management and monitoring techniques in response to climate change and/or other pressures and demands? *(Pre-construction)* Has this been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
	A5	Protected & Notable Species	Have mitigation strategies for protected and notable species considered how these populations will survival during construction and post-construction, and their capacity to adapt, recover or resist disturbances? *(Pre-construction)* Have these mitigation strategies been enforced, implemented, and monitored or evidenced on the site? *(Post-construction)*
Planning System	P1	Planning Application	Is there evidence of pre-application discussions with LPA and/or NRW and that these have influenced proposals relating to ecology and/or for Net Benefits for Biodiversity? *(Pre-construction)*
	P2	Planning Application	Was there an Ecological Impact Assessment (EcIA)? If so, has the EcIA identified impacts and mitigation, and were these considered fit for purpose to be in line with current Policy relating to protection and enhancement of biodiversity? Is there evidence of the step-wise approach being employed and influenced development designs? *(Pre-construction)*
	P3	Planning Regulation & Determination	Were there ecological concerns still outstanding when the officer recommended approval and were these adequately referenced in the officer's report? Were there other benefits considered to outweigh biodiversity impacts and where there were 'planning balance' considerations were these evidenced in reports? If so, what were these? *(Pre-construction)*
	P4	Planning Regulation & Determination	Has the implementation of mitigation measures associated with construction and off-setting impacts been secured through a planning condition and/or S106 commitments (specify which)? If so, are they sufficiently worded to be both enforceable by the LPA, and clear for the applicant? *(Pre-construction)*
	P5	Planning Regulation & Determination	Were any longer-term management and/or monitoring requirements attached to the planning approval (specify which, or both)? If so, have the management and monitoring commitments been secured through planning conditions and/or S106 commitments (specify which, or both)? Are these sufficiently worded to be both enforceable by the LPA, and clear for the applicant? *(Pre-construction)*
	P6	Post Planning Regulation	Did the applicant/LPA enforcement provide 'adequate' evidence to support the discharge of conditions relating to the implementation of mitigation measures and management and monitoring requirements? (identify what these were) *(Post-construction)*
	P7	Post Planning Regulation	Is there any evidence of the LPA and/or NRW enforcing any failure to comply with planning conditions and/or obligations? *(Post-construction)*

4.1.4 Limitations and Assumptions

A level of professional judgement was required to determine both the confidence levels and the sites' performance against the criterion questions. Limitations were associated with obtaining suitable information for the sites. As mentioned in Chapter 3, the relevant planning portals were searched for key documentation under the relevant planning application references. However, searching for relevant documents on the planning portals proved challenging due to inconsistent naming of reports/files, incorrect titles of documents and large number of documents for the larger and more complex planning applications, as such some documents may have been missed. However, and as described above, the confidence levels and consequence on the performance level selected, provided some allowance in these cases.

The multiple variables across the different sites and sample size would not allow for a viable statistical analysis between each site and/or development type. Therefore, the sites were individually compared against each other within the analysis of the assessment outcomes, according to the DECCA and Planning System criterion questions, and as such the results are presented collectively as means across the five selected sites. This enables analysis of the best and worst criterions for both pre-construction and post-construction, determined by evidence. Individual scores for the selected sites have not been provided within this Study for discretional reasoning; these are considered as **confidential** and are not available for wider viewing and/or consideration. Furthermore, the aims and objectives of the Study were not to critically assess individual developments or local authorities or others in relation to biodiversity safeguarding and design, implementation, and regulation, rather to determine trends and learn lessons to look forward in ways to ensure that net benefits for biodiversity are achieved through the planning system going forward. Commentary is however provided where significant results, abnormalities and/or observations have been made on specific sites during the assessments.

The initial brief from WG aimed to select a range of sites that were representative of different development types built across the three LPAs within the Gwent Levels to compare differences in impacts, mitigations and potential alignment with current policy, legislation and guidance. However, this comparison in terms of different types of development was not statistically viable due to temporal factors and sample size and became evident early on at the site selection stage of the project. Chapter 3 describes the Site Selection and Appraisals process.

Additionally, a lack of evidence of pre-application advice and documentation and no attachments to decision notices to discharge conditions, also provided some limitation to auditing and evidence building for the assessment.

4.2 Results and Analysis

The results of the DECCA assessment and the Planning System assessment have been presented collectively, bringing together, and averaging the results from each of the criterion questions, for each pre-construction and post-construction stage or criterion, to provide the mean result across all the five selected sites. Radar diagrams have been used to represent the collective sites performance against the criterion, these are presented and analysed below.

4.2.1 The DECCA Assessment Results

The results below firstly present and analyse the overall DECCA radar diagram (Figure 8) which demonstrates the averaging across all five criteria within each of the DECCA criterion groups. The results then focus on each criterion groups individually and in turn, each of which comprises five questions per criterion group (*e.g.* for Diversity the radar diagram shows results from criterion D1 to D5, see Table 1 above, and Figure 9 below). This allows for both general comparison of how well the sites performed against the DECCA criterion, both at pre-construction and post-construction, as well as allowing for a more detailed comparison within each DECCA criterion group to determine trends, and where the sites consistently perform well and where they perform poorly.

The averages for each DECCA criterion group, across the five selected sites, are shown in Figure 8. This shows how the sites performed in each criterion group on a scale (weak, moderate and strong) within the pre-construction (blue) and post-construction (purple) stages.

The results in Figure 8 show that all sites collectively scored lower at post -construction compared to pre-construction, owing typically to a lack of successful implementation of biodiversity designs, mitigation and onward management and monitoring plans as prescribed within the planning applications, compared to the performance/level of details relating to surveys, designs and plans produced and submitted at the 'pre-construction' planning application stage and/or to discharge planning conditions.

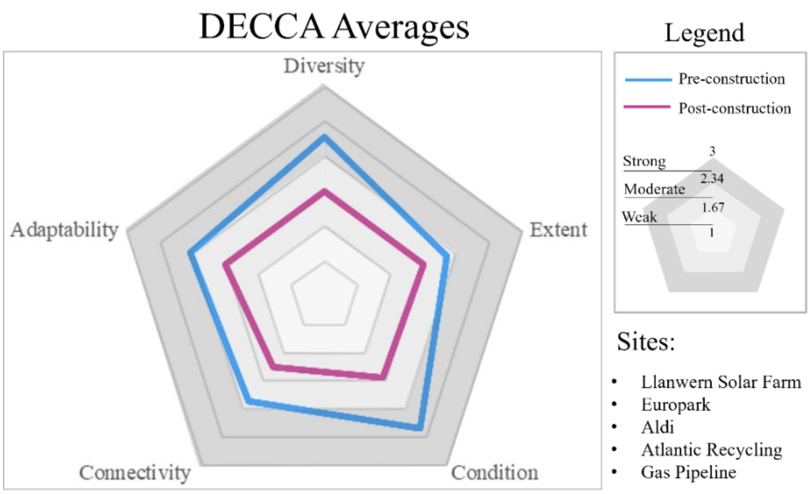

Figure 8: Pre-construction and Post-construction DECCA Averages Across Five Sites

Condition collectively scored the highest within the pre-construction stage with a mean strong performance (mean score being 2.56). This score is weighted by the performance of all five sites being strong, relating to the criteria concerning sufficient measures for pollution control and water quality to avoid and mitigate impacts to aquatic habitat (C3, Table 1), and sufficient reen/ditch buffers from construction and operation activities to avoid and mitigate impacts to the condition of the SSSIs features (C4, Table 1). The score for the **Condition** criterion group however dropped at the post-construction stage down into moderate performance (mean score being 1.96), owing to a lack of implementation, management and appropriate monitoring evidence, as well as recording of any remedial action requirements relating to targets condition for habitats.

Extent and **Connectivity** collectively scored the worst within the pre-construction stage (mean score being 2.24 for both), with **Connectivity** remaining the worst within the post-construction stage (mean score being 1.84). **Connectivity** scoring was weighted by a weak performance scoring across all sites for criterion Co4 relating to lack of evidence of applications considering the functionality of their mitigation and compensation designs in relation to the water management of the reen network and whether the ditches and reens proposed would provide suitable conditions for SSSI species to establish and thrive. **Extent** scoring was weighted by a weak performance scoring across all sites for criterion E4 relating to a very similar criterion being whether the applications demonstrated that the reens and/or ditches compensation or enhancement designs would hold depths of water (extent of water) during the summer months that are suitable to support SSSI species (**Extent** post-construction mean score being 2.00).

Adaptability collectively scored moderately for both pre-construction (mean score being 2.36) and post-construction (mean score being 2.00), and as with the other DECCA criteria showing a drop in score between pre- and post-construction.

Overall, **Extent**, **Connectivity** and **Adaptability** scored lower than **Diversity** and **Condition**. Analysing the data revealed that it was the older applications, or those linked to older outline planning applications that were influencing these lower scores. This is possibly owing to those sites, or their outline planning applications, pre-dating some of the key legislation, policy and guidance relating to biodiversity and ecosystems resilience. For example, the Gwent Europark reserved matters application was linked to the 1995 outline planning application (as detailed in Section 3.3.5) which pre-dates the Countryside and Rights of Way Act 2000, which was of particular significance to nature conservation in relation to the changes to Part I of the Wildlife and Countryside Act 1981, and pre-dates the Environment (Wales) Act 2016[6], and had poor performance against some of the **Extent**, **Connectivity** and **Adaptability** criterion. Generally, across most of the sites, there was lack of evidence provided by the applicants to support the functionality of mitigation designs, such as within **Connectivity** networks, i.e. water availability within created and enhanced ditches and reens, and evidencing mitigation designs **Adaptability**, i.e. the designs resilience to recover from demands and pressures, and consideration of local and climate-related needs. Further to this, these older applications pre-date the notion of 'ecosystem resilience' and DECCA in policy, which recognises each of the ecosystem attributes and emergent properties, and moreover the need for preservation and enhancement within each. Ecosystem resilience was introduced in 2016 with the Environment (Wales) Act, but it was not until 2020 the DECCA Framework was first introduced within the SoNaRR (2020)[14] report and later explained in NRW's Terrestrial and freshwater Resilient Ecological Networks: a guide for practitioners in Wales (2021)[22].

Condition and **Diversity** may have scores collectively higher across the sites, owing to historically nature conservation and protected sites, including SSSIs, being recognised and designated for their diversity and importance of species, and have been measured by their condition of habitats and species abundances. Through policy and legislation is was possibly easier for developers to be guided by these requirements driven by condition and diversity, and justified through the condition assessment requirements of the SSSIs citations (1987 – 1993) and their SMSs produced in 2008[36, 39, 42, 45, 47, 49, 50]. **Diversity**, like **Condition**, scored a strong performance at the pre-construction stage, dropping to moderate at post-construction, for similar reason described for **Condition** above.

Noticeably older applications or those associated with older outline consents scored worse across all DECCA criterion groups. Interestingly, the performance differences were less significant when considering criterion questions relating to water quality and pollution, presumably due to more established controls, regulations and guidance relating to construction environmental compliance and pollution prevention measures[64], compared to habitat creation and restoration and its onward management and monitoring requirements.

4.2.1.1 Diversity Results

Results across the five sites for Diversity are shown in Figure 9. Full criterion descriptions for criterions **D1** – **D5** are set out in Table 1 earlier in this chapter. As shown in Figure 9 and summarised in Table 2 below, Diversity criterion **D4** scored the highest on average across all five sites. **D4** was related to whether appropriate habitat enhancements and creation techniques had been provided at the pre-construction stage with reference to guidance and/or approval by NRW and/or the LPA. **D2** also score strong collective performance at the pre-construction stage, relating to the avoidance of moderate to high diversity habitats, and if this was not possible, mitigation or compensation being of 'like for like' or an improved habitat with greater diversity (this did not consider extent, just diversity of habitats). Both Diversity criterions, **D4** and **D2**, scored worst at the post-construction stage, along with **D3** relating to evidence of the selection and implementation of locally suitable diverse seed mixes and planting. The drop in performance for these Diversity criterions was owing to the lack of evidence to demonstrate the designs, management and monitoring associated with the developments had been achieved in relation to the diversity of habitats proposed at the pre-construction stages, including a lack of evidence of remedial actions to rectify failures. For some sites, these failures to achieve 'diverse' designs were evident during the site appraisal visits, as *described* in Section 3.3 above.

D1, **D3** and **D5** all scored worst within Diversity, although collectively just into the strong performance score, at the pre-construction stage (as shown in Table 2 below). These relate to appropriate ecological baseline to inform designs, mitigation, management, and monitoring requirements relating to the SSSIs,

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[64] Such as Pollution Prevention Guidelines (PPGs) that are based on relevant legislation and good practice to provide guidance on how to prevent pollution and comply with environmental law at construction and demolition sites.

evidence of local factors influencing designs, and appropriate species surveys to inform mitigation strategies, respectively.

Post-construction, **D1** and **D5** score slightly higher than the other criterion, however all are within the moderate performance score collectively. **D1** may have scored slightly higher at post-construction owing to better established guidance for post-construction monitoring of the SSSIs since the CCW guidance produced between 1991[56] and 1996[57, 58, 59, 60], and as such historically there has been better guidance for wording of planning conditions relating to monitoring of SSSI features. Similarly, mitigation strategies concerning protected species (criterion **D5**), are often linked to Protected Species Licences which provides a separate management and enforcement route for biodiversity requirements to be delivered, other than under planning conditions and regulation.

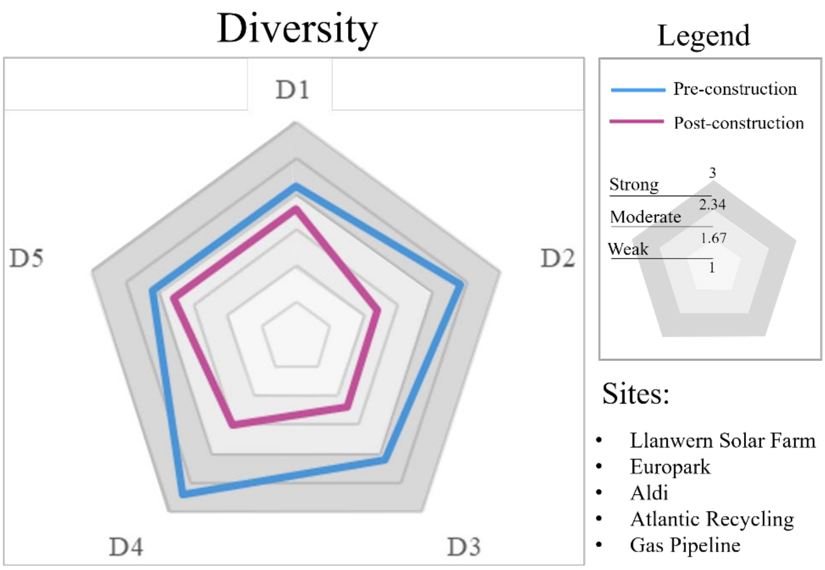

Figure 9: Pre-construction and Post-construction Diversity criterion averages across five sites

Table 2: Summary of the Diversity Scorings

Diversity – Mean Scores from all Sites	
Best Scores	**Worst Scores**
Pre-construction	
D4 (best) – appropriate mitigation and enhancement designs with reference to LPA and NRW guidance (Score 2.80) **D2** – avoidance of moderate to high diversity habitats and/or appropriate mitigation/compensation (Score 2.60)	**D1**- appropriate ecological surveys relating to the SSSI (Score 2.40) **D3** - suitability of mitigation proposal in terms of local context, such as seed mixes (Score 2.40) **D5** - suitability of species surveys to inform population dynamic, carrying capacities and mitigation strategies (Score 2.40)
Post-construction	
D1 – monitoring of habitats and species potential impacted (*however, often limited to just water quality and SSSI aquatic species*) (Score 2.20) **D5** – implementation of mitigation proposals relating to protected species (Score 2.20)	**D2** – implementing and management of designs to diversity specifications relating to moderate to high diversity habitats (Score 1.80) **D3** - implementing and managing mitigation proposal in terms of local context (Score 1.80) **D4** - implementing and managing mitigation proposal in line with NRW and/or LPA guidance (Score 2.00)

4.2.1.2 Extent Results

Results across the five sites for Extent are shown in Figure 10 and summarised in Table 3 below. Full criterion descriptions for criterions **E1** – **E5** are set out in Table 1 earlier in this chapter. The Extent criterion questions **E2**, **E3** and **E5** all scored highest at the pre-construction stage, collectively scoring just within the strong performance level. **E2** and **E3**, which related to the compensation of reens and ditches in terms of extent and design, likely scored well owing to the CCW 1991 Guidance[56] which provides developers and LPAs guidance on mitigations for reens and ditches relating to extent and designs, such as the realignment of ditches around the perimeter of the development or a compensatory length of ditch should be cast elsewhere within the site, extent of buffers from reens and ditches from development, inclusion of berms on ditches for water voles and other aquatic species. Criterion **E2** also demonstrated the selected sites planning applications partial alignment with the step-wise approach within PPW[8], with some applications avoiding or minimising impacts to reens and ditches completely through designs with appropriate buffers to reens and ditches, and construction methods such as through directional drilling. The step-wise approach as presented in PPW, follows the principles of the mitigation hierarchy as set out in both Environmental and Ecological Impact Assessment (EIA and EcIA) regulation and guidance relating to planning[65, 66, 67, 68 and 69] which provides further requirements for applicants to follow such a hierarchy which puts avoidance first and compensation last.

E5 relating to whether appropriate extent of protected and notable species surveys have been undertaken to inform the maintenance of species favourable conservation status, also likely score well due to the more established guidance on survey methodologies and requirements relating to protected and notable species and the development of Protected Species Licences.

Both **E1** and **E4** scored within the moderate performance level for pre-construction, being of the lowest scores at this stage, with **E4** being worst. **E4** related to whether the applications demonstrated/proved that the reen and/or ditch compensation or enhancement designs would hold depths of water during the summer months that are suitable to support SSSI species. Although some recommendations of seasonal or annual water coverage is mentioned in the CCW 1991 guidance[56], details of depth of summer water levels for reens and ditches that would support SSSI species was not specifically provided. More recent studies on the Gwent Levels, such as the Ecohydrological Studies of the Gwent Levels (2022)[70] have provided further information on preferred summer water levels of 0.30m to 1.25m (average 0.40m) for ditches and 0.60 m to 2.00m (average 1.25m) for larger reens. These water levels are supported by the plant communities described in Wheeler et al. (2004)[71] which have similar compositions as those found on the Gwent Levels. As such, lack of guidance specific to summer water level requirements may have been a factor in **E4** being of low performance.

The criterion **E1** which scored the second lowest at the pre-construction stage was related to compensation of moderate to high value terrestrial habitats in relation to extent, and whether habitat calculations were used to determine NBB which factored in relative extent gains in relation to the habitats baseline conditions. Here

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[65] Environmental Impact Assessment (EIA) Directive (2011/92/EU as amended by 2014/52/EU).

[66] The Town and Country Planning (Environmental Impact Assessment) Regulations 2017.

[67] The Environmental Impact Assessment (Agriculture) (Wales) Regulations 2017.

[68] Welsh Government. 2019. The Environmental Impact Assessment (Agriculture) (Wales) Regulations 2017: General Guidance.

[69] CIEEM. 2018. Guidelines for Ecological Impact Assessment in the UK and Ireland: Terrestrial, Freshwater, Coastal and Marine version 1.2. Chartered Institute of Ecology and Environmental Management, Winchester.

[70] Low, R., Mould, D., Taylor. A., Jonathan G. and Hammond, M. 2022. Ecolohydrological Studies of the Gwent Levels, South Wales, Rigare, RSPB and WG.

[71] Wheeler, B.D., Gowing, D.J.G., Shaw S.C., Mountford J.O., and Money R.P. 2004. Ecohydrological Guidelines for Lowland Wetland Plant Communities (Eds. A.W. Brooks, P.V. Jose, and M.I. Whiteman,). Environment Agency (Anglian Region).

applications scored low as many had predominantly focused on mitigating and compensating aquatic features associated with the SSSIs reens and ditches, with many terrestrial habitats not being fully considered.

Post-construction, **E4** remained with the lowest score however this was the same as the score at pre-construction, likely owing to some of the sites providing evidence of summer water levels within management and monitoring reports. **E1**, **E3** and **E5** all scored worse at post-construction than pre-construction owing to lack of evidence that mitigation designs had been implemented, managed and/or monitored as described or was not included within the application at the planning stage. **E2** scored the best in the post-construction stage, owing to evidence relating to the implementation of avoidance of reens and/or ditches and where this was not achievable the compensation of reens and/or ditches relating to extent.

There was, however, less evidence for this criterion on continued management and monitoring of these features post-construction.

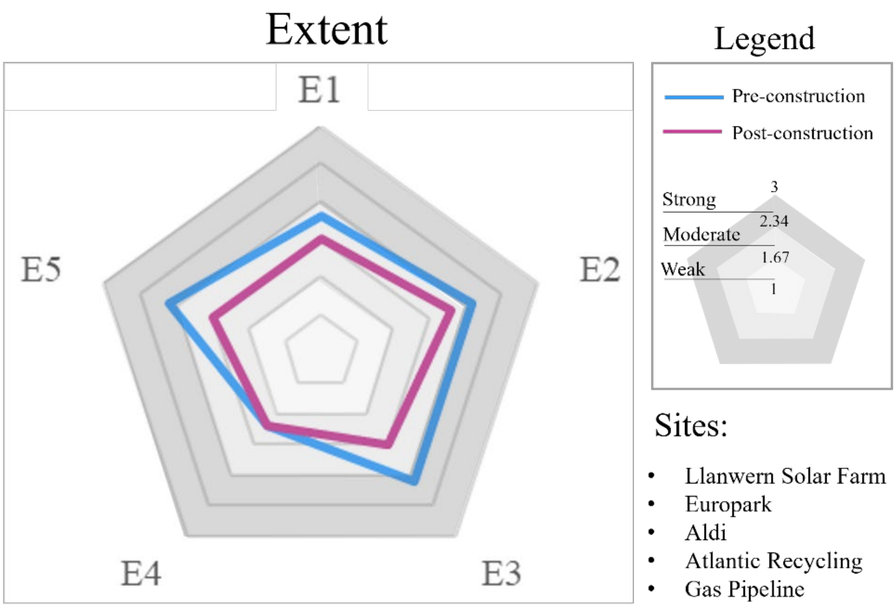


Figure 10: Pre-construction and Post-construction Extent criterion averages across five sites

Table 3: Summary of the Extent Scorings

Extent - Mean Scores from all Sites	
Best Scores	**Worst Scores**
Pre-construction	
E2 – avoidance of reens/ditches, and/or compensation in extent (Score 2.40) **E3** - new or enhanced reens/ditches being designed to NRW guidance, i.e. slope, inclusion of berms *etc*. (Score 2.40) **E5** – appropriate extent of survey areas for protected and notable species (Score 2.40)	**E4** (worst) – new and enhanced reens/ditches evidence to demonstrate functionality, i.e. depth of water during summer months (Score 1.80) **E1** - suitability of terrestrial habitat mitigation and compensation (Score 2.20)
Post-construction	
E2 (best) – implementation of avoidance, mitigation and compensation of reens/ditches relating to extent (*less on continued management and monitoring*) (Score 2.20)	**E4** (worst) - implementing, managing and monitoring ‘functionality’ (water depths *etc*) of new or enhanced ditches and reens (Score 1.80) **E1**, **E3** and **E5** - implementing, managing and monitoring mitigation and compensation habitats and the protected and notable species they support (Scores 2.00)

4.2.1.3 Condition Results

Results across the five sites for Condition are shown in Figure 11 and Table 4 below. Full criterion descriptions for criterions **C1** – **C5** are set out in Table 1 earlier in this chapter. The Condition criteria **C3** and **C4** both scored the maximum performance level across all sites at the pre-construction stage, being the only criteria across all the DECCA assessment criterion groups to score strong performance for every study site. The maximum scoring is due to more established controls, regulations and guidance relating to construction environmental compliance and pollution prevention measures to ensure no deterioration of water and habitat conditions (**C3**), and as mentioned above, the CCW 1991 guidance[56] that explicitly states the buffers required from reens and ditches to avoid impact to these features conditions (**C4**). Contrary to this, there is an absence of specific and/or detailed guidance, regulations and/or controls relating to requirements for SSSI condition assessments relating to developments and mitigation (**C1**), and management and monitoring plans relating condition assessments and targets for habitats (**C2**) and species (**C5**). Evidence supporting criterion **C3** included water quality reports to prevent, manage and monitor reen/ditch water quality. However, and in contrast, the poor score for **C2**, for example, was due to a notable lack of clear condition targets and subsequent timescales/actions within the management and monitoring strategies for habitats being created and/or restored and enhanced.

C3 was the only criterion to collectively score within the strong performance level during post-construction across all the DECCA assessment criteria, as shown in Figure 11. This is also owing to the more established controls, regulations and guidance relating to construction environmental compliance and pollution prevention measures, and requirements for post-construction monitoring of water quality (which was also a CCW requirement under the Gwent Levels guidance for developers from 1991[56] and 1996[60]). **C4** and **C5** post-construction criteria scored within the moderate performance level, whereas **C1** and **C2** scored even lower and within the weak performance level.

C1, **C2** and **C5** performed poorly at post-construction stages owing to the lack of condition assessments and targets being set for habitats and species within management and monitoring strategies to inform improvements to conditions and to achieve net benefits. Condition targets were generally lacking for the applications, with limited references to actions required if conditions of habitats are not achieved to deliver net benefit for biodiversity and the SSSIs. Some applications did, however, have adaptive management plans set over specific periods of time, which suggest management would be adapted relative to the monitoring survey results to work towards net benefits for the SSSI. However, the audit trail of whether such adaptive management and remedial actions had been implemented was difficult to evidence.

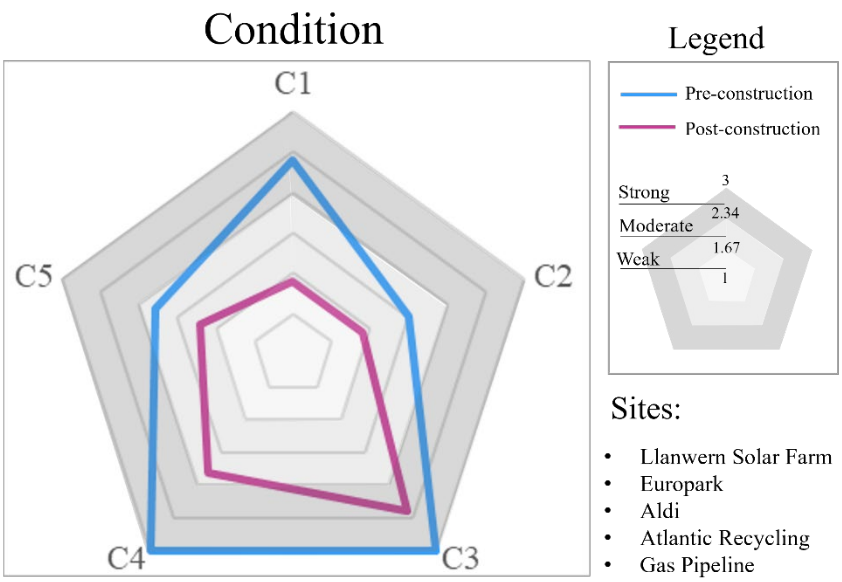


Figure 11: Pre-construction and Post-construction Condition criterion averages across five sites

Table 4: Summary of the Condition Scorings

Condition - Mean Scores from all Sites	
Best Scores	**Worst Scores**
Pre-construction	
C3 (best) – sufficient measures proposed to prevent pollution and decline in water quality (Score 3.00) **C4** (best) - sufficient buffers from reens and ditches proposed (Score 3.00) **C1** – SSSI condition assessment/surveys conducted to inform baseline and scheme designs (Score 2.60)	**C2** (worst) – management and monitoring strategies with clear condition targets within set timescales and actions if not achieved (Score 2.00) **C5** - condition assessments for protected and notable species demonstrating net benefits (Score 2.20)
Post-construction	
C3 – water quality monitoring during and post-construction (Score 2.60) **C4** – implementation and management of buffers from reens and ditches (Score 2.20)	**C1** – implementation, management, and monitoring of SSSI conditions improvements proposed (Score 1.60) **C2** - implementation and monitoring of condition targets and remedial actions conducted to achieve improved conditions (Score 1.60) **C5** – implementation and monitoring of condition assessments for protected and notable species demonstrating net benefits (Score 1.80)

4.2.1.4 Connectivity Results

Results across the five sites for Connectivity are shown in Figure 12 and Table 5 below. Full criterion descriptions for criterions **Co1** – **Co5** are set out in Table 1 earlier in this chapter. The Connectivity criterion **Co1** scored highest as an average across all five sites at both the pre-construction and post-construction stages. This is owing to **Co1** being related to proposals demonstrating that designs have been incorporated to avoid and minimise impacts to ecological functional networks and connectivity, and where this has not been possible, mitigation and/or compensation has been provided which clearly demonstrates the maintenance and/or enhancement of ecological functional networks and connectivity. Most of the sites in this Study demonstrate designs that have considered the SSSIs reen and ditch connected networks, wooded habitat connectivity for terrestrial species, as well as the requirements for species-rich grasslands within the Gwent Levels landscape, even if these are provided more as stepping-stone habitats within the landscape rather than physical corridors.

Co3 also performed strong at pre-construction, which also related to reens and ditches avoidance, but where replacement and/or enhancement reens and ditches are proposed demonstrating that these were on site and/or within the same SSSI unit to maintain connectivity and resource with the same SSSI unit. The score for **Co3** was reduced to moderate performance however at post-construction owing to lack of management and monitoring to maintain long-term connectivity, such as re-casting of ditches and hedgerow cutting to reduce shading of ditches and reens.

Co5 scored just into the strong performance at pre-construction, but reduced down to moderate performance at post-construction, owing to the differences relating to pre-construction (planning application) species surveys to inform species ecological functional networks relative to the distance a species can move to feed, breed and complete life cycles, to those post-construction, or lack of, to monitoring whether an impact, positive or negative, has been realised.

Co4 performed the worst at pre-construction and post-construction, being the only criterion of all the DECCA assessment criterion groups to score collectively within the weak performance level for pre-construction as well as having the lowest weak score at post-construction. The weak performance is a result of the applications lacking evidence to demonstrate, or monitor consequences, that replacement and/or restored reens and ditches, as part of the mitigation strategies, will be functioning connected networks with appropriate water levels to sustain SSSI species, and that these changes in water management will not impact the existing reen network and its water management. **Co2** also performed poorly for both pre- and post-construction relating to a lack of consideration of in combination effects pre-construction, and lack of monitoring potential impacts post-construction.

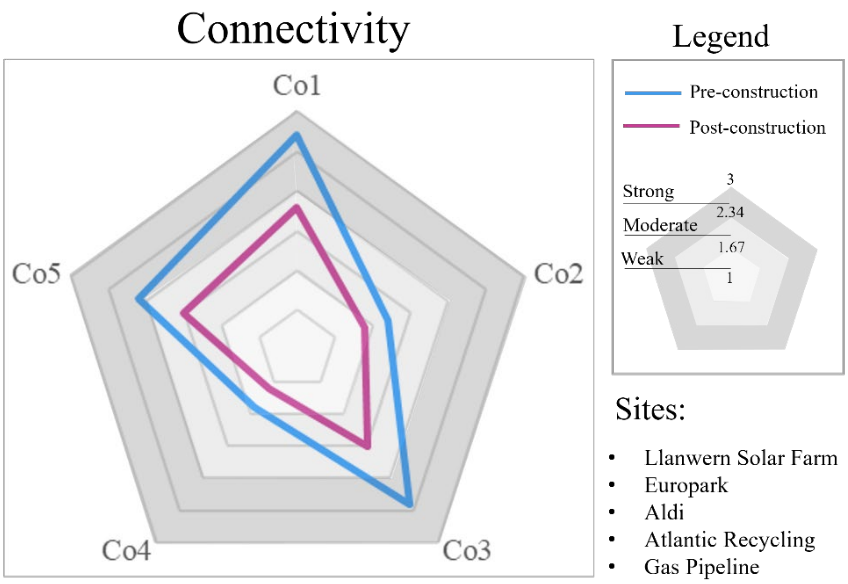


Figure 12: Pre-construction and Post-construction Connectivity criterion averages across five sites

Table 5: Summary of the Connectivity Scorings

Connectivity - Mean Scores from all Sites	
Best Scores	**Worst Scores**
Pre-construction	
Co1 (best) – avoidance of and/or appropriate mitigation/compensation of ecological networks to maintain connectivity (Score 2.80) **Co3** – replacement reens/ditches created on site and/or same SSSI unit maintaining connectivity (Score 2.60) **Co5** – species surveys to inform strategies to maintain ecological functional networks (Score 2.40)	**Co4** (worst) - mitigation and enhancement plans for reens/ditches demonstrating water availability and no impacts to the network (Score 1.60) **Co2** - consideration of in combination effects to biodiversity and the SSSI (Score 1.80)
Post-construction	
Co1 (best) – implementation, management, and monitoring of ecological networks (Score 2.20) **Co3** – implementation, management, and monitoring for the success of the connective habitat (Score 2.00) **Co5** – implementation and post-construction monitoring of ecological functional networks for species to determine impacts (positive or negative) (score 2.00)	**Co4** (worst) - implementation, management and monitoring of water availability and impacts to the wider network (Score 1.40) **Co2** - monitoring of any in combination or cumulative impacts during or post construction (Score 1.60)

4.2.1.5 Adaptability Results

Results across the five sites for Adaptability are shown in Figure 13 and Table 6 below. Full criterion descriptions for criterions **A1** – **A5** are set out in Table 1 earlier in this chapter. The criteria **A1** and **A2** scored best at both pre-construction and post-construction, whilst **A3** and **A4** scored worst during these stages.

A1 and **A2** scored an average strong performance at pre-construction, owing to evidence that the applications demonstrate partial alignment with the step-wise approach[63] as described in PPW, and that sufficient understanding of local environmental aspects, understanding place, had been evidenced when developing mitigation and compensation strategies. The scores for **A1** and **A2** dropped down at the post-construction stages to a moderate performance level, predominantly due to lack of continued management and monitoring to ensure continued alignment with step-wise approach and long-term viability of the mitigation and compensation strategies.

A5 scored reasonably for both pre-construction and post-construction, with a strong performance at pre-construction and dropping to moderate at post-construction. **A5** relates to whether mitigation strategies considered how populations of protected and notable species will survive during construction and post-construction, with consideration of their capacity to adapt, recover and resist disturbances. Generally, surveys to inform assessments relating to this improved over time when comparing between the planning application/ecological impact assessments for the selected sites, which ranged between 2005 and 2019, as shown in Figure 3, Chapter 2. However, limited monitoring or planning conditions to enforce monitoring of species was evident across the sites, unless linked to a Protected Species Licence or a specific monitoring of species linked to the SSSI, such as aquatic invertebrates.

A3 and **A4** scored the worse across both pre-construction and post-construction, scoring an average moderate performance for both. **A3** and **A4** both relate to considerations of climate change impacts; **A3** relating to consideration of impacts of climate change on mitigation strategies, and **A4** relating to whether the mitigation strategies cover sufficient period of time to the scale of the development and habitat types to achieve target conditions, and whether the management plans are adaptive to respond to climate changes and/or other pressures and demands.

Understanding, implementation and managing of Adaptability in terms of climate change and long-term viability of net benefits for biodiversity was generally found to be insufficient. Many habitat management and monitoring plans did not cover sufficient time scales to allow for habitats to achieve target condition or there was no evidence or auditing to suggest that adaptive management was being conducted.

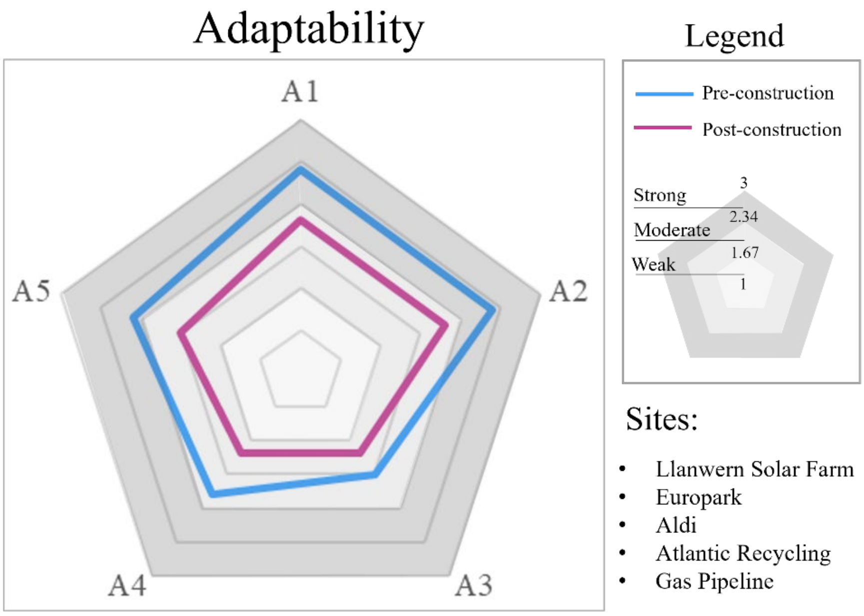


Figure 13: Pre-construction and Post-construction Adaptability criterion averages across five sites

Table 6: Summary of the Adaptability Scorings

Adaptability - Mean Scores from all Sites	
Best Scores	**Worst Scores**
Pre-construction	
A1 – proposals alignment with stepwise approach (Score 2.60) **A2** – sufficient understanding of local environmental aspects, landscape/place when developing proposals (Score 2.60) **A5** – mitigation strategies for protected and notable species survival and their capacity to adapt, recover and resist disturbance (Score 2.40)	**A3** (worst) - consideration of potential impact of climate change when developing mitigation and compensation proposals (Score 2.00) **A4** – management and monitoring plans covering a sufficient time period for habitats to achieve target conditions, and evidence of adaptive management in response to pressures (Score 2.20)
Post-construction	
A1 – implementation and continued management of stepwise approach proposals (Score 2.20) **A2** - implementation and management of proposals relative to local environmental aspects (Score 2.20) **A5** – monitoring protected and notable species survival and their capacity to adapt, recover and resist disturbance during and post-construction (Score 2.00)	**A3** - implementation, management and monitoring of climate change impacts and any remedial actions (Score 1.80) **A4** - implementation, management and monitoring over a sufficient period of time relative to the develop impacts and habitats with adaptive management implemented/enforced (Score 1.80)

4.2.2 Planning System Assessment Results

The Planning System assessment has a total of seven questions grouped into three planning stages; 'Planning Application', 'Planning Regulations and Determination' and 'Post-Planning Regulations'. Results across the five sites for the Planning System assessment are shown in Figure 14 and summarised in Table 7 below. Full criterion descriptions for criterions **P1 – P7** are set out in Table 1 earlier in this chapter. Criterion **P1 – P5** cover the **Pre-construction stages** of the development whilst **P6 – P7** cover the **Post-construction stages**.

Overall, **Planning Regulation & Determination (P3 - P5; Pre-construction stages)** performed the best, however this was weighted by the high score of criterion **P4** relating to whether the mitigation measures during construction have been secured through adequately worded planning conditions and/or S106 commitments that are both enforceable and clear to the applicant. When scoring each of the selected sites for this criterion, much of the evidence was weighted by adequately worded planning conditions relating to construction environmental protection measures and pollution controls, as the wording for these conditions, such as for a Construction Environmental Management Plan (CEMP) are normally explicit and lengthy, listing out all the environmental consideration and controls that need to be incorporated to discharge the condition.

In contrast, the lowest scoring criterion in **Planning Regulation & Determination (Pre-construction)** was **P5** which relates to adequately worded planning conditions and/or commitments through a S106 relating to longer-term management and monitoring requirements. These were found to contain a lot less detail and often just refer to the need for a Management and Monitoring Plan to be produced, but not detailing any specifics such as what habitat and species require management and monitoring, specifics on the type of management and/or guidance on management and monitoring that should be followed, time period of the plans and requirement for adaptive management based on feedback from the monitoring reports. Further to this, planning conditions relating to longer-term management and monitoring have historically been worded so that the production of the management and monitoring plans is enough to fully discharge the conditions, rather than the implementation of the long-term commitments.

Criterion **P3** in the **Planning Regulation & Determination (Pre-construction)** scored on average within the strong performance level. **P3** relates to the planning balance at determination, and whether there were any ecological concerns outstanding when the officer recommended approval and whether these were adequately referenced in the officer's report. Generally, the officer's reports concluded that no harm to ecology, provided mitigation and enhancements are delivered. Some reports highlight remaining concerns but deem them acceptable due to planning balance and/or planning justifications, and that objections in relation to inadequate information can be addressed through conditions.

The **Planning Application (P1 – P2; Pre-construction stages)** stage performed on average only just below the Planning Regulation & Determination stage, with both criterions **P1** and **P2** scoring reasonably. **P1** scored slightly higher, averaging a low strong performance score, owing to most applications/sites providing some evidence that pre-application discussions with the LPA and/or NRW had taken place in relation to net benefits for biodiversity. **P2** scored slightly lower, averaging a high moderate performance score, owing to most applications/sites providing some level of ecological baseline reporting, however the level of appropriate ecological surveys and EcIA to inform mitigation designs varied between applications.

The worst of the planning stages was **Post-Planning Regulations stage (P6 – P7; Post-construction stages)**, with criterion **P7** scoring the lowest of all criteria with all sites scoring moderate or weak performance. **P7** related to whether any evidence was found of the LPA enforcing any failure to comply with planning conditions and/or obligations. In the most cases there is a lack of evidence to support this, with only letters of objection found from NRW and others in relation to discharge of conditions relating to ecology and management plans. Furthermore, at some sites it was evident from the site appraisal visits that the delivery of management plans had not occurred as vegetation had grown mature where it was meant to be managed, and/or reen and ditch buffers were being lost due to encouragement by development activities. This may however be a failing in part in relation to the wording of the planning conditions, with conditions being discharged with the production of a management plan, rather than the execution of the plan over the long-term, which also makes the enforcement of the delivery more challenging for the LPAs.

P6 scored higher within the **Post-Planning Regulations stage (Post-construction)**, relating to whether adequate evidence was provided to discharge planning conditions or enforcement was provided to ensure compliance with condition requirements. The evidence was hard to find in some cases, due to no specific audit trail that can be followed. Furthermore, reports and/or evidence to support the discharge of condition are not always attached to the decision notice. However, evidence was found through objection letters to discharge of conditions from NRW, and the use of partial discharge of conditions to ensure complete and adequate information is provided.

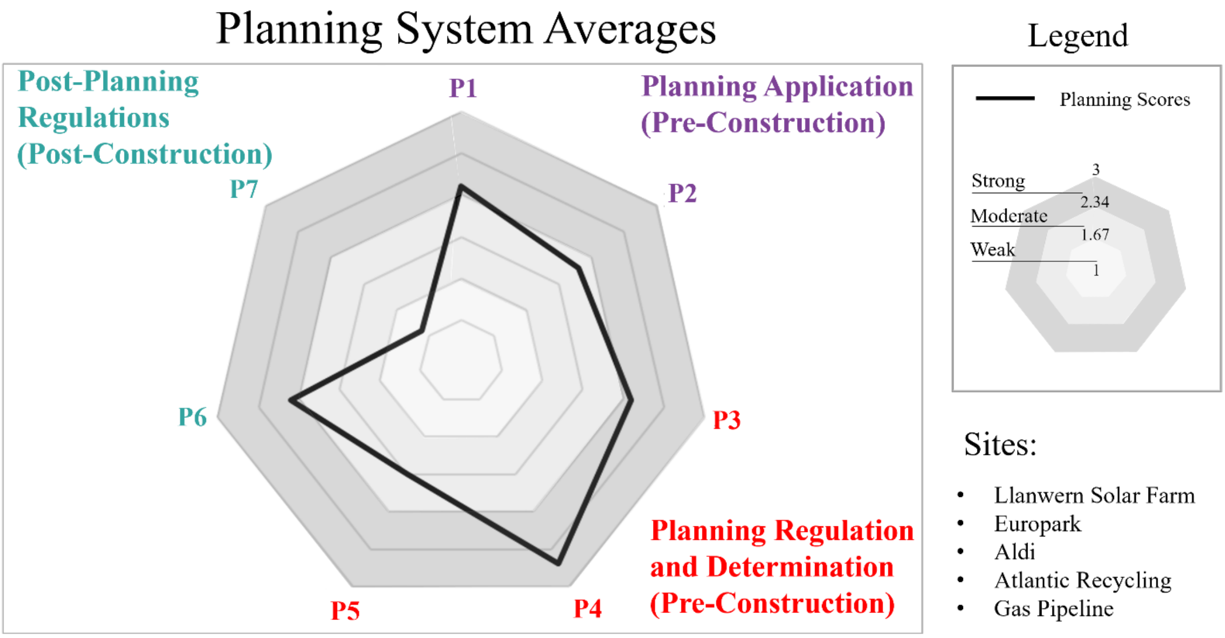


Figure 14: Planning question results from five sites

Table 7: Summary of the Planning System Scorings

Planning - Mean scores from all sites & averages per planning stage		
Planning Application (Pre-Construction)	**Planning Regulation & Determination (Pre-Construction)**	**Post-Planning Regulations (Post-Construction)**
Strong	**Strong**	**Moderate**
Collective score across group of 2.30 which was slightly lower than 'Planning Regulations'. **P1** (best of group) – evidence of pre-application consultation with LPA and NRW in relation to NBB and influencing application designs (Score 2.40) **P2** - submission of suitable ecological reports to determine impacts (Score 2.20)	Collectively scored highest across planning stages with overall average in group of 2.40. **P4** (best in group and overall) - adequately worded planning conditions that are enforceable for the 'construction mitigation' (Score 2.80) **P3** - Evidence of planning balance where applicable and where ecological concerns remain (Score 2.40) **P5** (worst in group) – adequately worded planning conditions for management and monitoring plans (*often just to production of plans not the long-term successful implementation of them)* (Score 2.00)	Collectively scored lowest across planning stages with overall average in group of 1.90. **P7** (worst in group and overall) - evidence of the LPA and/or NRW 'enforcing' any failure to compile with conditions and long-term commitments (Score 1.40) **P6** - adequacy of information provided to discharge conditions (Score 2.40)

5. Stakeholder Engagement

As described in the 'Outline Methodology and Delivery Approach' in Chapter 1, the development and refinement of the methodology was guided and influenced by stakeholder engagement; and that stakeholder engagement itself formed part of the methodology. Figure 1 in Chapter 1 sets out how both the Steering Group and the Stakeholder Group were integral to the co-development of both site selection and the criteria-based assessment. Table 8, below, provides as overview of the two workshops held with the Stakeholder Group. Both workshops were split into two parts. Part One focussed on presenting the Study methodology and/or preliminary results, and then promoting the collective refinement of methodology. Part Two focused on targeted activities to draw out the group's thoughts to what they collectively and individually considered to be limiting factors and most impactful changes required for NBB within the planning system of the Gwent Levels. Part Two of both workshops created an iterative set of discussions, started in Workshop 1, and built on in Workshop 2 when informed more by preliminary results.

As described in Section 1.3, the Stakeholder Group was encouraged to think for the long-term needs of nature recovery, planning policy and developmental requirements, avoiding short-termism and considering how decisions could impact on the well-being of future as well as current generations. The synthesis and analysis of the information gathered during Part Two of the two interactive workshop sessions are present in this chapter. These results are largely opinion-based and/or based on Stakeholder experiences. Although these have not necessarily transferred into direct recommendations in all cases, they do provide a valuable means of validation to the trends and recommendations derived from the criteria-based assessments.

The results obtained from the interactive workshop sessions are of value as they are the opinions of those integral to the planning system within the Gwent Levels. These results could potentially be tested against the wider opinions, relating to achieving NBB, of planning authorities and their nature advisors in other areas of Wales.

Two interactive workshops were held with attendance from over 30 individual stakeholders across the sessions. Perspectives and knowledge were attained from participants including WG (Planning, Biodiversity and Property Infrastructure divisions), NRW, GWT, Living Levels Project, RSPB, Newport City Council, Cardiff City Council and Monmouthshire County Council. A high-level overview of the workshops is summarised in Table 8. The following sections 5.1 and 5.2 give detail to the findings of the interactive sessions which made up Part Two of both workshops, and how the information was collected and synthesised.

Table 8: A summary of each stakeholder workshop held over the course of this project.

Stakeholder Workshop	Date	Summary of Discussions
Workshop 1: Criteria-based DECCA assessment and analysis of planning process	08.11.2023	**PART ONE** • Project aims and objectives introduced. • Short-listed site overview and discussion for additional sites. • Request for any additional documentation on the sites. The conversation centred around Imperial Park, as it had not been possible to obtain any documentation for the associated planning applications. • Development of the criteria-based DECCA assessment presented and discussed. The full table of DECCA assessment questions/criterion were circulated post the workshop and a two-week consultation period offered for detailed comments from the stakeholders. • Worked examples shown to demonstrate how the DECCA assessment data can be analysed and presented.

Stakeholder Workshop	Date	Summary of Discussions
		• Emerging themes of preliminary analysis of data to date was presented and discussed. **PART TWO** • Analysis of Planning Process: Interactive online session, using a digital collaboration platform, formed around questions relating to the planning process and achieving net benefits for biodiversity – this is further detailed in **Section 5.1** below. • Next steps for the project presented. • Post the workshop and based on discussions and information obtained during the interactive session, a set of planning process/system questions were circulated, with a two-week consultation period, and with the aim to co-develop a set of criteria relating to the planning system to be added to the assessment.
Workshop 2: Assessment results and developing recommendations	19.02.2024	**PART ONE** • An overview of Workshop 1 data analysis and findings. • Selected sites and site visit updates. • Reflection of findings, analysis and emerging key themes from the DECCA and Planning System assessments, demonstrating difference between pre-construction and post-construction and differences at the individual criterion group level (i.e. within Diversity, Extent, *etc*.). The group was asked to comment on whether there were any surprises in the data, or whether the results were as expected, and whether they have any specific comments on each of the criterion group level results. **PART TWO** • Analysis of the Assessment and Recommendation Building: Interactive online session using a digital collaboration platform, following on from Part Two in Workshop 1 but incorporating the preliminary analysis from the assessments. Stakeholders were asked to consider the emerging key themes from the Study, and considered how can these challenges be overcome, and the planning system enhanced to support NBB – this is further detailed in **Section 5.2** below. • Post the workshop, the digital collaboration platform was shared for continued ability for the stakeholders to provide comment, along with a set of slides of the workshop, with a two-week consultation period provided to allow further co-development of recommendations for the Study. Feedback received was included in the synthesis of the information and perspectives as detailed in **Section 5.2** below.

5.1 Stakeholder Workshop 1 – Part Two Summary and Findings

The first workshop was held on 8th November 2023. In total, 21 stakeholders attended, with at least one from each represented organisation. This first part of the workshop was mainly comprised of an introduction to the Study, the approach and the development of the DECCA-based assessment criteria and the short-listed sites selected at that point. An opportunity for refinement and comment on the assessment criteria was provided through a two-week consultation period with the stakeholder group post the workshop. The second part of the workshop was based on an interactive online session using a digital collaboration platform with the objective to encourage stakeholders to discuss and analyse the planning process and associated limitations, challenges and what would be the most impactful changes with regard to achieving NBB and long-term management and monitoring. Stakeholders engaged through a set of five questions, as listed below, capturing their comments on the digital collaboration platform (example screen shot provided in Appendix C.1):

1) What are the limitations and challenges regarding achieving NBB through the planning application process?
2) What would be the most impactful change within the planning system to achieve NBB?
3) What are the limitations and challenges regarding securing NBB through the planning process?
4) What are the main failures of implementation, long-term management and monitoring, and enforcement of NBB requirements?
5) How can we interrogate the selected sites to understand where failings and successes may occur with the planning process?

The comments were analysed and grouped into emerging themes under each of the five questions; these are summarised in the subsequent sections below.

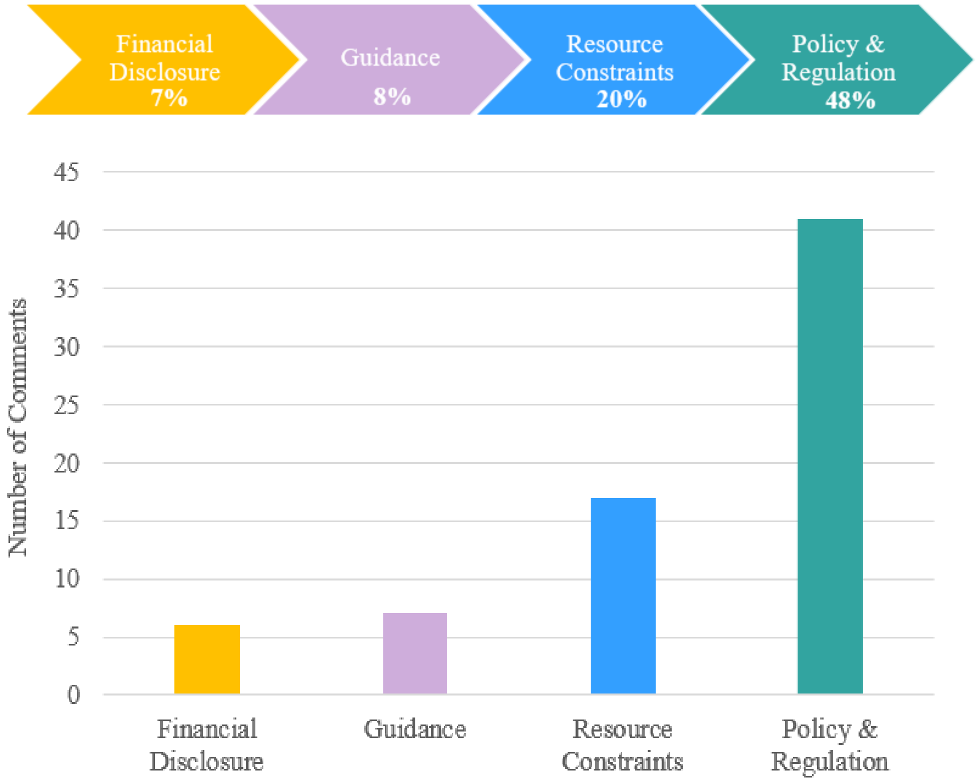
A total of just over 100 comments were captured on the digital collaboration platform during the interactive workshop and consultation from 21 different contributors. A total of 86 comments were collated for the first four questions relating to delivering NBB. The combined analysis of these four questions showed that the majority of the concerns and 'need for change' revolved around 'Policy and Regulation' with 48% of all comments (as shown in Figure 15), and predominantly linked initially to the lack of developers implementing in accordance with their proposals as per agreed planning decision, and as subsequently the LPAs inability to enforce, long-term management and monitoring for the delivery of NBB. 'Resource Constraints' came in second with 20% of all comments, mostly relating to lack of resources to monitor and enforce NBB on applications.

New and updated guidance was suggested to be needed to deliver successful NBB, with 8% of all comments relating to 'Guidance', and 'Financial Disclosures', with 7% of all comments, also presenting to be a common concern relating to developers needing to demonstrate long-term financial commitments for the delivery of NBB. Comments also suggest the post-consent and post-construction stage of the planning process is where most concerns lie for successful NBB implementation rather than the actual demonstration of the likely ability to achieve within the planning applications themselves.

Question 5 was analysed separately to the first four, as the question was more relating to what should be looked at to inform this specific study rather than questions specific to the implementation and delivery of NBB on projects.

Figure 15 shows the four most common themes, which are further described in the subsequent sections under the individual questions asked to the stakeholders relating to NBB and planning (Questions 1 – 4).

Figure 15: Most common themes across Workshop 1: Total number of comments and percentage across all comments



5.1.1 Q1 - What are the limitations and challenges regarding achieving NBB through the planning application process?

A total of 16 comments were recorded for this question, which were grouped into four key themes, as shown in Figure 16 below. The greatest proportion of these comments related to limitation and challenges generated by Policy & Regulation within the planning system (44%). The majority of the comments related to the current challenges in the long-term demonstration and enforcement of NBB; other comments are shown in Figure 17 below.

The second largest group of comments centred around challenges relating to Ecology & SSSI considerations, as shown in Figure 16 and 17 below. Comments related to the challenges specific to the Gwent Levels SSSIs, such as the competing ecological objectives relating to the SSSIs and other ecological features (i.e. Protected Species Licencing), as well as more general concerns relating to the quality of ecological baselines collated and assessed for planning applications and whether they are sufficient to determine impacts and design mitigations and enhancements to achieve NBB to enable a decision to be made on the planning application. Other comments are shown in Figure 17 below.

Resource Constraints within LPAs for monitoring applications, mitigations and post-construction management and monitoring was also considered a limitation and challenge in achieving NBB, as was the Competing Priorities LPAs face relating to the planning balance and other planning matters ‘watering NBB down’; other comments are shown in Figure 17 below.

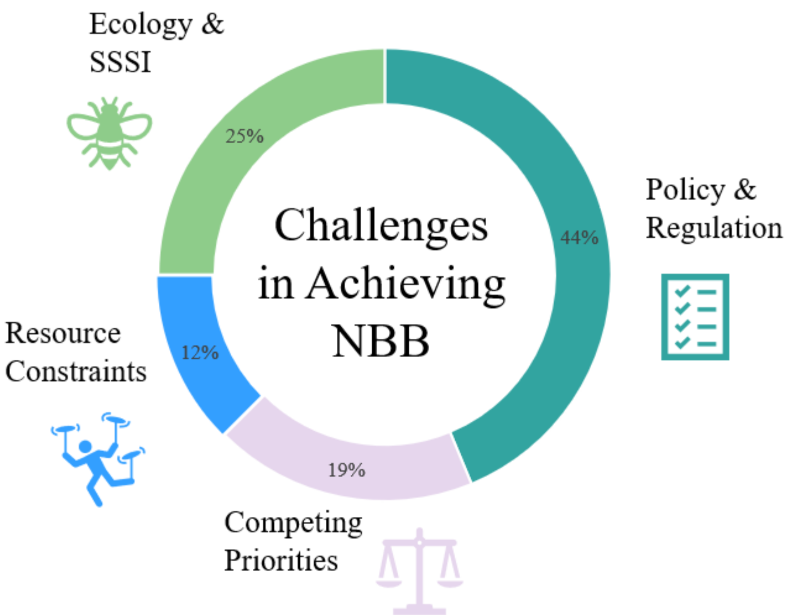


Figure 16: Comments distribution in response to the limitations and challenges regarding achieving NBB through the planning application process (Question 1 - Workshop 1).

- Policy & Regulation:
  - Long-term demonstration and enforcement of management plans.
  - LDP allocations make it hard to object to inappropriate development.
  - Planning officers making ecological decisions.
  - Hard to know if enhancement being achieved in a meaningful way.
  - Time periods of management plans, responsibilities to deliver enhancements and enforceability.
- Competing Priorities:
  - Balance of SSSI and NBB versus planning balance.
  - Consideration of other planning matters in effect watering NBB down.
- Resource Constraints:
  - LPA ecologists with limited resources to comment and/or monitor applications and mitigations, concern that often no resource to comment on smaller applications.
  - Lack of resource for post-construction monitoring internally within LPA.
- Ecology & SSSI:
  - Competing ecological objectives *e.g.* SSSI versus protected species.
  - Mitigation and compensation to ensure resilience of the SSSI.
  - Mitigating for development impacts within the SSSI – running out of land.
  - Need for good quality ecological baselines and assessments to be submitted with planning application to determine NBB.

Figure 17: Summary of key points under the key themes in response to Question 1 (Workshop 1).

5.1.2 Q2 - What would be the most impactful change within the planning system to achieve NBB?

A total of 14 comments were recorded for this question, which were grouped into three key themes, as shown in Figure 18 below. The greatest proportion of these comments related again to Policy & Regulation (44%), with suggestion for impactful change being the introduction of 'non-performance bonds' for management and monitoring plans, better auditing and need for a consistent approach for NBB across the LPAs. Comments relating to Resource was second highest, all relating to the need for more resource to monitor and enforce NBB through the planning system for the long-term.

The need for more guidance was raised as an impactful change required in delivering future NBB, relating to both NBB application and measurement, as well as management and monitoring guidance specific to the Gwent Levels.

A summary of the comments under the key themes are presented in Figure 19 below.

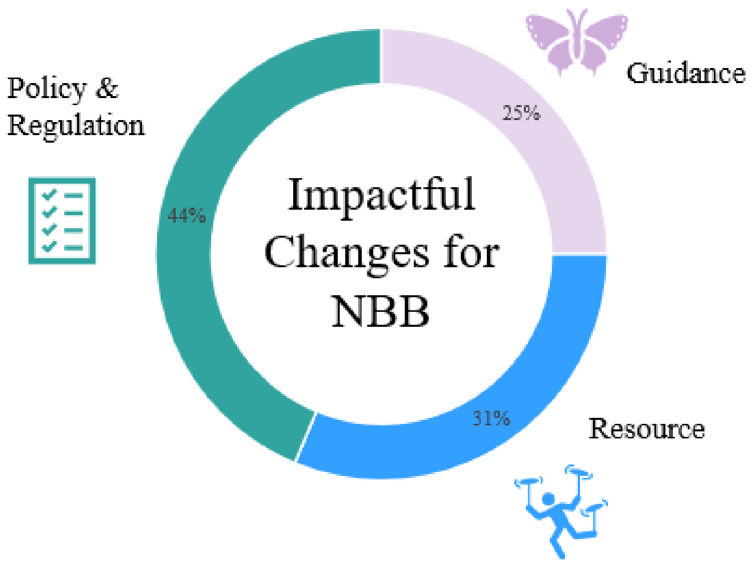


Figure 18: Comments distribution in response to the most impactful change within the planning system to achieve NBB (Question 2 - Workshop 1).

- Policy & Regulation:
  - Enforce non-performance bonds for monitoring and management plan through S106.
  - Better post-construction management of sites and audit trail between owners/tenants relating to NBB commitments.
  - Need for consistency across LPAs in relation to delivering NBB.
  - More clarity on Planning Policy and delivery of NBB.
- Resource:
  - More resources to monitor long-term and enforce.
  - Allocate funds for specific officers to have oversight of long-term management and monitoring.
  - Consolidate resources and documents as few staff to implement and digest.
  - Increase planning application fees to fund monitoring staff.
- Guidance:
  - More and updated guidance on NBB, management and monitoring.
  - Supplementary planning guidance across all LPAs in Gwent Levels on consistent approach to NBB, management and monitoring.

Figure 19: Summary of key points under the key themes in response to Question 2 (Workshop 1).

5.1.3 Q3 - What are the limitations and challenges regarding securing NBB through the planning process?

A total of 20 comments were recorded for this question, which were grouped into seven key themes, as shown in Figure 20 below. Again, the highest number of comments related to Policy & Regulation; focussed on the limitations and challenges relating to long-term management and monitoring policy requirements, regulation, and enforcement. Suggestions relating to 'change' and how NBB may be secured in the future, were also made. This included reflection of other established mechanisms for securing long-term commitments for habitat restoration in Policy, such as non-performance bonds and lessons learnt from the minerals planning policy in Wales in relation to restoration, aftercare and after-use of mineral sites[72]. Comments also related to use of the Green Infrastructure Statements, that are now required under Chapter 6 of PPW[8], being used to demonstrate and secure long-term NBB, as well as the need to consider wording of planning conditions and ability to only discharge completely when the NBB works are completely delivered using partial discharging over the longer term.

The need for guidance relating to the delivery of NBB was also discussed here in relation to better security in delivering and regulating NBB in the future. A lack of consideration of cumulative impacts was commented on, in terms of spatial and temporal negative cumulative impacts on NBB, as well as concerns over smaller projects and permitted development's cumulative impacts not being accounted for. Resource was commented here also, again relating to lack of resources to monitor and regulate delivery of NBB, as was Competing Priorities, for similar reasons provided for Question 1 above.

Financial Disclosure was introduced as a limitation in securing NBB, relating to applicants not demonstrating finance has been secured and available for the delivery of NBB over the long-term including the management and monitoring of NBB, as was Resistance, relating to developers' resistance to delivering NBB due to loss of developable areas and long-term costs. A summary of the comments under the key themes are presented in Figure 21 below.

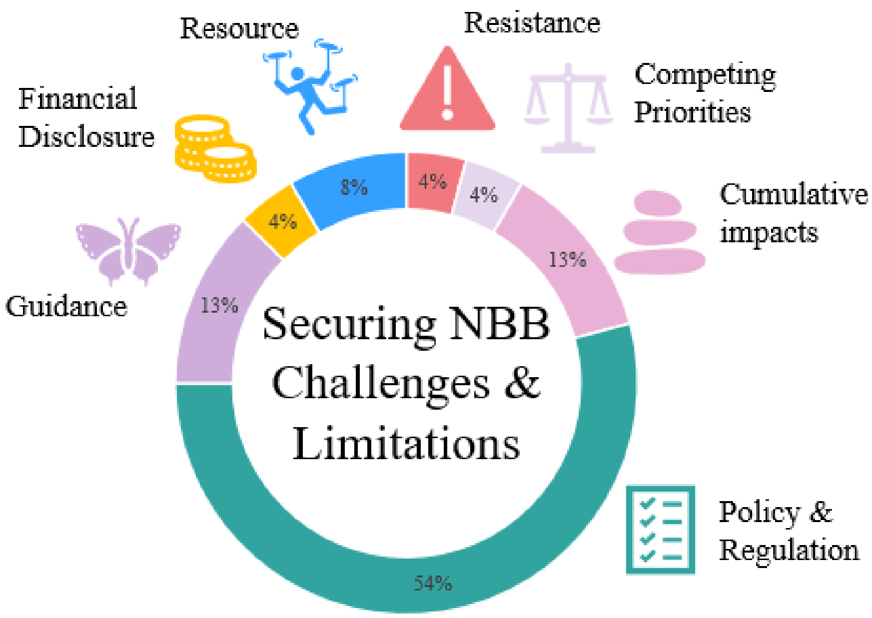


Figure 20: Comments distribution in response to the limitations and challenges regarding securing NBB through the planning process (Question 3 - Workshop 1).

[72] Effectiveness of Restoration Conditions for Mineral Workings and the need for Bonds (DoE – Arup Economics) 1993, and as described in Minerals Planning Policy Wales 2000.

- Policy & Regulation:
  - Post-construction is more challenging to manage/enforce
  - Longer term management difficult to control
  - Non-performance bonds/fees for control of management and monitoring to achieve NBB – learn from minerals planning policy in Wales relating the restoration of habitats)
  - Use S106/legal agreements to secure non-performance bonds/fees
  - Use Green Infrastructure Statements (new PPW policy) to demonstrate and secure/enforce longer term NBB
  - Sustainable Drainage System (SuDS) Approving Body (SAB) to also contain NBB requirements
  - Wording of planning conditions and ability to discharge when NBB works complete – more partial discharging over short to long-term

- Resource:
  - Lack of resource to monitor and regulate delivery of NBB

- Guidance:
  - Lack of guidance for developers to deliver NBB successfully and holistically within ecosystem
  - Need for developing 'standards' based on 'successful' enhancements – such as new Supplementary Planning Guidance (SPG)
  - Need for sharing best practice and successes for delivering NBB

- Cumulative Impact:
  - A lack of consideration for cumulative impacts over multiple projects and years
  - A lack of consideration of the smaller projects and permitted developments and their cumulative impacts
  - Cumulative impacts of unsuccessful habitat creations/enhancements, that were seen as 'tick-box activity'
  - Whole system cumulative impacts not considered, such as water availability and nutrient enrichment

- Resistance:
  - Developer resistance to NBB due to reduced developable land and increasing costs

- Competing Priorities:
  - Conflicts between planning permission and subsequent requirements, such as SAB, Protected Species Licencing

- Financial Disclosure:
  - Developers demonstrating finance for NBB for the long-term and security of both successful and adaptive delivery

Figure 21: Summary of key points under the key themes in response to Question 3 (Workshop 1).

5.1.4 Q4 - What are the main failures of implementation, long-term management and monitoring, and enforcement of NBB requirements?

A total of 24 comments were recorded for this question which were grouped into five key themes, as shown in Figure 22 below. Again, the highest number of comments concerning failures of long-term NBB related to Policy & Regulation, and the lack of enforcement, responsibility, and consequences in relation to delivering NBB and associated long-term management and monitoring. Lack of Resource scored second, which also included comments on lack of skills, knowledge, and expertise in teams (LPAs) regarding the long-term needs for NBB management and monitoring. This lack of knowledge is also replicated to the applicants' side, where comments on Achievability presented evidence on mitigation and enhancement plans not always being practical with over complicated management schemes, which are often delivered by the cheapest management companies that also lack skills in habitat restoration and creation, and the associated long-term aftercare.

Financial Disclosure was commented on similar to Q3, relating to transparency of funds being made available by the developer for the long-term delivery and asset/land transfers, but also more positively when considering opportunities for 'Green Investment' in the future to deliver NBB and long-term management plans. Green Infrastructure was considered in terms of 'green spaces' not being offered by the applicants/ developers for adoption by Local Authorities (LAs).

A summary of the comments under the key themes are presented in Figure 23 below.

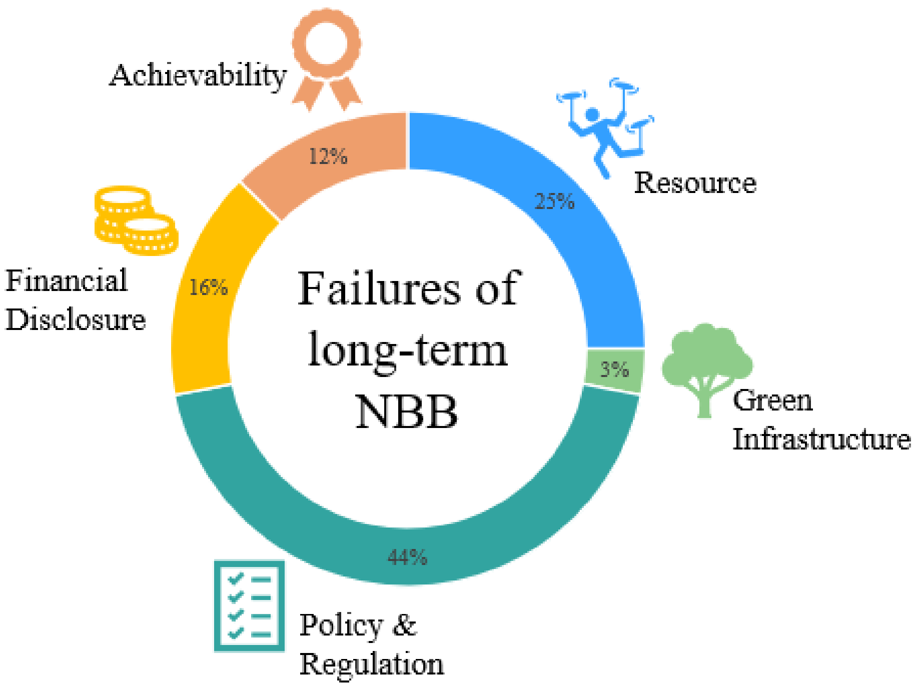


Figure 22: Comments distribution in response to the main failures of implementation, long-term management and monitoring, and enforcement of NBB (Question 4 - Workshop 1).

- Policy & Regulation:
    - Changes in governments altering the planning system and protection of nature.
    - Failure to remove contradictory Permitted Development (PD) rights on consents.
    - Lack of auditing non-compliance and enforcement of NBB.
    - Complexities of enforcement - uncertainty on actions and responsibilities if NBB has failed, especially if condition discharged.
    - Land ownership changes and reducing NBB maintenance regimes.
    - No consequences for developers and/or landscaping companies to ensure they deliver against NBB, often changing how NBB implemented without penalties.
- Resource:
    - Lack of resource, skills, knowledge/expertise of teams for long-term NBB enforcement and monitoring.
    - Difficulty and lack of resource to monitor detailed and extensive management plans and to chase applicants/developers or enforce against conditions.
- Financial Disclosure:
    - Emphasis on green investment may help in developing a coherent approach.
    - Green Infrastructure assets being sold to individual households/landowners after site completion.
    - Transfer of land/built development often loses the transfer of NBB requirements and management.
    - Lack of initial consideration by the applicant/developer of cost of management and achieving NBB.
- Achievability:
    - Initial mitigation/enhancement plans are not always practical.
    - Over complication of management schemes by ecologists with low achievability.
    - Lack of long-term management costs consideration by the developer/applicant - impacting achievability.
    - Companies going for lowest bidder to implement mitigation and management, risking NBB.
- Green Infrastructure:
    - Green spaces/habitat areas not being offered by the applicant/developer for adoption by LAs.

Figure 23: Summary of key points under the key themes in response to Question 4 (Workshop 1).

5.1.5 Q5 - How can we interrogate the selected sites to understand where failings and successes may occur with the planning process?

The final question considered during the interactive Workshop 1 was focused more on the application of how to assess failings and successes within the planning process relative to this Study. A total of 14 comments were recorded for this question, which were grouped into five key themes, as shown in Figure 22 below. The majority of the comments related to looking for inconsistencies/consistencies between approved plans and the planning application, planning conditions and their discharge decision notices, as well as management and monitoring plans versus reports on whether these have been undertaken and what impact (negative or positive) this has had on the local biodiversity. Comments also related to the need to consider temporal differences in legislation and policy between the selected sites and need to discuss sites with stakeholders to confer the noted positives and negatives that have occurred for each of the sites. A summary of key comments is provided in Figure 25.

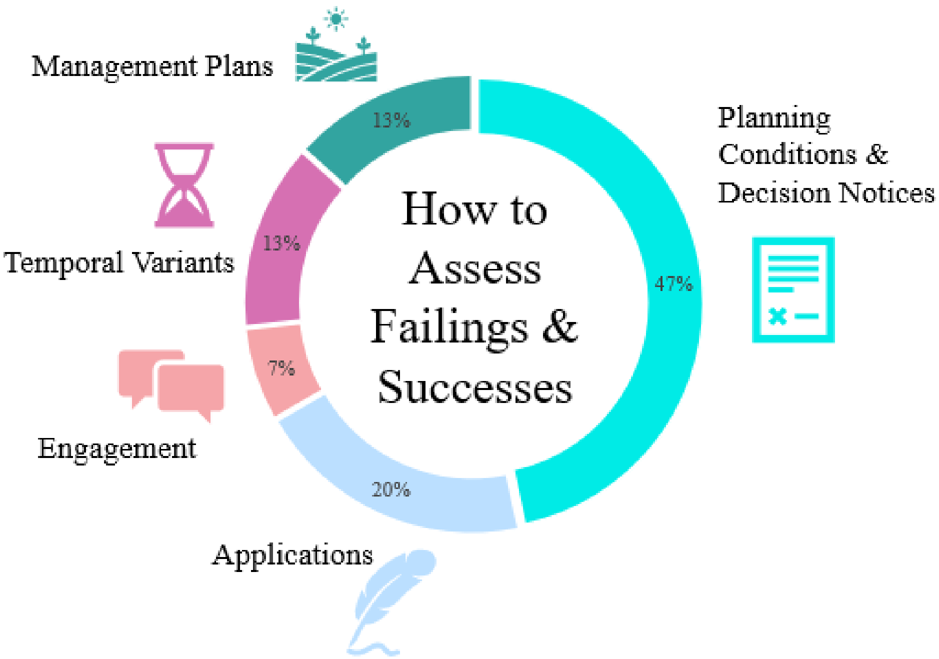


Figure 24: Comments distribution in response to how this Study can integrate failings and successes in the planning process when considering the selected sites for this Study (Question 5 - Workshop 1).

- Planning Condition & Decision Notices:
  - Time consuming to check against conditions on planning portals but necessary.
  - Checking whether monitoring conditions are being conducted and where the responsibility lies once the application is approved.
  - Any flexibility in planning conditions to allow for targets to be achieved.
  - Checking for applications and approvals for evidence of removal of key conditions.
  - Checking for transparency of consultation process.
  - Strength of language used in conditions, S106 and management plans.

- Applications:
  - Look for consistency/inconsistency in approved plans, and changes between allocations, outline applications, detailed applications/reserved matters and discharge of conditions.

- Management Plans:
  - Look for proactive behaviours by applicants to align with management and reporting schedules.
  - How are interconnected sites delt with in management and monitoring plans.

- Temporal Variants:
  - Need to bring out temporary variations on applications assessed in terms of policy and guidance relating to NBB.

- Engagement:
  - Need for engagement with LPAs, to gain both ecological and planners' perspective, to determine positives and negatives.

Figure 25: Summary of key points under the key themes in response to Question 5 (Workshop 1).

5.2 Stakeholder Workshop 2 – Part Two Summary and Findings

The second workshop was held on 19th February 2024, with a total of 18 stakeholders attending with at least one from each represented organisation. The workshop was comprised of two parts. Part One provided an update on progress to date including a summary of initial findings from Workshop 1, an overview of the final selected sites, a summary of the findings from the site visits, an overview of the initial findings, analysis and emerging key themes from the DECCA and Planning System assessments.

Part Two formed an interactive session where reflections from the discussed analysis of the Study assessment were built into a recommendation building exercise, getting stakeholders to consider how challenges in achieving NBB relative to DECCA and the Planning System can be overcome; capturing their comments on the digital collaboration platform (example screenshot provided in Appendix C.2). The recommendations were later grouped by key themes to start to consolidate the stakeholders rational and recommendations, a summary of this is present in Figure 26 below.

- Data Storage and Management Systems
    - A tracking and monitoring system is needed to easily locate planning documentation associated to the same site and is therefore easy to find (rather than multiple planning references) and with potential application across all Welsh planning authorities.
    - Improving accessibility to information to improve systems for checking documents.
    - System/data storage of managing planning and post-construction obligations.
    - Need for ‘red flag’ system to determine whether NBB related targets have been reported.

- Fines and Incentives
    - Carrot and Stick implementation – a need for financial incentive and/or increased fines, as currently hard to justify LPA resource as it is a lot of work/time to build a case for non-compliance of delivering NBB.
    - Bonds a potential solution - to be released back to the applicant/developer/landowner as they deliver agreed NBB.
    - Should follow a process similar to: providing advice and guidance, issue a warning letter, issue final notice and last resort is enforce mitigation through non-compliance.

- Cultural Change
    - A whole system change is required, and people aren't engaged enough in climate and nature recovery.
    - A need for an approach to planning policy Wales to be collaborative and bring the private sector in too.
    - Mindsets change - LAs should not have to be an enforcer – developers need more appreciation of nature and ecosystem services.
    - Understanding of Wales NBB and approach to nature recovery, and best practice implementing measures for NBB.
    - 'Partnership' working to achieve greater outcomes.
    - Turning the narrative from focused on economy to be more holistic including climate and nature.

- Corporate Performance & Nature-based Targets
    - Economic roles (Confederation of British Industry (CBI)) to accept responsibility and avoid green washing - ecology on par with economy.
    - Applicants reporting on climate and nature targets (the Taskforce on Nature-related Financial Disclosures (TNFD) and the Taskforce on Climate-related Financial Disclosures (TCFD)).

Figure 26: Summary of key points under the key themes developed during the discussions of the analysis and recommendations emerging from the criteria-based assessments (Workshop 2).

Stakeholders were then asked to consider their comments and recommendations set against the scale of the challenge in terms of effort and the relative impact the recommendation would bring. This exercise and its outcomes were based on stakeholder opinions and perceptions rather than any tested outcomes. As such, recommendations ranged from perceived potential ‘quick wins’ likely to require minimal effort, achievable in the short-term but the impact may be limited to longer term actions/goals likely to require more effort and time to achieve but could have maximum impact. A summary of some of the key recommendations generated and populated into the ‘Impact Effort Matrix’ are shown in Figure 27. Stakeholders also had the opportunity to rank and comment on the extent to which they agreed with the viability of the recommendations that had been generated by the criteria-based assessment process prior to the workshop. These recommendations were also added/consolidated into Figure 27 below.

The ‘Impact Effort Matrix’ revealed what the stakeholder thought might, potentially, be relatively ‘quick wins’ that could be actioned in the short-term and have a moderate impact, including new and updating guidance and training on achieving NBB in planning, Green Infrastructure Statements, long-term management and monitoring of habitats and species and how this could be implemented in the planning system, as well as the possibility of introducing NBB ‘independent assessors’ and an ‘accredited’ system for contractors that deliver NBB mitigations and management.

Creation of a data management system for planning applications and post-construction deliverables, including a ‘red flag’ system for monitoring and auditing NBB commitments, alongside more resource for LPAs enforcement teams, were considered by stakeholders likely to require more effort but was considered to potentially bring moderate impact.

The introduction of a requirement for applicants/developers/landowners to report on their climate and nature targets to drive change NBB delivery through corporate monitoring, such as that provided by the TNFD and the TCFD, was discussed. This was considered to have a potential moderate impact and stakeholders thought this would require moderate effort and will potentially take a longer time period to achieve.

Greater partnership working was also thought to be beneficial to bring greater outcomes for nature, including breaking down existing and historic barriers such as partnerships between developers and nature conservation bodies to deliver high quality NBB for the long-term. This was considered by stakeholders as likely to require minimal effort to deliver but the impact could be great. A similar effort to impact ratio was considered for creating some ‘standards’ around planning conditions for achieving NBB and post-construction management and monitoring requirements.

The introduction of levies, bonds and/or financial benefits, rather than enforcement fines, for delivering NBB, alongside legislative and policy change to support better protection of nature and delivery of NBB was considered to have the potential to be highly impacting but stakeholders thought it likely to require time and effort to put in place.

Finally, the wider cultural and system change which underpins the shift required to deliver nature recovery and NBB at scale was considered by stakeholders to potentially have the highest of impact but was also recognised to require significant efforts. Whole-system changes and a rethinking of how incentives and penalisation are currently dealt with alongside a mind shift of developers will require some big changes and longer-term strategic approaches to achieve.

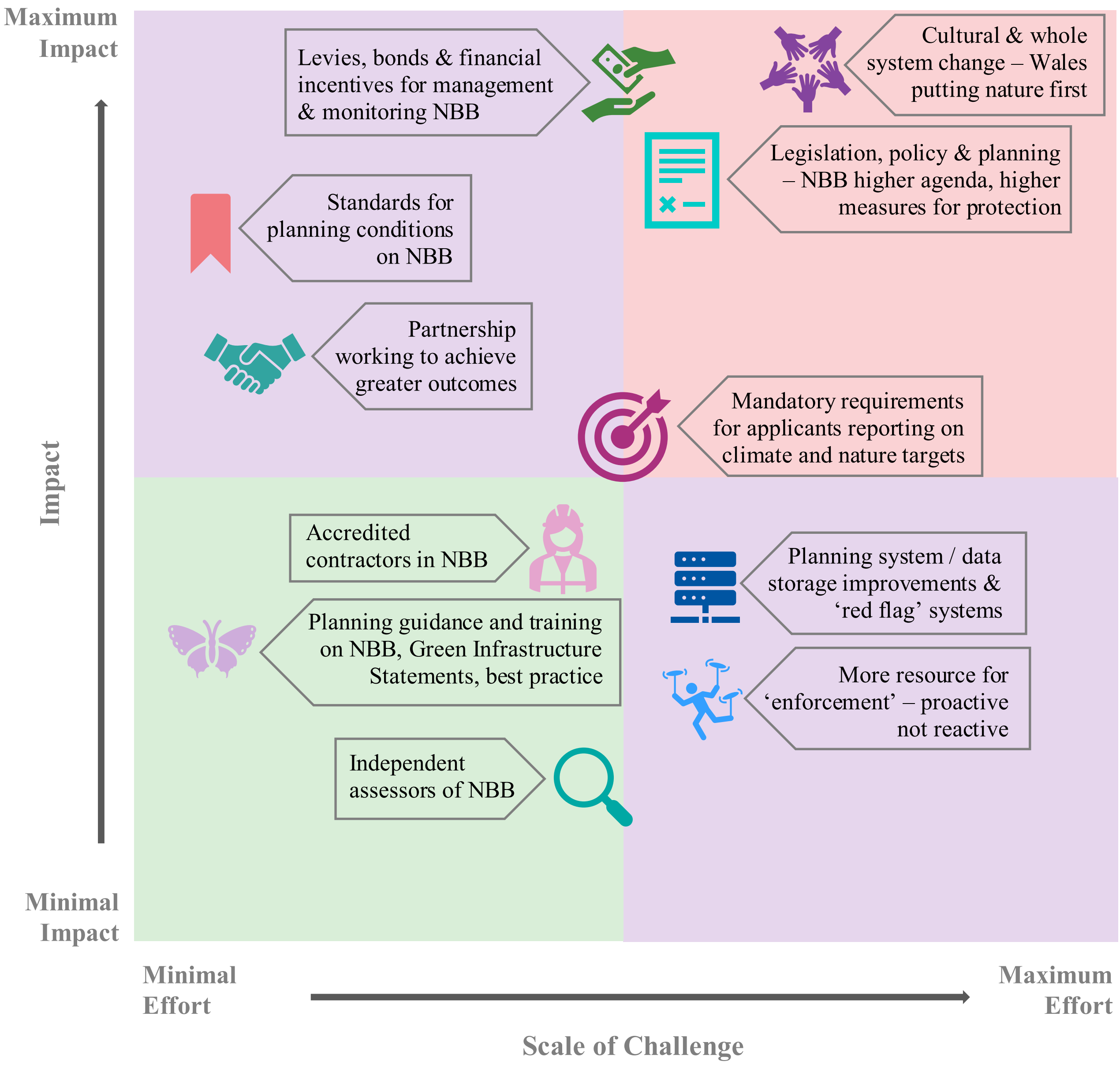


Figure 27: Summary of key discussions and recommendations generated and populated into the 'Impact Effort Matrix' based on stakeholder views (Workshop 2).

Discussions, commendation and recommendations generated during the workshops, were used to help validate the recommendations derived from the criteria-based assessment, which are present and discussed in Chapter 6.

6. Key Themes and Recommendations

As discussed in Chapter 1 of this report, the ambitions of the Policy 9 Pilot Project recognise the potential need to go beyond traditional planning practice to address the multiple and interconnected challenges and opportunities facing the Gwent Levels. It is important, in the context of the complexity and fragility of the Gwent Levels and its role as a NNRA, that a sound evidence base informs planning and wider land use decisions and the deployment of resources. This Post Construction Monitoring Study is a key strand in this evidence gathering imperative.

Through the development and application of the DECCA Framework criteria-based assessment, this Study has been able to consider whether the selected, already built, development sites within the Gwent Levels would, potentially, be compatible today with the current aims of Policy 9 of Future Wales and the objectives and principles of ecosystems resilience. The approach taken by the Study therefore recognises and builds in parameters into the assessment that allow for older applications, that pre-date the publication of Policy 9 in 2021, to contribute to the identification of trends and key themes despite Policy 9 not existing at the time of their being permitted and being built (see Chapter 4 for more detail). Thus, provides a means to gain insights and learn from what has happened previously and apply that learning for the future.

This was achieved by considering how well the selected sites responded to each of the DECCA attributes and emerging properties through a set of distinct DECCA-related questions specific to the Gwent Levels. Through the design and refinement of the assessment in consultation with the Stakeholder Group, further analysis could be made between different stages of the planning process; the pre-construction planning stage versus the post-construction long-term management and monitoring stage. The need to develop an additional set of criteria-based assessment questions relating to the Planning System also became apparent through engagement and workshops with the Stakeholder Group, to allow for further analysis of the planning system stages and to evaluate their relative strengths and weakness. The outline methodology and delivery approach of the Study is presented in Figure 1, and summarised in Section 1.3, Chapter 1.

The synthesis and analysis of the criteria-based assessments presented in Chapter 4, produced some clear trends and key themes of how developments within the Gwent Levels would fail and succeed in the delivery of NBB, alignment with Policy 9 and the resilience of ecosystems (DECCA), as well as the step-wise approach in protecting and enhancing important habitats and protected areas. One of the most significant and noteworthy results being that all sites collectively scored higher at pre-construction compared to post-construction, owing typically to a lack of successful implementation and delivery of mitigation, management and monitoring plans by the developer/landowner, compared to the level of details relating to what the mitigation, management and monitoring plans would deliver to mitigate any negative impacts to the Gwent Levels, which were produced by the applicant/developer at the 'pre-construction' planning application stage and/or to discharge planning conditions.

The synthesis and analysis of the Stakeholder Engagement presented in Chapter 5, was used to verify the trends emerging from the assessment as well as to refine the recommendations of this Study both in line with the assessment findings but also from the knowledge gained from the discussion between the key stakeholders related to the delivery of NBB in the Gwent Levels. Those discussions identified the challenges, limitations, and failures to long-term NBB, as well as what might be the most impactful solutions required to overcome these challenges, as detailed in Chapter 5. One of the most significant and noteworthy results from this analysis being the Stakeholder Group considered that current implementation of policy and regulation was the main limitation, and would be the most impactful change, for achieving NBB in the future in the Gwent Levels.

Section 6.1 below summarises these emerging trends and key themes from the data analysis of the assessment along with the views from stakeholder discussion, and Section 6.2 takes these trends and themes to develop recommendations which may have the potential, subject to further investigation, to drive impactful transformation for the long-term needs of nature recovery, through planning policy, legislation, guidance and collective actions. These recommendations have been validated and built on through the stakeholder engagement and collaborative activities and discussions around the success and failures relating to the delivery of NBB in the Gwent Levels. These recommendations aim to avoid short-termism, so that the recommendations can provide impact on the well-being of future, as well as current, generations.

6.1 Key Trends and Themes from the DECCA and Planning System Criteria-based Assessments

6.1.1 Successful Alignment with Policy 9 Requirements

Analysis of the DECCA and Planning System assessments allowed for trends and key themes to be established relating to where past developments are successfully aligning with Policy 9 and the resilience of ecosystems (DECCA) to achieve long-term NBB. Successes were determined where developments in the Gwent Levels generally **performed well** within the DECCA and Planning System assessment. However, often this good performance was linked to a particular aspect of DECCA and/or stage of the Planning System and as such has not necessarily led to a holistic successful delivery of NBB for the SSSIs; this is further explained in the first bullet below. The key successes and/or good performance criteria were:

- **Developing ecological designs and habitat management and monitoring plans which demonstrate understanding of the requirements of maintaining and enhancing diversity and condition to achieve NBB** – Ecological designs, as well as habitat management and monitoring plans to support those designs, submitted at the planning application stage (pre-construction) generally showed good understanding and application of demonstrating how habitats could be enhanced and/or created to provide net benefits in terms of **diversity** and **condition** of habitats for species. However, designs and plans lacked understanding and application of other ecosystem resilience requirements such as **extent**, **connectivity** and **adaptability**, which are required for successful and holistic delivery of NBB for the longer-term. This may be owing to the historic better understanding and knowledge of ecosystem function and mitigation relating to **diversity** and **condition**, as these have historically been the primary reasons for protected site selection and designation, compared to more recent understandings around **extent**, **connectivity** and **adaptability**. The SSSI's SMSs [36, 39, 42, 45, 47, 49, 50] also focus on **diversity** and **condition** of reens and ditches, with management relating only to reens and ditches such as ditch clearance, water levels and quality (although no measures and/or targets are provided) and shading by hedgerows. Also, in relation to the Gwent Levels SSSIs there are historic CCW guidance's[56, 57, 58, 59, 60] relating to protecting and enhancing SSSI features, as well as requirements of monitoring for **diversity** and **condition** in terms of water quality and species diversity and abundances. Although some habitats and ecosystem functions will benefit from designs and plans which have focused on **diversity** and **condition**, others may be more critically dependant on some or all other aspects of DECCA, such as **extent**, **connectivity** and/or **adaptability**. This Study has shown that these aspects are however less successfully considered within the developing of designs and plans to achieve and demonstrate NBB within the Gwent Levels; these are further discussed in the 'failure to align' below. The long-term implementation of designs and plans are also discussed in the 'failure to align' below.
- **The delivery of mitigation, management and monitoring associated with pollution prevention measures and water quality** - Mitigation measures and monitoring plans and reports for these specific matters were prescriptive and generally had been conducted for the years agreed through the planning determination. Similarly, the planning conditions relating to pollution controls and water quality were prescriptive and had clear targets for monitoring and reporting. This Study concluded that the well-established published regulations and controls which exist for pollution prevention measures for construction, and maintaining water quality, could have been the reasoning for this good performance against these criteria (such as Guidelines for Pollution Prevention (GPP/PPG[73]),

[73] NetRegs. Guidance for Pollution Prevention (GPP) documents. Available at: [redacted] [Accessed December 2023]

particularly GPP "Works and maintenance in or near water: GPP 5[74], and industry best practice (GPP75, CIRIA76)).

- **The avoidance and protection of SSSI reen and ditches and implementation of buffers from development demonstrating partial alignment with the step-wise approach** – Most planning applications have followed advice and guidance provided by NRW (including CCW Guidance's 1991 to 1996[56, 57, 58, 59, 60]). That advice relates to the avoidance where possible of reens and ditches, providing replacement reens and ditches where these are lost or impacted, the design of reens and ditches in terms of location and profile, and providing a buffer to development from these features. Most developments have also demonstrated partial alignment with step-wise approach through avoidance first of the Gwent Levels SSSI's features, namely the reens and ditches, and then mitigating and compensating impacts through provision of replacement features. However, it is important to be mindful that in moving forward the revised wording to PPW Chapter 6 is far more stringent in terms of any proposed developments in or affecting a SSSI and looks to avoid development unless it meets the specifics of PPW Chapter 6. Any successful delivery of the protection of SSSI reens and ditches to date is likely owing to the specific CCW guidance relating to developments within the SSSI[56]. Replacement reens and ditches, where the originals have been infilled and replacement lengths created elsewhere, however are not always successful in terms of their function in being suitable for SSSI flora and invertebrate species to thrive and survive. This is likely owing to lack of consideration of hydrological connectivity and water availability, which is further described in the 'failure to align' below. Grassland buffers were also generally provided between development and reens and ditches, however these were only providing support to the SSSI features and functions if they were being managed appropriately to provide a species-rich sward and were not being encroached by earthwork and/or scrub.

6.1.2 On what matters would these past developments have failed to Align with Policy 9 Requirements

Analysis of the DECCA and Planning System assessments allowed for trends and key themes to be established relating to where developments would repeatedly and are consistently failing to align with Policy 9 and the resilience of ecosystems (DECCA) to achieve long-term NBB. It is important to note here that when mitigation and habitat enhancement plans for developments are failing to delivery NBB it is often for multifaceted and integrally linked reasons. The key reasons for failures found through the assessment are presented below, however their integrated nature often leads to similar recommendations for potential improvements for the future, which are presented in Section 6.2 below.

Failures to align with Policy 9 and the resilience of ecosystems (DECCA) to achieve long-term NBB were determined within the assessment where developments in the Gwent Levels generally **performed poorly** within the DECCA and Planning System assessment. The key failures and/or poor performance criteria were linked to the following aspects:

- **Not developing ecological designs and habitat management and monitoring plans which are 'fit for purpose' and demonstrate understanding of the requirements of maintaining and enhancing biodiversity in relation to all aspects of DECCA to achieve NBB** – There was a general lack of the proposed developments (that is at the planning application stage) demonstrating that mitigation measures will be functional and 'fit-for-purpose' and achieve NBB through all

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[74] NetRegs. Guidance for Pollution Prevention Works and maintenance in or near water: GPP 5 Version 1.2 February 2018 Available at: [redacted]/ [January 2024].

[75] Natural Resources Wales (NRW), the Northern Ireland Environment Agency (NIEA), Scottish Environment Protection Agency (SEPA) (2018). Guidance for Pollution Prevention – Works or maintenance in or near water: GPP5 v1.2 Feb 2018. Available at: http://www.netregs.org.uk/media/1418/gpp-5-works-and-maintenance-in-or-near-water.pdf [January 2024].

[76] CIRIA (2018) CIRIA. Available at: http://www.ciria.org [January 2024].

aspects of DECCA. For example, planning applications, and their accompanying habitat designs and plans didn't show or evidence that replacement or restored SSSI reens and ditches would have sufficient water levels during the summer month to sustain SSSI species, and that the works would not impact the existing networks water management of the SSSI, i.e. would not de-water other parts of the SSSI reen and ditch network to fill the new or restored ditches. This example links to the need for complex consideration of **extent**, **connectivity** and **adaptability** of the water resource and availability, as well as the **diversity** and **condition** of the proposed SSSI features, when developing design to achieve NBB at the planning application stage and for these designs to be successful at the construction/post-construction stage. Further to this, there was a lack of submitted planning applications providing consideration for habitats other than those directly listed as SSSI features and/or those linked to Protected Species with licencing requirements, particularly in relation to **extent**, **connectivity** and **adaptability** of habitats to support the SSSI. For example, the supporting nature of semi-improved and species-rich grassland habitats for invertebrate species associated with the SSSI, including the shrill carder bee, was often only considered in terms of the buffers to reens and ditches rather than considering the ecosystem resilience requirements of **extent** and **connectivity** of these important grasslands across the Gwent Levels. As such, grasslands were often lost in terms of **extent**, and cumulatively across the Levels this could have an impact to the numbers and survival of invertebrate species. The lack of consideration of grasslands could be reflective of the lack of details and requirements relating to grasslands within the SSSIs citations, SMSs[36, 39, 42, 45, 47, 49, 50] and in the CCW guidance's[56, 57, 58, 59, 60]; consideration of updating all of these are provided in the recommendations.

Another example of where design of ecological mitigation and habitat management and monitoring plans have not considered all aspects of DECCA and the future use of the sites by species, relates to the location of mitigation areas such as for sensitive breeding bird habitats. Llanwern Solar Farm designed a retained breeding lapwing area and an 'Off-Site Lapwing Mitigation Area' both being adjacent to the solar arrays. Lapwing have not been recorded to be breeding in the off-site mitigation area, and although lapwing have been observed in the retained fields, no breeding was confirmed in Year 2 and Year 3, and numbers have continued to decline from the baseline before the development was built (as described in the Llanwern Solar Ecological Monitoring and Review - Year 3, January 2024). A possible and logical explanation as to why the breeding lapwing have not returned to the retained area and/or established as predicted within the off-site mitigation area could be due to the **extent**, **condition** and **connectivity** of their habitat significantly changing due to the solar development being built and reducing both the visual appearance of the area to the lapwings and the **extent** and **connectivity** of available habitats for breeding and foraging. In short, the location of the mitigation areas may not be 'fit for purpose' due to the species requirements for breeding not being fully met through the mitigation measures, which needs to be rigorously investigated at the planning application stage to fully demonstrate through the evidence-base that the mitigation designs being proposed are achievable in maintaining and enhancing biodiversity, in this case the breeding population of lapwing. Llanwern's management and monitoring plans, however, are adaptive and adaptive management is discussed within the Year 3 monitoring and review report, which includes the implementation of additional measures into the 'Lapwing Mitigation Area' to increase the potential for the area to attract lapwing.

Understanding, implementation and managing of 'adaptability' in terms of climate change and long-term viability of NBB was generally found to be insufficient. Many habitat management and monitoring plans did not cover sufficient time scales to allow for habitats to achieve target condition and/or there was no evidence or auditing in most cases to suggest that adaptive management was being conducted in relation to NBB, see point below for more details.

- **Not developing management and monitoring plans which are targeted, long-term and adaptive** – Many of the developments within the Gwent Levels, particularly the older developments, did not have management and monitoring plans which covered sufficient time periods to allow for 'successful' mitigation and compensatory habitats to establish, did not have sufficient details to inform 'target conditions' of habitats, and/or were not adaptive to allow for contingencies and remedial actions to be established to ensure NBB are delivered and maintained for the future. More recent planning applications did perform better against the criteria linked to this, which is likely due to changes to and/or new regulations, policy and guidance which has helped shape understandings of both developers and planners of the requirements needed to achieve NBB for the longer-term, although there is still an absence of specific guidance, regulations and controls relating to long-term management and monitoring of NBB, and in the case of the Gwent levels how they related to condition assessments of the SSSI. Recommendations relating to further guidance regulations and controls is provided in Section 6.2 below.

- **Planning conditions relating to long-term management and monitoring for biodiversity not being fit for purpose** – There was a lack of suitably worded planning conditions and/or commitments through a S106 relating to longer-term management and monitoring requirements. Planning conditions relating to the delivery of ecological mitigation and long-term management and monitoring to ensure the delivery of NBB were generally not as descriptive and measurable as those relating to water quality and construction mitigation, and often the planning condition just referred to the need to produce a management and monitoring plan, not the delivery of it. As such, the planning condition could be discharged fully with the production of habitat management and monitoring plan report. Although this appears to have changed in some of the more recent applications where certain planning conditions have only been partial discharged relating to the delivery of the management and monitoring plans, there still appears to be lack of understanding, guidance, regulations and controls relating to both the contents and delivery of habitat management and monitoring to ensure that NBB is delivered for the long-term. This is picked up in the recommendations in Section 6.2 below.
- **Failing to implement and deliver of long-term management and monitoring for biodiversity –** There was an absence of detail or reference to species guidance, regulations and controls within the submitted management and monitoring plans, and as such long-term management and monitoring to achieve NBB was shown to be generally failing in the Gwent levels. This could also be owing to the current planning system approach of how long-term NBB delivery is secured and delivered, as well as the mechanisms available to ‘enforcement’ of failure to deliver. The criteria-based assessment showed across all areas of the DECCA Framework and the Planning System that post-construction delivery of NBB dramatically reduced compared to measures prescribed within the planning applications based upon which the development had been granted permission. There was evidence that some of the long-term management plans had not been implemented successfully, particularly relating to ditch management in the form of hedgerow management to reduce shading of the ditch/reen and/or re-casting of the ditch to create conditions suitable for SSSI species, and there appears to be lack of adaptive plans or remedial actions implemented by those with responsibility for the land. There was also a lack of evidence for some of the developments relating to ‘enforcement’ of failures to comply with long-term commitments for NBB.
- **Not undertaking an audit trail of the implementation, management and monitoring of NBB –** The greatest challenge for this Study was locating all the planning application documents associated with ecological assessments, biodiversity designs, nature conservation consultations, decision notices for discharge of conditions and habitat management and monitoring plans and reviews. Many of the documents were not appropriately named on the planning portals and/or had various planning references for the same application which made it difficult to locate documents to get a clear understanding of the developments alignment against Policy 9 requirements and the delivery of NBB. Three of the of preliminary 13 sites under consideration for the assessment were considered not ‘fit for purpose’ due to the lack of planning application documents located from the planning portal systems which made the assessment unviable for those sites/developments.
- **Inadequate ecological information at planning application stage being addressed through conditions** – Planning conditions had been used for some of the developments of this Study to provide ecological survey information and/or the details required for the delivery the NBB after the site had been given planning permission. This was then further compounded by the lack of adequately worded planning conditions and/or commitments through a S106 relating to longer-term NBB management and monitoring plans, inadequate ecological survey information to support

management plans, and that management and monitoring plans themselves have historically been used to discharged planning conditions, rather than implementation of the plans themselves. Recommendations for planning conditions standardisation and wording are provided below. Further consideration should be given as to whether the details required for the delivery the NBB, which are integrally linked to the designs and mitigation of any development, are appropriate to be deferred for later consideration and thus included as a planning condition.

6.2 Recommendations

The key trends and themes summarised above from the criteria-based assessment, along with stakeholder refinement of recommendations on the potential impactful changes within the planning system to achieve NBB, have been used to develop recommendations for further consideration. The recommendations in Table 9 below are mainly described in the context of the Gwent Levels, however further testing and investigations are suggested where the recommendations need more development and/or whether they could be widely tested across Wales to determine whether national application would be appropriate. Also, some of the actions may be resource intensive and could be better suited to be investigated at a wider scale – possibly Wales wide.

Table 9 below, uses and adapts the symbology used in Chapter 5 for the recommendations and actions, with narrative on the specific actions relative to the Gwent Levels, potential wider national application, if relevant. Alignment and contribution to the successful delivery of NBB of Policy 9 and SMNR, the Biodiversity Deep Dive recommendations[12] and the Five Ways of Working of the Well-being of Future Generations Act are also provided. Recommendations in Table 9 are not in any order of priority or timebound, and the effort and impacts associated with implementing these recommendations have not formed part of this Study and would therefore require further consideration and are indicative only where such reference has been made. Where next steps and further investigations have been identified however, these are described to aid the decision-makers with considerations of how the recommendations could be further developed. It should be noted that:

- Any recommendations relating to future development proposals are made in the context of PPW: Chapter 6 which places a general presumption against developments in SSSIs. PPW chapter 6 does however acknowledge that there are some developments which would be permitted (as explained in PPW Chapter 6) and as such those developments would still benefit from improvements within the planning system; and,
- The recommendations apply to the whole of the Gwent Levels, and potentially areas which may affect the Levels. As such not all parts are covered by SSSI status and the protection they are afforded and hence would also benefit from improvements within the planning system.

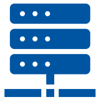
The recommendations in Table 9 below should be read with both of these points in mind.

Table 9: Recommendations specific to the Gwent Levels, potential for wider national application, and alignment and contribution to policy.

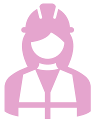
Recommendation Category	Specific Gwent Levels Actions & Potential National Application	Alignment & Contribution to Policy
SSSI Citation and SMS	• **Update the Gwent Levels SSSI's citations and Site Management Statements (SMSs)** to be relevant to current features and functions, but to also include more details on the supporting habitats such as the grasslands. The citations are dated between (1987 – 1993) and the SSSI's SMS's were produced in 2008[36, 39, 42, 45, 47, 49, 50]. Consideration could be made to ensure these align with the Conservation Objectives (COs) and the Performance Indicators (PIs) of the SSSIs and provide rigorous and sufficient details on management to ensure that the CO and PIs can be understood by developers, landowners and planners and thus brought into the pre-application advice and development of design schemes. The SMS could consider providing details on summer and winter penning levels and the requirements of water levels for the assemblage of SSSI species to survive, this would aid the decision making of developers, landowners and planners regarding enhancing the reen and ditch networks of the SSSIs. The SMS should also reflect the recent PPW changes relating to presumption against development. Updating these documents could provide better support to developers and LPAs to ensure the SSSIs and designing NBB is sufficiently considered early in proposed development design or even site selection, and at the pre-application stages which may reduce time and resource associated with consultation for development by the LPAs and NRW. It is recognised that the work involved to achieve this would take time as there are legal requirements relating to all re-notification proposals and each site would require its own individual re-notification. In the short-term consideration should be given as to whether there are any clarification points such as the water level issue that could be picked up for the Gwent Levels, specifically through the pilot planning guidance work which is currently being undertaken to complement Policy 9 of Future Wales.	Would support better development and delivery of NBB within and adjacent to the Gwent Levels SSSIs from the developer; potential to reduce time associated with pre-application advice for both LPAs and NRW. Aligns and contributes to Biodiversity Deep Dive action: 7. Develop and adapt monitoring and evidence frameworks to measure progress towards the 30x30 target and guide prioritisation of action; and the Five Ways of Working of the Well-being of Future Generations Act: Prevention.
Legislation, Policy & Regulation	• **Strengthening legislation to support the delivery of NBB for the long-term.** Further investigation would be required, and this would be considered more of a longer-term action/consideration to better enable the delivery of NBB and nature recovery for the future. This could be around demonstrating NBB and making its delivery explicitly timebound over a period in which habitats would be expected to establish, mature and provide NBB into the future (i.e. in excess of 30 years, if not for in perpetuity). Although this is not a direct action for the Gwent Levels, strengthening legislation and policy on NBB and nature recovery would lead to better outcomes for nature recovery across Wales including the Gwent Levels. • **Further updates to PPW and TAN 5: nature conservation and planning** could be considered in the short to medium-term to provide guidance and more details on the assessment and delivery of NBB, and on the long-term management and monitoring of NBB, including the length of time, if not for in perpetuity, for management and monitoring plans to ensure that NBB is delivered and continued for the future.	Would support better delivery of NBB at legislative and policy level and through improved regulation and controls. Aligns and contributes to Biodiversity Deep Dive action: 8. Embed Nature Recovery in policy and strategy in public bodies in Wales; and the Five Ways of Working of the Well-being of Future Generations Act: Long-term, Prevention & Integration.

Recommendation Category	Specific Gwent Levels Actions & Potential National Application	Alignment & Contribution to Policy
	• **Improved regulations and controls for NBB delivery, management, and monitoring** could be considered, including the application of standardised planning conditions to be more suitable for the delivery of NBB and ways to incentive the developer to ensure NBB is delivered for the long-term through non-compliance bonds and levies (which are explored separately below). Consideration should be given as to whether any of these matters could be picked up in the interim, specifically through the Gwent Levels pilot planning guidance work.	
Guidance	• **Guidance and/or a check list developed from the DECCA Framework criteria-based assessment** produced for this Study, tailored to the specific requirements of the Gwent Levels under the DECCA Framework that could be used by both developers and planners. Such a check list would need to be further co-developed across the LPAs, NRW, and local nature conservation organisations to ensure the list is complete and that it references relevant regulations, policy and guidance relative to the delivery of NBB in the Gwent Levels. Such a checklist would supplement the Pilot Policy 9 work identified above on NBB assessment and application and could provide a 'quick win' in terms of providing better support to developers and LPAs to ensure NBB is sufficiently designed, managed and monitored, as well as reduce time and resource associated with consultation for development by the LPAs and NRW. • **Specific planning guidance for the Gwent Levels**. It is acknowledged that work on additional planning guidance as a pilot for the Gwent Levels is already committed to and is underway. The guidance is currently being developed across the 3 LPAs in the Levels to ensure a consolidated approach. **This guidance could look further at NBB assessment and application** in relation to developments affecting the Gwent Levels. Including the requirements for adaptive long-term management and monitoring, length of time required for management and monitoring, and need for target conditions to evaluate successful delivery of NBB. Further work would be required to develop a standardised approach to NBB assessment and application and could be considered as a relatively 'quick win' to support improved alignment of Policy 9 requirements within the planning system relative to the Gwent Levels. • **Update guidance specific for the Gwent Levels** to reflect more recent best practice and evidence-based knowledge relating to successes and failures of habitat creation, restoration, management and monitoring in the Gwent Levels, as well as recent PPW changes relating to presumption against development in SSSIs. The CCW guidance's were produced between 1991 and 1996[56, 57, 58, 59, 60], and as such much evidence has been accumulated on what mitigation and enhancement works or not, as well as balancing competing objectives found in the SSSI, such as open ditches vs hedgerow connectivity and resource for dormice. Consideration could be given to further advice for existing landowners, developers, and for those limited development proposals that do accord with Chapter 6 of PPW which affect the Gwent Levels, on developing and adapting existing plans. This could help	Would support better development and delivery of NBB from the developer; potential to reduce time associated with planning application consultation for both LPAs and NRW. Aligns and contributes to Biodiversity Deep Dive action: 7. Develop and adapt monitoring and evidence frameworks to measure progress towards the 30x30 target and guide prioritisation of action; and the Five Ways of Working of the Well-being of Future Generations Act: Prevention.

Recommendation Category	Specific Gwent Levels Actions & Potential National Application	Alignment & Contribution to Policy
	ensure that plans are 'fit for purpose', such as the design, location and need to demonstrate hydrological function and water availability of replacement and restored reens and ditches. Further details and guidance on matters such as summer and winter penning levels and the requirements of water levels for the assemblage of SSSI species to survive, would also aid the decision making of developers, landowners, those currently implementing management plans on the Levels, as well as planners regarding enhancing the reen and ditch networks of the SSSIs. Integration of the SSSI Performance Indicators (PIs) surveys and monitoring into guidance would also ensure that existing and proposed management and monitoring plans are developed/adapted to be consistent with the SSSI's conservation objective, as well as providing some standardisation of management plans. • **Further investigation to determine the factors which have influenced habitat creation and restoration on the Levels to be successful or to have failed**. Providing updated and consolidated guidance for the Gwent Levels SSSI relative to past and present developments could be considered as a relatively 'quick win' (subject to the usual procedural requirements for adoption) to support improved alignment of Policy 9 requirements within the planning system.	
Planning Conditions	• **Planning condition standards and consistent wording for the security and delivery of NBB and adaptive long-term management and monitoring** for the Gwent Levels. Standard wording could be co-developed across the LPAs to ensure that planning conditions allow for the complexities and length of time required to successfully deliver NBB for planning applications/developments. Planning condition standards and wording should also allow for partial discharge of conditions, only fully discharged at end of management plans lifetime, or when target conditions met, as well as the ability of 'enforcement' and/or 'penalties' of non-compliance. Also consider how non-compliance should be addressed where it becomes clear that a development cannot deliver on the proposals set out in the planning approval (and/or associated management plan), *e.g.* mitigation or enhancement requirements applied but they didn't work. The Gwent Levels Policy 9 Pilot Project could test the development and standardisation of planning conditions that are suitable for the delivery of NBB in line with Policy 9 requirements and ensure NBB commitments in planning applications continues to deliver into the future. If these are tested and prove to be successful, then national application across Wales could be considered to ensure developments are delivering NBB for the long-term. Providing standards for securing and achieving NBB through planning conditions could be considered as a relatively 'quick win' to support improved alignment of Policy 9 requirements within the planning system relative to the Gwent Levels. This could then be considered for roll out nationally.	Would support better delivery and enforcement of NBB from the developer and LPAs/NRW; potential to reduce time associated with planning application consultation and determination for both LPAs and NRW. Aligns and contributes to Biodiversity Deep Dive action: 8. Embed Nature Recovery in policy and strategy in public bodies in Wales; and the Five Ways of Working of the Well-being of Future Generations Act: Long-term & Prevention.

Recommendation Category	Specific Gwent Levels Actions & Potential National Application	Alignment & Contribution to Policy
	• **Detailed delivery, management and monitoring plans for NBB considered to be part of the planning application rather than through a planning condition and/or commitments through a S106**. Further consideration should also look at whether planning conditions and/or a S106 are adequate routes for the details required for ensuring the delivery the NBB which are integrally linked to the designs and mitigation of any development, and as such the decision-making process with regards the acceptability of a proposal at the outset. • Decision notice of discharge condition to have attached to it clear evidence of auditing as to the basis upon which the condition has been discharged, also see Data Management System below.	
Data Management Systems 	• **Consistent data management system for planning on the Gwent Levels** for LPAs to manage planning applications, with improved digital solution of document storage and document registers, consistent naming of reports/files for reporting of NBB, linking planning applications, decision notices and NBB management and monitoring reports, and 'red flag' system to assist with NBB monitoring on applications. Finding planning documents associated with NBB from pre-planning to post-construction was found to be difficult for all the applications within this Study, many with multiple planning references and no consistent approach to report and document names on the planning portals. Further work and investigation would be required to evaluate options for updating or developing a data management system to better manage and store planning application documents and commitments for NBB. The Gwent Levels Policy 9 Pilot Project could test the development of a data management system with the option to test requirements for wider role out across Wales, should similar data management and storage issues be apparent across other LPAs. However, it is acknowledged that this may be difficult to achieve in the short-term and that it may be better suited to look at more widely across Wales. This recommendation will therefore require further consideration.	Would support better delivery of NBB through improved auditing and digital management of planning applications; potential to reduce time associated with monitoring and management of planning applications within LPAs and NRW through digital transformation. Aligns and contributes to the Five Ways of Working of the Well-being of Future Generations Act: Long-term & Prevention.
Resource 	• **More resources in LPAs to monitor long-term NBB and enforce across the Gwent Levels** would have a positive impact on the successful delivery of NBB. This would also enable capacity to feedback into the planning system on what mitigation and enhancements are successful and what regularly fail. Budgetary increases/further funding for more ecological staff in LPAs and/or upskilling in-house expertise in the assessment and application of NBB, long-term management and monitoring requirements, and general biodiversity and restoration requirements specific to the Gwent Levels would improve the LPAs ability to both assess NBB within planning applications and monitor its delivery. Further investigation would be required to determine the mechanisms for funding such opportunities, but there may also be opportunities for funding to come from the developers rather than public funding; these are further explored in the recommendations below.	Would support better delivery and enforcement of NBB; would increase resource allocation in LPAs. Aligns and contributes to Biodiversity Deep Dive action: 6. Unlock public and private finance to deliver for nature at far greater scale and pace; and the Five Ways of Working of the Well-being of Future Generations Act: Long-term & Prevention.

Recommendation Category	Specific Gwent Levels Actions & Potential National Application	Alignment & Contribution to Policy
NBB Bonds, Levies, Penalties or Incentives 	• **Introduction of NBB bonds/'non-performance bonds', levies, penalties or incentives into policy and regulation to improve delivery of NBB.** This puts more onus on the developer to ensure the delivery of NBB which they have committed to deliver for the longer-term in order for the permission to be granted, rather than on the LPA and NRW to monitor NBB for non-compliance, and taking enforcement actions and fining developers when non-compliance is demonstratable. This is a more positive and proactive approach. Non-compliance of the delivery of NBB for many of the planning applications looked at within this Post Construction Monitoring Study, would have been difficult to peruse for some of the reasons provided in the 'failures to align' trends described in Section 6.1.2, particularly relating to lack of details of target conditions in management and monitoring plans, lack of details provided in planning condition relating to achieving NBB and lack of guidance on how to assess and deliver successful NBB; which have been addressed independently in the recommendations above. Further investigation would be required to assess which mechanism would be best suited to the long-term delivery of NBB in the planning context. Lessons learnt from other policy regarding long-term restoration requirements, such as restoration bonds in the minerals policy may be applicable. The Gwent Levels could be considered as a test area for such NBB bonds or other, as part of the Policy 9 Pilot Project. However, to achieve successful future NBB delivery across Wales, and to halt and reverse the decline in biodiversity, a more national-focused investigation would be advisable.	Would support better delivery of NBB through improved governance and enforcement. Aligns and contributes to Biodiversity Deep Dive action: 8. Embed Nature Recovery in policy and strategy in public bodies in Wales; and the Five Ways of Working of the Well-being of Future Generations Act: Long-term & Prevention.
Nature-based Performance 	• **Further studies could be undertaken to investigate if there are other ways to incentivise developers to deliver successful NBB** in the planning system and for the long-term nature recovery of areas such as the Gwent Levels. This may include integrating developers and companies own reporting on nature-based targets, such as TNFD, into the decision-making process for planning applications and the built environment. Such reporting could also incorporate developers to demonstrate the finances required and its availability for the delivery of NBB on projects and for the long-term. This would provide transparency to the decision-makers that the funding for NBB is secured and available for the successful delivery of NBB. To bring such changes and requirements into the planning system, may require significant changes to planning policy in Wales and as such is considered as a longer-term consideration. Further investigations could also be considered to develop a clear policy position on private investment in nature recovery, and how NBB may be developed to unlock investment into areas such as the Gwent Levels in the future. This could consider the establishment of a framework or standards to ensure the high integrity of Wales nature/environmental markets.	Would support better delivery of NBB through improved private sector governance and finance. Aligns and contributes to Biodiversity Deep Dive action: 5. Build a strong foundation for future delivery through capacity building, behaviour change, awareness raising and skills development, and 6. Unlock public and private finance to deliver for nature at far greater scale and pace; and the Five Ways of Working of the Well-being of Future Generations Act: Long-term, Prevention, Integration, Collaboration, and Involvement.

Recommendation Category	Specific Gwent Levels Actions & Potential National Application	Alignment & Contribution to Policy
Accredited Schemes & Contractors 	• **Green Infrastructure Statements (GIS) and Building with Nature application across the Gwent Levels to improve NBB delivery for the long-term**. PPW Edition 12[8] has introduced the need for GISs to be submitted with all planning applications to demonstrate how the step-wise approach has been applied, and that the Building with Nature standards represent good practice and are an effective prompt for developers to improve the quality of their schemes and demonstrate the sustainable use of natural resources. This addition in planning policy should continue to improve development planning applications in terms of demonstrating the deliverability of NBB, and LPAs within the Gwent Levels could consider collectively how they are going to advise and assess GISs which are proportionate to the scale and nature of the development. • **Consideration of an accredited scheme or approved suppliers list of contractors suitable to deliver habitat creation and restoration, and long-term management to successfully deliver NBB** could be further investigated for the Gwent Levels. As described in the key themes from the assessment (in Section 6.1 above), the implementation of NBB and the post-construction management and monitoring to ensure long-term successful delivery of NBB is where key failures are being observed within the Gwent Levels. Ensuring the implementation and onward management is being delivered by approved suppliers that understand habitat creation and restoration would benefit the delivery of NBB in the Gwent Levels. The development of an accredited scheme or approved suppliers list could be tested within the Gwent Levels with consideration of national application. Further investigation should be sought as to whether other areas of Wales, other authorities (such as National Park Authorities), or other countries, have a similar approach to the delivery of nature conservation management. • **Ecology Impact Assessment (EcIA) Accreditation Scheme** is currently being developed by the Chartered Institute for Ecology and Environmental Management (CIEEM) and the Gwent Levels LPAs could consider how they utilise this to better the EcIAs being produced for planning applications. Both consultants and ecological and environmental planners are able to acquire the accreditation. To ensure consistency and rigorous approach to EcIA planners from the LPAs could acquire accreditation, or a requirement for lead consultants of EcIAs to show accreditation, particularly for large and complex EcIAs.	Would support better delivery of NBB on the ground, and informed management to ensure NBB longevity. Aligns and contributes to Biodiversity Deep Dive action: 8. Embed Nature Recovery in policy and strategy in public bodies in Wales; and the Five Ways of Working of the Well-being of Future Generations Act: Long-term & Prevention.
Nature Protection 	• **Further protection for habitats that provide ecosystem resilience to Protected Areas and/or new nature conservation measures to avoid loss of nature networks**, could be considered for the Gwent Levels. PPW now provides further protection of SSSIs with a presumption against development within a SSSI as well as land not within a SSSI but likely to damage a SSSI. Consideration could be sought across the Gwent Levels authorities and advisors in how this should be taken forward in terms of additional guidance and resources, such as mapping of supporting habitats which are likely to damage and/or are areas for opportunities (*e.g.* nature recovery). Work on considering how this might be done is	Would support better delivery of NBB through improved protection and enhancement of biodiversity, and governance of development location. Aligns and contributes to Biodiversity Deep Dive actions: 1. Transform the

Recommendation Category	Specific Gwent Levels Actions & Potential National Application	Alignment & Contribution to Policy
	already underway as part of the Pilot Project work for the Gwent Levels. Further consideration is needed of how 'Other Effective Area-based Conservation Measures' (OECMs) and Nature Recovery Exemplar Areas (NREAs) could work within the Gwent Levels, in relation to SSSI features and supporting habitats. The Gwent Levels could be considered as a NREA with both Protected Areas and OECMs, and how these would interact to provide sufficient guidance, regulation and controls to deliver NBB and nature conservation across the Gwent Levels would need to be looked at further.	protected sites series so that it is better, bigger, and more effectively connected, and 2. Create a framework to recognise NREAs and OECMs that deliver biodiversity outcomes; and the Five Ways of Working of the Well-being of Future Generations Act: Long-term & Prevention.

7. Concluding Remarks

The purpose of the Post Construction Monitoring Study was to help inform an evidence base for the Pilot Project which will assist with the delivery of Policy 9 in the Gwent Levels. The approach undertaken involved an assessment of built developments within the Gwent Levels, focusing on SSSI features and their potential compatibility now with the current objectives and principles of Policy 9, in order to deliver NBB.

The report recognises the limitations of such assessments given that many of the developments assessed pre-date a number of the legislative requirements now in place. Nevertheless, this retrospective assessment gives some insight into how they would potentially fare if being determined and monitored in relation to policies as they stand at the time of this Study. Therefore, the outcomes of this somewhat retrospective assessment were intended as a means to gain insights and learn from what has happened previously and apply that learning for the future.

One of the most significant conclusions from the assessment work was that performance in relation to NBB was better at the pre-construction phase (when development proposals were being considered) than performance post-construction. The potential for successful compliance with Policy 9 was identified where developments in the Gwent Levels generally performed well based on the Study's DECCA and Planning System assessment. Where potential good performance was identified, it was often linked to one or two particular aspects of DECCA rather than all aspects and/or stage of the Planning System. As such this piecemeal good performance would not necessarily have led to a holistic successful delivery of NBB for the SSSIs. Where developments generally performed poorly based on the DECCA and Planning System assessment in this Study, this identified the potential failure of the development to comply with Policy 9 and the resilience of ecosystems (DECCA) to achieve long-term NBB. An example of poor performance was the absence of management and monitoring plans which are targeted, long-term and adaptive. Another being measures required as part of the planning decision either not being fully implemented or being implemented and not working. See Chapter 6 of this Study for full details.

The Study sets out a suggested list of actions (the Recommendations) which could help ensure that biodiversity is preserved and enhanced, and net benefits are achieved for the future of the Gwent Levels. Some of the recommendations made have the potential to be replicable and applied at a wider level and/or across Wales to help facilitate NBB. These recommendations have been categorised and include, but is not limited to, legislation, guidance, data management, resource and incentives. Examples of specific recommendations include regulations and controls for NBB delivery, management and monitoring; planning guidance to include requirements for NBB and further protection for habitats that provide ecosystem resilience and measures to avoid losses of nature networks. All recommendations have been provided in Table 9 (Chapter 6), which should be read in full.

The Study does not rank the recommendations according to priority, resource required, effort or impacts of implementation. However, next steps have been provided in some instances, to aid decision-makers with consideration of how the recommendations could be further developed.

Recommendations from this Study will now need to be further explored as part of the Pilot Project work for the Gwent Levels and other appropriate workstreams. Solutions are likely to need a multi-agency approach in many cases to help achieve the protection and recovery of nature ecosystems within the Gwent Levels and potentially elsewhere. The recommendations could potentially help drive better outcomes for biodiversity and nature recovery within the planning policy and economic development context, as well as wider contribution to secure a nature conscious and nature positive place.

Appendix A

List of Developments

A.1 Preliminary List of Developments

Table 10: Preliminary List of 13 Built Developments

Name of Development		
Preliminary List (planning application reference)	**Short-list of Seven sites**	**Final Five Sites**
Aldi Distribution Centre (04/01109/E)	✓	✓
Area 9 - 12 (06/00524/E)	✓	
Atlantic Recycling (08/00626/E)	✓	✓
Imperial Park (96/0650/CD *et al.*)	✓	
Glan Lyln - Redevelopment of Llanwern Steelworks to create a mixed-use urban extension comprising (06/0471)		
Gwent Europark - (18/1234)	✓	✓
Lamby Way Solar Farm (19/00397/MJR)		
Langstone Vale Crematorium plus car parking and memorial parkland (15/0646)		
Llanwern Solar DNS (18/0198)	✓	✓
Llanwern Steelworks tipping of residual slag and mitigation/restoration works (96/1083)		
Natural Gas Pipeline Marshfield to Uskmouth (01.08.04.07/13C)	✓	✓
Queensway Meadows Newport, Land Adjoining Meadows Road – construction of 3527m.sq industrial unit, parking, access road and associated site works (01/1428)		
Wind Turbine - Land To The North Of Little Longlands Longlands Lane Magor Caldicot (12/1001)		

Appendix B

Site Visit Form

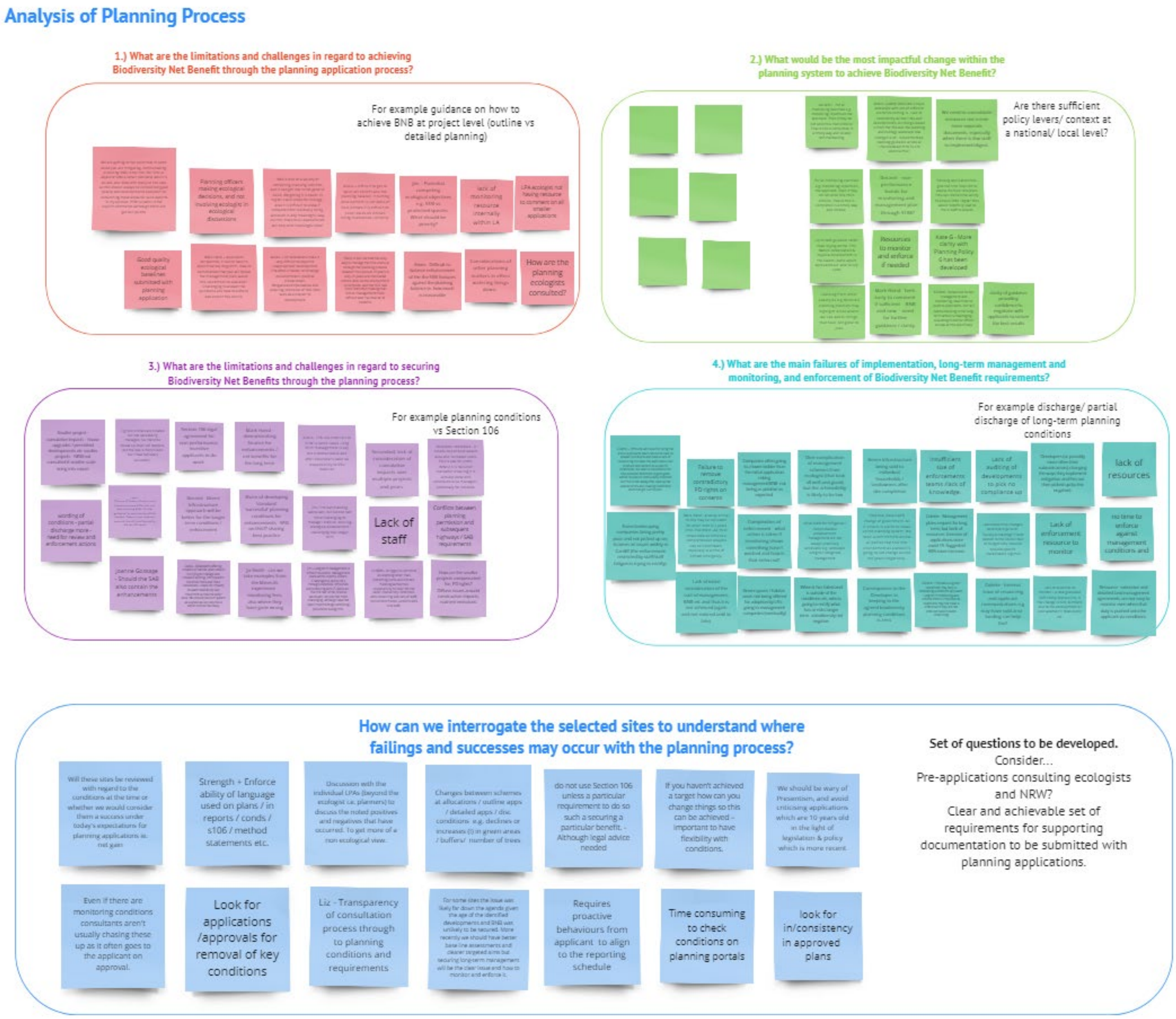
B.1 Site Visit Form (Compressed)

Habitat Type	Reference to Mapped Area and/or Proposed Mitigation	Notes (include extent (ha), key species, condition, suitability for protected species and evidence of habitat/agricultural management)	Ditches and Reens	Reference to Mapped Area and/or Proposed Mitigation	Notes (including measures, key species, and suitability for protected species)
Small landscaping areas and SuDS			**Water Levels (m) and Extent of Vegetation Cover (*e.g.* % chocked with reeds, % cover of submerged veg, *etc*)**		
Arable			**Water Quality (*e.g.* signs of pollution, oil, litter *etc*)**		
Modified grassland			**Nutrient Enrichment (*e.g.* presence of species indicative of nutrient enrichment such algal blooms)**		
Semi-natural grassland (including buffers to ditches and reens, and suitability for shrill carder bee)			**Notable Plant Species (e.*g.* SSSI species and rare/notable - frogbit, tubular water-dropwort, arrowhead *etc*)**		
Woodland			**Hedgerow Presence (both or one side of ditch, % shading *etc*)**		
Hedgerows and Scrub			**Connectivity to surrounding network and evidence of barriers**		
Fen, Marsh, and Swamp			**Bank side slopes (type) and vegetation, and size (m) and type of grassland buffer to feature**		
Freshwater & Ponds (excluding ditches and reens – see separate table)			**Evidence of Management (e.g. recently cast, bank veg cutting, hedgerow cutting *etc*)**		

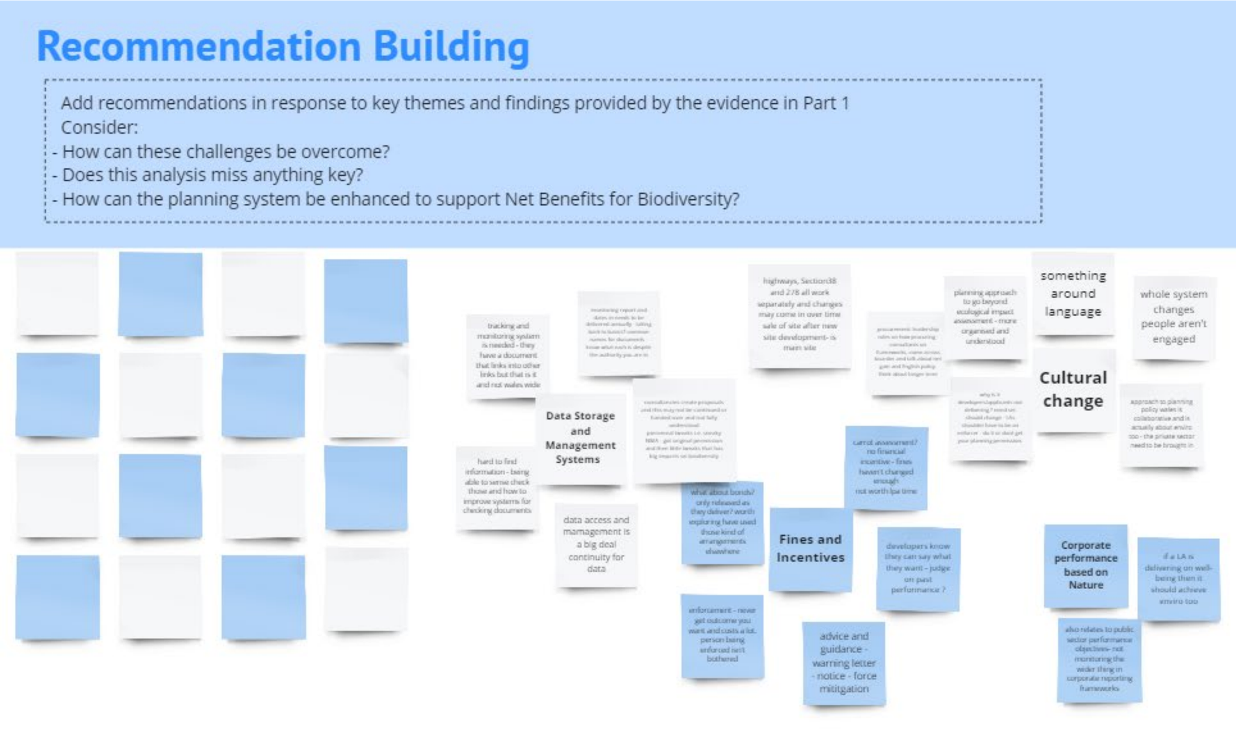
Appendix C

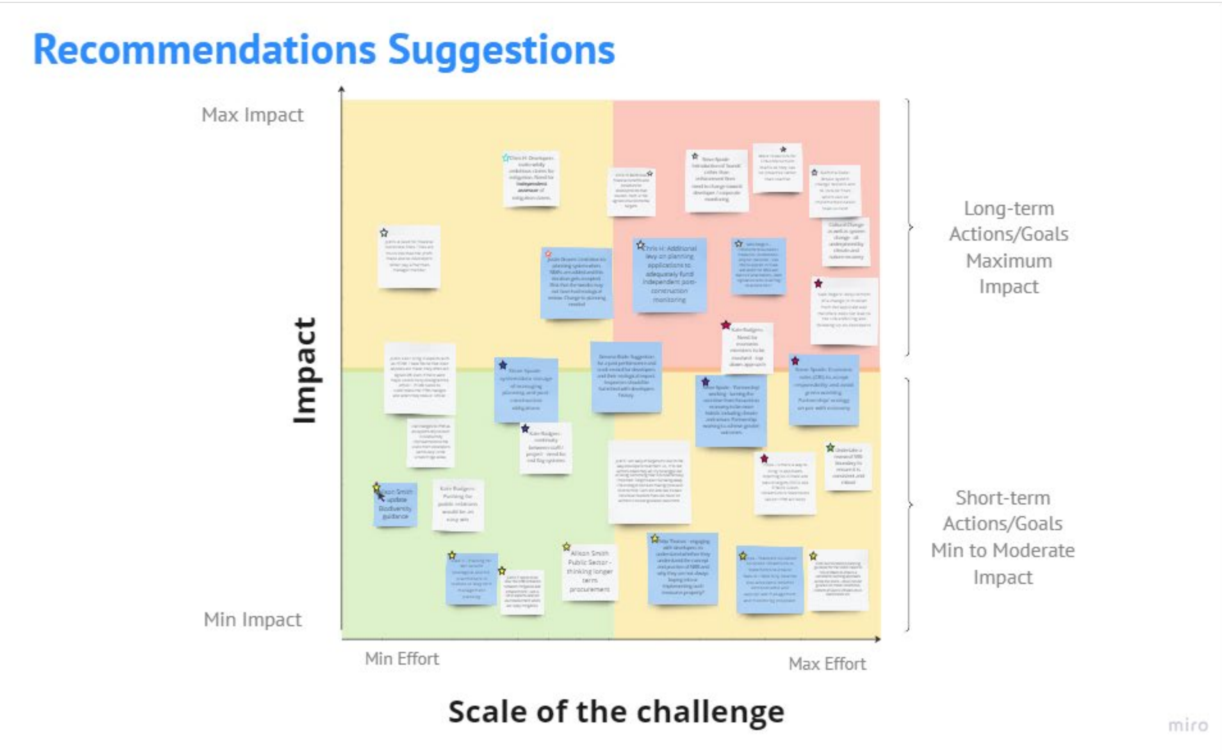
Stakeholder Workshop

C.1 Example of stakeholder engagement activity from the digital collaboration platform in Workshop 1



C.2 Example of stakeholder engagement activity from the digital collaboration platform in Workshop 2





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Innate recognition of water bodies in echolocating bats

Stefan Greif[1] & Björn M. Siemers[1]

In the course of their lives, most animals must find different specific habitat and microhabitat types for survival and reproduction. Yet, in vertebrates, little is known about the sensory cues that mediate habitat recognition. In free flying bats the echolocation of insect-sized point targets is well understood, whereas how they recognize and classify spatially extended echo targets is currently unknown. In this study, we show how echolocating bats recognize ponds or other water bodies that are crucial for foraging, drinking and orientation. With wild bats of 15 different species (seven genera from three phylogenetically distant, large bat families), we found that bats perceived any extended, echo-acoustically smooth surface to be water, even in the presence of conflicting information from other sensory modalities. In addition, naive juvenile bats that had never before encountered a water body showed spontaneous drinking responses from smooth plates. This provides the first evidence for innate recognition of a habitat cue in a mammal.

[1] Max Planck Institute for Ornithology, Sensory Ecology Group, Eberhard-Gwinner-Straße, Seewiesen 82319, Germany. Correspondence and requests for materials should be addressed to S.G. (email: greif@orn.mpg.de) or B.M.S. (email: siemers@orn.mpg.de).

It is crucial for animals to find their often species-specific, suitable habitat or microhabitat for fitness relevant behaviours, such as mating, breeding, foraging or drinking[1,2]. Although both empirical and theoretical work have investigated whether and under which conditions habitat preference is innate or learned[3–7], very little is known about the sensory cues that actually mediate habitat recognition in vertebrates. The only studies known to us show that fish innately find riverine habitats by olfaction[8] and that migrating birds may use song of bird species with similar habitat requirements to find suitable stopover sites[9]. Bats are an especially interesting group in which to study the sensory basis of habitat recognition, because they are highly mobile, can cover 200 km in one night's flight and yet predominantly rely on a short-range sensory system, echolocation[10]. Although it is well understood how bats echolocate insect-sized point targets[10,11], it is unclear how they recognize extended objects such as forest edges or lakes.

Ponds, lakes and rivers are important for bats in various ways. They offer an abundance of prey, often soft bodied and easily digestible[12], and several bat species are specialized to forage in aquatic habitats[13]. Because of acoustic mirror effects, bats can detect insects sitting on the smooth water surface easier[14,15] and from further away[16] than on vegetation or when air-borne. With respect to flight costs, bats benefit from the ground effect when flying close to the water surface[17]. Many bat species likely use bodies of water as landmarks for orientation and navigation[18]. Also, most of the about 1,000 extant species of echolocating bats must visit ponds or rivers for drinking (Fig. 1). But how do bats find and recognize the most prominent element of such an aquatic habitat, the water body? Water surfaces are special in that they represent the only extended, acoustically smooth surfaces in the natural environment. We therefore hypothesized that bats would rely on the mirror-like echo reflection properties of smooth water surfaces to detect and recognize bodies of water. When a bat flies over a water surface and the axis of its echolocation beam intersects with the surface at an acute angle, the main energy of the echolocation calls is reflected away from rather than back towards the bat, so it does not receive an echo from ahead (Fig. 2). However, some off-axis energy of the sound beam hits the surface perpendicularly and does generate an echo returning from straight below the bat. On the basis of our above hypothesis, we predicted that bats confronted with any sufficiently large smooth, horizontal surface having these acoustic mirror properties will perceive it to be water.

In this study, we show how free flying bats recognize and classify spatially extended echo targets in an ecologically and evolutionarily relevant context. We took a behavioural approach to find out how bats recognize a key habitat element in their environment: bodies of water. We found that bats take horizontal, acoustical mirrors to be water. This behaviour is extremely stereotypical, phylogenetically widespread among echolocating bats and innate. Echolocation is the key sensory modality triggering water recognition and takes dominance over conflicting information.

Figure 1 | Drinking bat. A greater mouse-eared bat, *M. myotis*, closing in on a water surface, opening its mouth and lowering the head to take a mouthful of water (Photo by Dietmar Nill).

Results

Echoacoustic water recognition. In a large flight room with weak red illumination, we presented experimentally naive, wild-caught bats with two plates (1.2×2 m) positioned on a sandy floor (Supplementary Fig. S1). The two plates presented simultaneously in each trial were always of the same material—either metal, plastic or wood—but one had a smooth and the other a textured surface (Fig. 3). Ensonification and qualitative assessment of the reflected echo scenes showed that the smooth plates were good echoacoustic mimics of a water surface, whereas the echoes of the textured plates resembled those of grained sand (Fig. 4). It is important to note that the smooth experimental plates only mimicked water in the echoacoustic domain, but did not in other modalities, including olfaction, vision, taste and touch. We scored a bat's attempt to drink from an experimental plate as our behavioural measure for the bats' perception of the experimental plate as a water body. To evaluate whether the bats were generally motivated to drink, we presented the bats a real water pool at the end of each experimental session (Supplementary Fig. S1).

We tested four different species of bat (each $n = 6$ individuals), from distinct ecological[10] and phylogenetic groups[19] with all three plate materials. Schreiber's bat (*Miniopterus schreibersii*) is an example of a species hunting in open space; Daubenton's bat (*Myotis daubentonii*) is specialized at hunting over bodies of water; the greater mouse-eared bat (*Myotis myotis*) forages predominantly for ground-running arthropods; and the greater horseshoe bat (*Rhinolophus ferrumequinum*) uses a distinct and highly specialized echolocation system to detect fluttering insects. All 24 bats of all four species spontaneously tried to drink from the smooth plates of all three materials, but never from the textured plates (Fig. 5, Fisher's combined probability test, all $P < 0.0001$). When they were offered a real water pool at the end of each experimental session (control of drinking motivation), they drank 4–19 times in 10 min (species means). To further explore the generality and taxonomic spread of echoacoustic water recognition, we additionally tested one individual from 11 more species with the metal plate setup. Our total data set thus comprises 15 species (7 genera) from 3 large bat families, Vespertilionidae, Miniopteridae and the phylogenetically distant Rhinolophidae[19]. All of the 11 additional species likewise tried to drink from the smooth but never from the textured metal plate (Table 1).

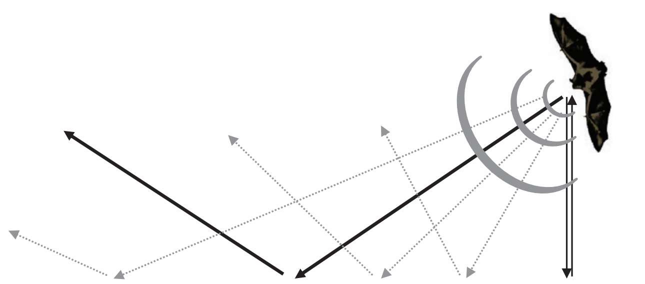

Figure 2 | Simplified representation of sound propagation and echo generation at a smooth surface. Most of the call energy is reflected away from the bat, with the exception of the small off-axis fraction that hits the surface perpendicularly.

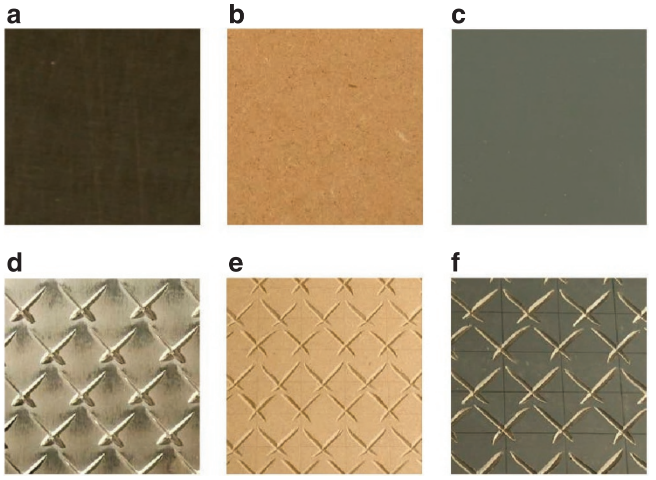

Figure 3 | Experimental plates. In the first row all smooth surfaces are shown: metal (**a**), wood (**b**) and plastic (**c**); and below the respective textured plates (**d**–**f**). Each photo shows a 0.13×0.13 m detail from the 1.2×2 m plates.

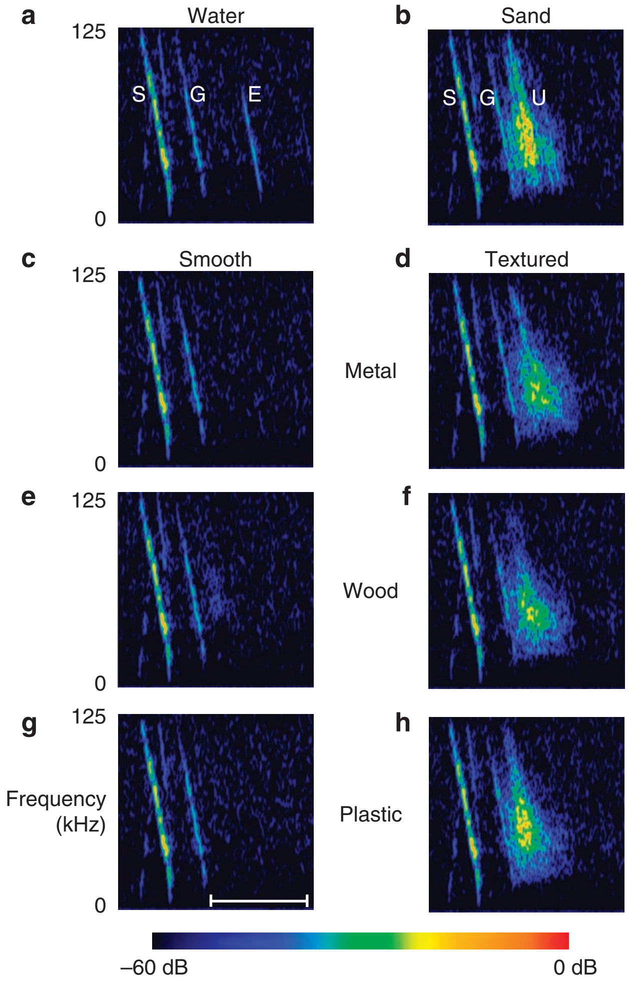

Figure 4 | Echo signatures of natural and experimental surfaces. In the first row a comparison of a natural smooth (water) (**a**) and a natural textured surface (sand) (**b**) is given. Below, the echo signatures of our three experimental materials (metal, wood and plastic) are compared for smooth and textured plates. Smooth plates are depicted on the left (**c**, **e**, **g**) and textured surfaces on the right (**d**, **f**, **h**). The white scale bar in **g** corresponds to 10 ms. The colour bar codes for the amplitude of the signal in a relative dB scale. *Smooth* (*left side*): After the outgoing signal (S), there is a time delay until the first echo returns; this is the echo front reflected perpendicularly from the ground (G). All other parts of the signal are reflected away and thus do not reach the microphone (see Fig. 2 for a schematic representation). In the water sonogram (**a**), an additional echo from the back edge (E) of the water pool shows up. *Textured* (*right side*): After the perpendicular ground echo (G), a series of many overlapping echoes from the uneven surface structures follows (U). Overall, the echo reflections of the smooth experimental plates strongly resemble those of a water surface, whereas the reflections of the textured plates mimic those of uneven ground.

The bats' behaviour during drinking attempts on the smooth plates and when drinking from the real water was identical (compare Fig. 5a with 5b and Supplementary Movies 1 with 2), which shows that the bats indeed tried to drink from the plates. *M. schreibersii*, the most persistent species, performed an average of 104±15 (mean±s.e.m.) drinking attempts on the smooth metal plate in two 5-min trials (Fig. 5c), whereas the other three species reached values of 95±20 (*M. daubentonii*), 47±15 (*M. myotis*) and 43±11 (*R. ferrumequinum*) attempts (analysis of variance, $F_{1,3}=4.23$, $P=0.0182$). The material of the plates had no effect on the number of drinking attempts in *M. schreibersii* (repeated measures analysis of variance, $F_{2,10}=0.01$, $P=0.9886$, Fig. 5c) and *M. daubentonii* ($F_{2,10}=1.06$, $P=0.3838$, Fig. 5d). By contrast, material type did affect the number of drinking attempts in *M. myotis* ($F_{2,10}=4.57$, $P=0.0389$, Fig. 5e) and *R. ferrumequinum* ($F_{2,10}=4.52$, $P=0.0399$, Fig. 5f). This was driven by a lower response to the wooden plate as compared with metal and plastic.

Robustness to conflicting information. On rare occasions, bats even resumed their drinking attempts after having accidentally landed on the smooth plate shortly before, whereby they should have perceived that it is not a water body. To further explore the behavioural response of *M. schreibersii* to an acoustically simulated water surface in a physically unrealistic situation, we placed the metal plate on a table (Supplementary Fig. S1). We were interested to see whether water recognition triggered by the acoustic mirror was imperative enough to override the generated conflict, namely, being able to echolocate underneath a perceived water surface. Some even flew underneath the tabletop. Nevertheless, they repeatedly tried to drink from the metal plate (43±9 attempts in 10 min, $n=6$ bats), suggesting that water-like echoacoustic cues take dominance over any other conflicting information.

In a next step, we evaluated the role of conflicting sensory stimuli with another set of Schreiber's bats. We assume conflicting sensory information in the domains of vision, chemoreception and touch, as a metal plate does not look, smell, taste or feel like real water. We repeated the initially described experiment with two metal plates on the ground, but this time eliminating potentially conflicting visual input by conducting it in complete darkness. Indeed, the number of drinking attempts rose from the previously recorded 104 attempts under red light conditions to 166 in darkness (*t*-test, $t_{10}=2.48$, $P=0.0325$), whereas the number of drinking events with real water did not differ between the two illumination treatments ($t_{10}=1.25$, $P=0.2408$) (Fig. 6a).

Innate response of juvenile bats. Bats are able to efficiently learn from conspecifics[20], but they typically roam and forage alone[21,22]. We thus hypothesized that echoacoustic recognition of water surfaces would most likely be innate. To test this hypothesis, we raised six juvenile Geoffroy's bats (*M. emarginatus*) at our field station together with their mothers. They were captured in a cave before they became volant and hence had never encountered a pond or river in their life.

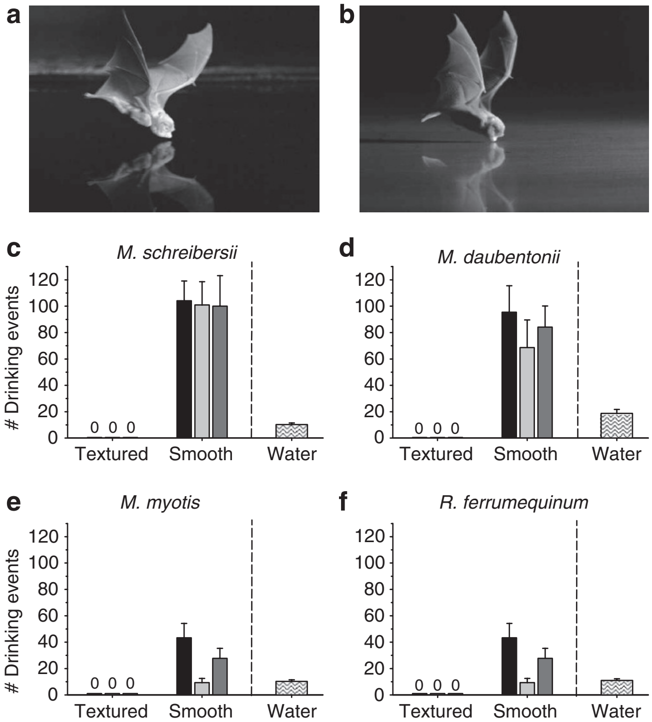

Figure 5 | Drinking attempts on textured versus smooth surfaces for the four tested bat species. The top panels show a *M. schreibersii* drinking from real water (**a**) and attempting to drink from a metal plate (**b**). All bats were tested (each species $n=6$) on all three plate materials: metal (black bars), wood (light grey bars) and plastic (dark grey bars). The textured plates are portrayed on the left and marked with a '0', as no drinking attempts occurred. All smooth plates are grouped on the right side. For each species the average drinking events on real water are depicted on the far right. Drinking attempts of (**c**) *M. schreibersii*, (**d**) *M. daubentonii*, (**e**) *M. myotis* and (**f**) *R. ferrumequinum*. Error bars show one standard error, for statistics see text.

Table 1 | Drinking attempts of additional bat species.

Species (one individual each)	Smooth plate	Textured plate	Water
M. emarginatus	66	0	5
M. nattereri	144	0	9
M. capaccinii	13	0	0
M. blythii oxygnathus	26	0	2
M. bechsteinii	94	0	0
M. aurascens	163	0	9
H. savii	8	0	0
P. austriacus	125	0	9
N. noctula	1	0	0
P. pipistrellus	64	0	10
R. mehelyi	56	0	47

All attempts to drink from the metal plates and average drinking events on real water are listed.

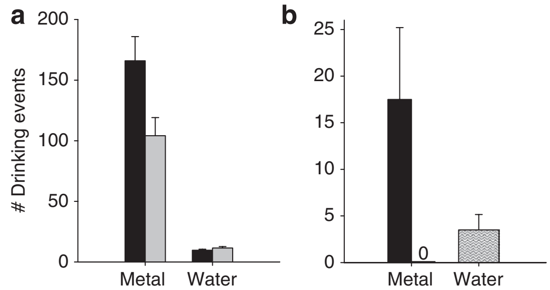

Figure 6 | Sensory conflict and innate water recognition. In further experiments we examined the role of conflicting information and an innate basis of water recognition. Error bars show one standard error, for statistics see text. (**a**) Drinking attempts of Schreiber's bat, *M. schreibersii* ($n=6$) on a smooth metal plate in different light conditions. No attempts occurred on the simultaneously present textured plate (data not shown). The bats tried to drink significantly more often in complete darkness (black bars) compared with the dim light condition (light grey bars). The drinking numbers on real water did not differ between the two treatments. (**b**) Drinking attempts of naive, juvenile Geoffroy's bats, *M. emarginatus* ($n=6$), from metal plates (black bars). Not a single attempt occurred on the textured plate, thus marked with a '0'. On the right the number of drinking events on real water is shown.

As soon as they flew well, these naive bats were tested with the metal plate setup. Five of the six juveniles, on this first contact in their life with an extended, horizontal smooth surface, spontaneously tried to drink from the smooth metal plate (18±8 times; Fig. 6b), but never from the textured plate (Fisher's combined probability test, $P<0.0001$, $n=6$ bats). The juvenile drinking attempts very much resembled those observed in the adults. The one juvenile bat that did not attempt to drink from the metal plate also did not drink from the subsequently presented real water and thus probably lacked sufficient motivation.

Discussion

The behavioural data corroborate our hypothesis that bats rely on the mirror-like echo reflection properties of smooth water surfaces to detect and recognize water bodies. It is astonishing that all individuals attempted to drink repeatedly, some even 100 times and more, from the plates with the water-like echo signature, despite conflicting information from other sensory modalities, such as touch, taste, olfaction and vision. This suggests that bats rely heavily on echolocation for assessment of their environment at close range and for the recognition of habitat elements. The observation that all 15 species, representative for three large and phylogenetically distant bat families, very reproducibly showed drinking attempts on large smooth plates furthermore suggests that echoacoustic water recognition is taxonomically wide spread, if not universal, among echolocating bats.

The high number of consecutive drinking attempts that the bats showed within a short time, despite being unsuccessful, indicates a hardwired neural processing of echoacoustic water recognition. However, the fact that two species showed fewer attempts on the wooden than on the metal and plastic plates indicates that other modalities also had some inferior role. Possibly, the light wooden plates were visually most dissimilar from water or had the most distinct non-water smell, and the conflicting information of these modalities lowered the bats' behavioural response. By conducting the experiment with *M. schreibersii* again in complete darkness, we removed the conflicting visual information and thereby altered the sensory scenery. We observed an increase of drinking attempts by almost 60% in complete darkness. As the drinking events on real water after the experiment stayed on the same level as before, this is not the result of a potential side effect due to increased drinking motivation. Our experiments suggest that the bats integrate information from several modalities to form a percept of their environment[23] and to inform their behavioural decisions. However, cue importance in this weighted sensory integration process seems to be heavily biased towards echoacoustic information, given that the echoacoustic illusion was sufficient to make bats perceive a water surface. Merely the robustness of this percept could be slightly modulated by other sensory modalities. With respect to small-scale navigation[10] and habitat recognition, bats thus appear to be an extreme example of predominant reliance on one main sensory modality. For large-scale navigation—where echolocation has a much smaller role[10]—bats use and integrate information across modalities, such as visual and magnetoreceptive information[24]. The present extreme case of one sensory input's prevalence might be an interesting model to further increase the current understanding of multisensory integration in the vertebrate brain[25,26]. To date, many other multimodal studies—often focused on communication—found a more balanced integration of multisensory stimuli. Communicating dart-poison frogs, for example, require concurrent visual and auditory cues for cross-modal integration to elicit a behavioural response[27].

With the bats' response being so extremely stereotypical and repetitive, questions about learning arise. Do bats have to learn water recognition by following conspecifics, for example, their mother? The answer is no. By contrast, the spontaneous and repeated drinking attempts of the juvenile, naive bats strongly argue for an innate basis of the echoacoustic recognition of water bodies. Given that bats mistake large horizontal mirrors innately and persistently for water, one might hypothesize that they occasionally try to drink from man-made smooth surfaces, such as car roofs, winter gardens and the like. Future studies will be necessary to assess the occurrence, extent and potential conservation relevance of such a scenario.

Certainly, bats also need to recognize other specific foraging habitats to which the respective species are adapted in, for example, wing morphology, echolocation system and food requirements[10,28–30]. Computers can classify tree species on the basis of echo statistics[31]—so bats may as well. Bats can distinguish the roughness of computer-generated echoes[32]; an ability that might help them classifying complex vegetation echoes. From a technical perspective, a detailed understanding of how bats echolocate and recognize spatially extended objects and habitat types will further the development of sonar-based autonomous robots.

In summary, our experiments revealed that the recognition of water bodies in bats is mediated by echoacoustic cues (mirror-like reflection). This recognition mechanism is taxonomically wide spread among bats, and our experiments strongly suggest it is innate. To our knowledge, this is the first example of innate recognition of a habitat cue in mammals. The innateness and the physically well-defined cues make water recognition in bats an ideal model to study the neural basis and potentially even the genetic correlates of habitat recognition.

Methods

Bats. This study was conducted at the Tabachka Bat Research Station of the Sensory Ecology Group (Max Planck Institute for Ornithology, Seewiesen), which is run in cooperation with the Directorate of the Rusenski Lom Nature Park in the district of Ruse, northern Bulgaria. Capture, husbandry and behavioural studies were carried out under license of the responsible Bulgarian authorities (Bulgarian Ministry of Environment and Water and Regional Inspectorate (RIOSV) Ruse, permits # 57/18.04.2006 and 100/04.07.2007). Bats were captured in the area of the Rusenski Lom Nature Park at or close to their roost caves by a handnet, mistnets or harp trap. For the duration of the experiment, bats were kept in a separate keeping room (temperature 18–24 °C, humidity around 75%; close to natural conditions in the caves, own data). Depending on the species, they were accommodated in either a 2.2×0.9×1.1 m mesh tent or 50×35×35 cm cages. On the capture night, bats were handfed with mealworms and watered until satiated. The experiment was usually started on the following night. All bats were released again at their respective capture site after completion of the experiment.

Four species of bat were used for the full set of the experiments with all three plate materials (metal, plastic and wood): *M. schreibersii*, *M. daubentonii*, *M. myotis* and *R. ferrumequinum*. Six adult individuals per species were tested in a balanced sex ratio. To test for the generality and the extent of the taxonomic spread of our findings, 1 individual each from 11 additional bat species was tested with the metal plate setting (see below). This group consisted of *Myotis emarginatus*, *M. nattereri*, *M. capaccinii*, *M. blythii oxygnathus*, *M. bechsteinii*, *M. aurascens*, *Hypsugo savii*, *Plecotus austriacus*, *Nyctalus noctula*, *Pipistrellus pipistrellus* and *Rhinolophus mehelyi*.

Six females of the Geoffroy's bat (*M. emarginatus*) were captured inside a cave with their young shortly before those became volant. Mothers were kept with the juveniles and nursed them until natural weaning. When released together into their home cave after completion of experiments, the juveniles were able to fly and forage independently.

Six additional adult *M. schreibersii* were used to test their drinking response in complete darkness (dark condition).

Flight room and experimental setup. All experiments were conducted in a large flight room (4×8×2.4 m). The floor was covered with sand, and the walls and ceiling with a felt-like, sound-dampening material ('Velter', thickness 5 mm, Arbanasy EOOD). The room was lit with two red bulbs (25 W, Osram), except for the dark condition (see below), where custom-made infrared strobe lights (Animal Physiology Department, University of Tübingen, Germany; 875 nm wavelength) were used.

In the centre of the room, a water pool was inserted into the sandy floor (1.8×1 m, 4 cm water depths) (Supplementary Fig. S1). The pool could be covered by a plate and sand, or uncovered to give the bats access to real water. To test our hypothesis that the bats would take any extended, acoustically smooth horizontal surface for water, we presented experimental plates (1.2×2 m) on the flight room floor. Always two plates of the same material but with different surface structure (one smooth, one textured) were presented side by side in the centre of the flight room (25 cm distance between plates; pool covered) (Supplementary Fig. S1). We used three different materials for the experimental plates: metal (aluminium), plastic (polyvinyl chloride) and wood (medium-density fibreboard). For the textured surfaces, we chose a metal diamond plate with 35×5 mm (~2 mm height) bumps at 4 cm spacing, while we carved depressions of the same size and spacing into the plastic and wooden plates (see Fig. 3).

The bats' behaviour was filmed with four synchronized video cameras (Watec, WAT-902H2 Ultimate; two for overview, two for close-up at the two experimental plates on the ground) for online observation from an adjacent room and for later off-line analysis (ABUS Security Center; Digi-Protect Video Surveillance PCI Card, 4 channel/100 fps). In addition, a high-speed camera (Mikrotron MotionBLITZ EoSens mini) was used for detailed comparison of drinking behaviour from real water with attempts to drink from the smooth experimental plates.

Experimental procedure. Experiments were conducted at night during the natural activity phase of the bats. The night before the experiment, bats were fed and watered until satisfied. They had access to food and water *ad libitum* for the rest of the pre-experimental night. Water was taken away in the morning to prevent drinking during the day and early evening. We thereby mimicked natural conditions and thirst levels of bats emerging from their day roosts at dusk.

Before each experiment, the bat was fed three to five mealworms. It was then released into the flight room where a smooth and a textured experimental plate were presented. If a bat did not fly and explore the flight room within 1 h, it was excluded from the experiment (total of 19 bats). All other bats attempted to drink from the plates within 1 h. With the first attempt a 5-min time window (time in flight) opened, during which the drinking attempts were counted in later off-line video analysis. We defined a drinking attempt as the bat touching the plate in a head-down position, which corresponds to drinking behaviour from a real water surface (compare Supplementary Movies 1 and 2). After these 5 min, the plate positions were exchanged. Again, the bat was given 1 h, and when it resumed drinking attempts, a second 5-min time window began, during which attempts were counted. With completion of this time slot, the plates were removed from the room and the water pool was uncovered. This was performed to assess whether the bat was indeed motivated to drink. It was given one final hour, with a 10-min time window starting as soon as the bat began to drink. All drinking events were counted. During all these trials the bat was free to fly around and explore the room. However, when a bat hung without moving longer than about 3 min, the experimenter went inside to gently stimulate flight by, for example, tapping on the wall. This was performed to prevent the bat from falling asleep.

After the experiment, the bat was fed and watered until satisfied, and then returned to its keeping cage. In the two consecutive nights, the experiment was repeated with the remaining two substrate types. To factor out effects of presentation sequence, the three plate materials (metal, plastic and wood) were assigned to nights and bats following a Latin square design.

To test for the persistence of the bats' drinking response in a physically unrealistic situation for a pond or river, the metal plate was placed on a standard plastic garden table (1.5×1 m, 1 m height) in a way that the bats could assess the open airspace below the tabletop by echolocation and fly underneath (Supplementary Fig. S1).

The *M. emarginatus* juveniles received regular flight training in the empty flight room to ensure natural development of flight abilities. Once fully volant, they were tested individually in the metal plate setup as described above for the adult bats.

Also the test of the six additional adult *M. schreibersii* in the dark condition (metal plates only) followed all experimental details as previously described, with the exception that infrared light was used instead of dim red light (see above).

Data analysis. Statistical analyses were run in SPSS 15.0 and Excel 2003. Because all tested bats showed zero drinking attempts for all of the textured plates, we refrained from using parametric tests for an assessment of surface structure on the bats' behaviour. Instead, we computed separate χ^2-tests to compare the number of drinking attempts for the smooth versus the textured plates for each bat and plate material. From these, we calculated combined *P*-values using Fisher's combined probability test.

Ensonification. For qualitative evaluation of the echo scenes reflected back by the experimental plates, by real water and a sand surface, we ensonified these surfaces with an artificial echolocation call created in Adobe Audition, sweeping from 120 down to 20 kHz with 3 ms duration (results given in Fig. 4). This artificial call encompasses the main frequency range used by all tested bat species. The call was played by a Polaroid loudspeaker and amplifier (custom-made, University of Tübingen, Germany), which was connected through a PCMCIA card (DAQ Card 6062E, National Instruments) with a computer running Avisoft (Avisoft Bioacoustics) software. Returning echoes were recorded by an Avisoft microphone (Type CM16/CMPA, Avisoft Bioacoustics) by an ultrasound recording interface (UltraSoundGate 416H, Avisoft Bioacoustics) and using Avisoft recording software (Avisoft Recorder USGH) with 500 kHz sampling rate. Speaker and microphone on top were mounted in parallel 62 cm above the ensonified surface and tilted downwards in a way that the speaker's acoustic axis intersected with the surface at an angle of 50°.

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Author contributions

S.G. and B.M.S. designed the study, analysed data and wrote the paper. S.G. performed the experiments.

Additional information

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SENSORY TRAPS

Acoustic mirrors as sensory traps for bats

Stefan Greif,[1,2]*† Sándor Zsebők,[1]†‡ Daniela Schmieder,[1]§ Björn M. Siemers[1]

Sensory traps pose a considerable and often fatal risk for animals, leading them to misinterpret their environment. Bats predominantly rely on their echolocation system to forage, orientate, and navigate. We found that bats can mistake smooth, vertical surfaces as clear flight paths, repeatedly colliding with them, likely as a result of their acoustic mirror properties. The probability of collision is influenced by the number of echolocation calls and by the amount of time spent in front of the surface. The echolocation call analysis corroborates that bats perceive smooth, vertical surfaces as open flyways. Reporting on occurrences with different species in the wild, we argue that it is necessary to more closely monitor potentially dangerous locations with acoustic mirror properties (such as glass fronts) to assess the true frequency of fatalities around these sensory traps.

Anthropogenic changes to the environment, such as habitat alteration or interference with food resources, are often evidently detrimental to wild animals. Furthermore, ecologically novel cues are capable of misleading animals into responding maladaptively to formerly reliable environmental cues (*1*–*4*). Well-known examples are artificial light sources attracting insects and birds at night (*5*) or smooth human-made surfaces that aquatic insects mistake for bodies of water because of similar light polarization patterns (*6*). To find, evaluate, and mitigate such sensory traps requires consideration of the sensory ecology of a particular animal (*7*, *8*). The primary sensory modality for most bats is their echolocation system (*9*, *10*). Bats use the returning echoes of emitted calls to detect, classify, and localize objects in their environment (*11*–*13*).

In a previous study, we showed that bats perceive any extended, smooth, horizontal surface as a water body, resulting in drinking attempts. This is attributable to the acoustic mirror properties of smooth surfaces, which reflect calls away from the bat except for a strong perpendicular echo from below (*9*) (Fig. 1A). Several observations of bats colliding with smooth vertical surfaces (such as glass windows) suggest that bats have problems recognizing them (*14*–*16*). This raises concerns about the millions of artificial vertical smooth surfaces introduced in bat habitats and their hazard potential for injuries. We predicted that these collisions are based on the acoustic mirror paradigm and investigated the underlying sensory mechanism and possible occurrence in natural settings.

For our flight room experiments, we flew greater mouse-eared bats (*Myotis myotis*) in a continuous, rectangular flight tunnel (height 2.3 m, width 1.2 m) in the dark. A smooth metal plate (1.2 m × 2.0 m) was placed 1.2 m away from a corner of the felt-covered tunnel, either horizontally on the ground or vertically on the wall. The bats' flight behavior was recorded with two high-speed cameras (100 fps) and their echolocation calls with an ultrasound microphone (Fig. 1B) (*17*). Eleven bats were presented with the horizontal plate on the first night and the vertical plate on the second night. The order was reversed for 10 other bats. A trial lasted between 5 and 15 min with, on average, 20 passes by the plate. We counted drinking attempts as well as collisions with the plate, the ground, and the normal wall. Of 21 individuals, 19 collided with the vertical plate at least once (on average 22.8% of passes) but never with the horizontal plate (Wilcoxon matched-pair test, $P < 0.001$) nor any other parts of the wall. Thirteen individuals made at least one drinking attempt from the horizontal plate (on average 13.0% of passes), but none from the vertical plate (Wilcoxon matched-pair test, $P = 0.002$) (Fig. 2). After the experiments, all bats were carefully examined and no injuries were found.

To understand the sensory basis of those collisions with the vertical plate, we conducted analysis of the flight and echolocation behavior in the space immediately in front of the plate ("plate zone," limited by the plate's perpendicular projection; Fig. 1B) for 25 bats when flying toward the vertical plate. On the basis of our high-speed recordings, we categorized the approach events into three groups: (i) "near collision," where bats approached to within 25 cm of the plate (body-to-plate distance) but did not touch it; (ii) "collision with maneuver," where bats collided with the plate despite clear evasive maneuvers at the last moment; and (iii) "collision without maneuver," where bats collided without any noticeable evasive action. We measured the time and counted echolocation calls from entering the plate zone until reaching the closest point to the plate (either collision or turning point). We further calculated the bat's flight speed, the three-dimensional angle between its flight trajectory and the plate, and its distance to the plate when it entered the plate zone. The 78 events of approaching the plate (3.1 ± 1.8 events per individual, mean ± SD) consisted of 25 "near collision" events, 13 "collision with maneuver" events, and 40 "collision without maneuver" events (movie S1). We found that for "collision without maneuver" approaches, bats produced fewer calls, spent less time in front

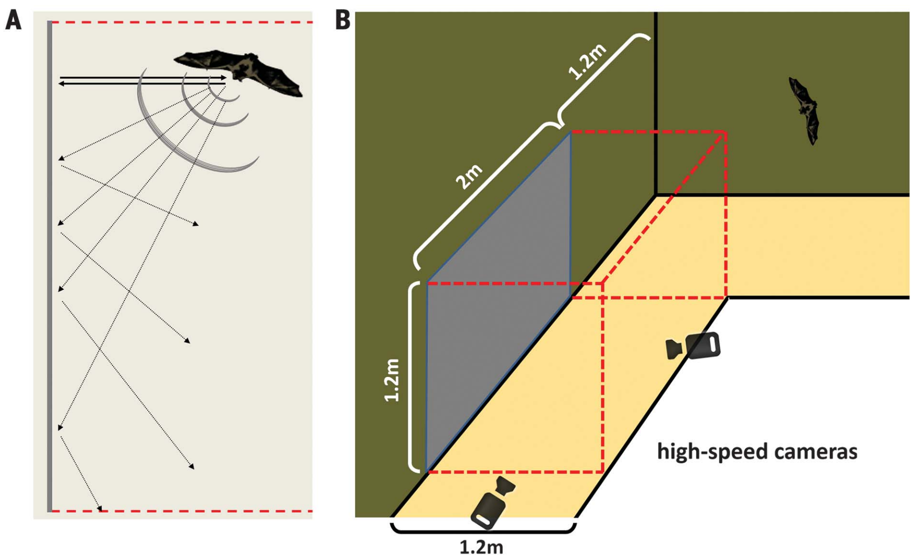

Fig. 1. Experimental setup. (**A**) Schematic of sound propagation at a smooth, vertical surface (top view). For a bat within the red-dashed "plate zone," sound impinging at an oblique angle is reflected away while only the perpendicularly impinging sound is reflected back. (**B**) Flight tunnel setup depicting the vertical situation. The smooth metal plate is shown in gray on the wall; the dashed lines represent the plate zone. In the horizontal situation, the smooth plate was lying on the floor of the plate zone (fig. S1).

[1]Sensory Ecology Group, Max Planck Institute for Ornithology, 82319 Seewiesen, Germany. [2]Department of Zoology, Tel Aviv University, Tel Aviv 6997801, Israel.
*Corresponding author. Email: stefan.greif@gmail.com
†These authors contributed equally to this work.
‡Present address: Behaviour Ecology Research Group, Eötvös Loránd University, H-1117 Budapest, Hungary.
§Present address: Institute of Ecology and Evolution, University of Bern, 3012 Bern, Switzerland.

of the plate, approached the plate at a more acute angle, entered the plate zone closer to the plate, and had higher flight speeds relative to the "near collision" situation (Fig. 3 and table S1). Values of the "collision with maneuver" approaches ranged between those of the other two categories and were generally closer to those of "collision without maneuver."

Bats adapt their echolocation system to varying situations, thus revealing their perception of the environment. We compared the echolocation calls of colliding bats (32 sequences of 19 individuals) with a control situation of flying past a normal wall (15 sequences of 10 individuals) (*17*). We found that during approach to the plate, the bats emitted significantly shorter calls, decreased their pulse interval, and lowered their end frequency (Fig. 4 and table S2).

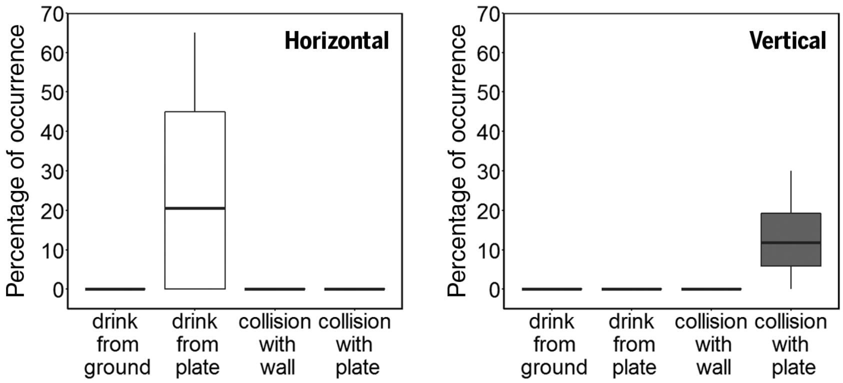

Fig. 2. Percentage of drinking attempts and collision events. Values were calculated per individual relative to its total number of passes in the horizontal versus vertical setup (median, interquartiles, and range; *N* = 21 bats).

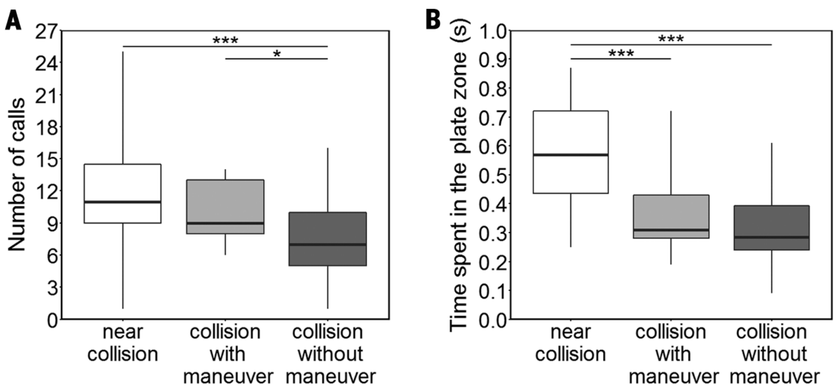

Fig. 3. Number of calls and time spent in the plate zone for the three approach categories. (**A**) Number of calls; (**B**) time spent in plate zone. Events are categorized as "near collision" (white, *N* = 25), "collision with maneuver" (light gray, *N* = 13), and "collision without maneuver" (dark gray, *N* = 40) (median, interquartiles, and range; *N* = number of events). $^*P < 0.05$, $^{***}P < 0.001$.

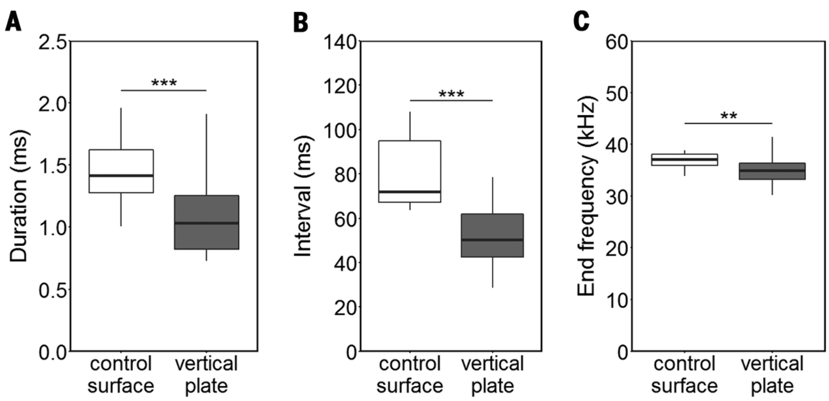

Fig. 4. Echolocation call parameters when approaching the vertical plate and a control surface. (**A** to **C**) Comparison for call duration (A), pulse interval (B), and call end frequency (C) (median, interquartiles, and range). $^{**}P < 0.01$, $^{***}P < 0.001$.

To investigate our findings' generality, we studied the effect of smooth, vertical surfaces on the flight behavior of different bat species in the field, conducting experiments near three bat colonies for one night each (*17*). After all individuals had left the colony, we placed one or two smooth, black, flexible plastic plates (2 m × 1 m, or 2 m × 2 m combined) vertically 1 to 3 m from the colony entrance (either perpendicular or parallel to the roost, but never in the actual flight path). We observed returning bats for 4 hours with an infrared camera while presenting the plate uncovered (i.e., smooth) or covered with a rough, ribbed plastic mat or branches (alternated in 15-min intervals). We counted 12, 1, and 10 collisions, respectively, at the three colonies when presenting the smooth plate, but none with the covered plate (movie S2).

Our results demonstrate that bats repeatedly collide with smooth, vertical surfaces both in the laboratory and in natural habitats. This is likely attributable to the acoustic mirror properties of smooth surfaces, where echolocation calls are being reflected away from the bat and no echoes return from the position of the plate while the bat is still outside the plate zone (*9*). Rough surfaces, on the other hand, produce clear echoes, which is why bats collided only with the smooth surface.

However, bats can exhibit a behavioral avoidance reaction when on a collision course. This can be explained by the second acoustic characteristic of a smooth surface: As soon as a bat enters the plate zone, any part of the calls reaching the plate perpendicularly will be reflected back to the bat more strongly than before (Fig. 1A and movie S3), whereas the perpendicular echo should disappear if there were a real open space. Our interpretation is further supported by an increased collision avoidance when bats approached the vertical plate at greater angles. The approach angle influences the echo strength: At smaller, more acute angles, the perpendicular echo strength is likely decreased as a result of the directionality of the bat's echolocation beam. Here, most of the call energy is aimed to the front of the bat and rapidly drops toward the side (*18*, *19*). But most important, the behavioral analyses showed that bats were more likely to avoid collisions when emitting higher numbers of calls. This complies with a bat's strategy to increase call rate when in need of more information (*12*, *13*). Also, slower flight speed and a greater entrance distance to the plate increased time in the plate zone and thus the chance to detect and avoid the plate.

The bats' echolocation behavior suggests that they did not approach the vertical smooth surface to land on or catch an object (*12*, *20*). In that case, they would decrease their pulse interval and lower their end frequency even more than we saw in our bats (see table S2). Because the plate does not reflect any echoes toward the bat until the bat is next to it, we suggest that they considered it to be an opening in the wall and intended to escape the room through this apparent, constrained flyway (*21*, *22*).

In the horizontal setup, bats never collided with but carefully approached the surface to drink. Thus, they demonstrate an orientation-dependent interpretation of their ensonified environment as the direction of the same cue (the lack of echo from an area ahead) elicits a different behavior. The change in amplitude of the perpendicular echo from a rough to a smooth surface might further give bats an orientational cue (movie S3). If the perpendicular echo is perceived from below in combination with otherwise missing echoes, bats interpret this as a water surface and can use it as a height estimator (*9*, *23*). Coming from the side, it warns them of an approaching obstacle in what they have until now construed as a clear flight path, if they have had enough time to process it. Bats have been found to fly against smooth surfaces in the lab and the field (*14*–*16*), but these observations were interpreted with a focus on visual influence and failed to explain the underlying sensory mechanism [however, see (*16*), pp. 51–52]. Furthermore, bats have been found dead and injured next to human-made structures such as the glass facades of a convention center or towers (*17*, *24*–*26*).

We now understand that smooth, vertical surfaces demonstrate a possible acoustic sensory trap for bats. Although none of our bats was hurt, an often higher flight speed in natural settings might lead to serious injuries such as concussions, broken wings, or broken jaws. Injured bats are often only accounted for as a by-product of investigations on avian mortality and furthermore might crawl away or fall prey to predators (*27*), thus concealing and underestimating the actual numbers of fatalities. For a better understanding of the actual impact on bats, increased monitoring and systematic recording of collisions at vertical mirror situations (such as big glass surfaces) are required. Moreover, smooth, vertical surfaces should be avoided at crucial sites such as "migratory highways," key foraging habitats, or bat colonies. And finally, mitigation efforts such as ultrasonic bat deterrents could be tested around selected human structures. Only if we identify and evaluate the real extent of collisions with acoustic mirrors can we avoid or mitigate potential detrimental effects on bat populations.

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/357/6355/1045/suppl/DC1
Materials and Methods
Supplementary Text
Figs. S1 to S3
Tables S1 and S2
Movies S1 to S3
References (*28*–*32*)

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Science

Acoustic mirrors as sensory traps for bats

Stefan Greif, Sándor Zsebok, Daniela Schmieder and Björn M. Siemers

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Building-blind bats

Human-generated structures now dominate much of the planet, but they have existed for but a blink of an eye from an evolutionary perspective. Animal sensory systems evolved to navigate natural environments and so may not always be reliable in anthropogenic ones. Greif *et al.* show that echolocating bats appear to perceive smooth vertical surfaces as open areas, a mistake that often leads to collisions (see the Perspective by Stilz). With millions upon millions of smooth vertical surfaces in our world today, such misperceptions could have considerable negative impacts on bat survival.

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Carpe noctem: The importance of bats as bioindicators

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4 authors, including:

[redacted]

Gareth Jones
University of Bristol

Paul A Racey
University of Exeter

[redacted]

David Steve Jacobs
University of Cape Town

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Contribution to the Theme Section 'Bats: status, threats and conservation successes'

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REVIEW

Carpe noctem: the importance of bats as bioindicators

Gareth Jones[1,*], David S. Jacobs[2], Thomas H. Kunz[3], Michael R. Willig[4], Paul A. Racey[5]

[1]School of Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, UK
[2]Zoology Department, University of Cape Town, Rondesbosch 7701, Cape Town, South Africa
[3]Center for Ecology and Conservation Biology, Department of Biology, Boston University, Boston, Massachusetts 02215, USA
[4]Center for Environmental Sciences and Engineering and Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, Connecticut 06269-4210, USA
[5]School of Biological Sciences, University of Aberdeen, Tillydrone Avenue, Aberdeen AB24 2TN, UK

ABSTRACT: The earth is now subject to climate change and habitat deterioration on unprecedented scales. Monitoring climate change and habitat loss alone is insufficient if we are to understand the effects of these factors on complex biological communities. It is therefore important to identify bioindicator taxa that show measurable responses to climate change and habitat loss and that reflect wider-scale impacts on the biota of interest. We argue that bats have enormous potential as bioindicators: they show taxonomic stability, trends in their populations can be monitored, short- and long-term effects on populations can be measured and they are distributed widely around the globe. Because insectivorous bats occupy high trophic levels, they are sensitive to accumulations of pesticides and other toxins, and changes in their abundance may reflect changes in populations of arthropod prey species. Bats provide several ecosystem services, and hence reflect the status of the plant populations on which they feed and pollinate as well as the productivity of insect communities. Bat populations are affected by a wide range of stressors that affect many other taxa. In particular, changes in bat numbers or activity can be related to climate change (including extremes of drought, heat, cold and precipitation, cyclones and sea level rise), deterioration of water quality, agricultural intensification, loss and fragmentation of forests, fatalities at wind turbines, disease, pesticide use and overhunting. There is an urgent need to implement a global network for monitoring bat populations so their role as bioindicators can be used to its full potential.

KEY WORDS: Chiroptera · Indicator species · Environmental stressors

INTRODUCTION

On a global scale, the structure and functionality of ecosystems are changing at an unprecedented rate (NRC 2001, 2003, Soares-Filho et al. 2006), primarily as a consequence of human activities associated with the provisioning of food and fibre, or the emission of greenhouse gases and use of carbon-based resources for energy production (Vitousek et al. 1997, Tilman et al. 2001, Hooper et al. 2005). Indeed, as human populations continue to expand in size and become increasingly urban in nature, such environmental problems promise to become even more exacerbated (Pimm et al. 1995, Thomas et al. 2004, Soares-Filho et al. 2006, Kareiva et al. 2007). At the same time, the magnitude of change around the globe is quite variable, as is the nature of the human activities that alter and fragment landscapes (Sala et al. 2000).

From the perspective of biota, 2 distinctly different kinds of global change are critical to understand and monitor. The first involves alteration of conditions associated with global climate change (Hughes 2000, Walther et al. 2002, Parmesan & Yohe 2003, Rosenzweig et al. 2007). This manifests as altered regional patterns of precipitation and temperature, including disturbance regimes (e.g. frequency and intensity of

*Email: gareth.jones@bristol.ac.uk

tropical storms or drought). The second involves conversion of natural habitats to those managed to directly or indirectly support humans, such as forestry, agriculture, industry and urbanization (Vitousek et al. 1997, Foley et al. 2005). Conversion ultimately reduces the extent and increases the fragmentation of natural habitats (Turner et al. 2001, Fahrig 2003). Taken together, global climate change and habitat conversion may threaten the long-term persistence of many species of plants and animals, alter distributional patterns at global and regional levels and result in local assemblages of species that are quite different from those that currently constitute coevolved communities (Wilcox & Murphy 1985, Chapin et al. 2000, McCarty 2001, Walther et al. 2002, Parmesan 2006).

Monitoring global climatic change and habitat conversion is not sufficient for understanding or managing the consequences of human activity on biological systems. Biological systems are geographically variable, inherently complex and comprise a multitude of interacting species. They likely respond in non-linear and scale-dependent fashions to aspects of global change, and may do so in idiosyncratic manners associated with the unique assemblages of species that they comprise (Levin 1992, Allen & Hoekstra 1993, With & Crist 1995). Thus, a broad-scale network of monitoring that captures local, regional and global components of the earth's biota is critical for understanding and forecasting responses to climate change and habitat conversion, as well as managing natural resources in a long-term, sustainable fashion.

In this paper we argue that bats are ideal indicators of human-induced climate change and habitat quality (Fig. 1). (1) We discuss features that define good bioindicator taxa. (2) We review characteristics of bats that make them ideally suited as bioindicators. (3) We present case studies where bats have been used successfully as bioindicators. We identify some of the major sources of environmental stress to which bats are subjected, and argue that some of the major stressors that have an impact on biodiversity in general also have major impacts on bat populations, emphasising their potential suitability as bioindicators. We conclude by identifying the need for implementation of large-scale monitoring schemes using bats as bioindicators.

INDICATOR TAXA FOR ECOLOGICAL MONITORING AND BATS AS BIOINDICATORS

Types of bioindicators

It is important to recognise the distinction between biodiversity, ecological and environmental indicators. Biodiversity indicators capture responses of a range of taxa and reflect components of biological diversity such as species richness and species diversity. Ecological indicators consist of taxa or assemblages that are sensitive to identified environmental stress factors that demonstrate the effect of those stress factors on biota, and whose responses reflect responses of at least a subset of other taxa present in the habitat. Environmental indicators respond in predictable ways to specific environmental disturbances (McGeoch 1998). Ideal biodiversity indicators may not exist because taxa often respond to environmental stressors in different ways. Nevertheless, indicators that represent responses over a range of trophic levels (e.g. insectivores and insect prey, pollinators and pollinated plants) can represent the effects of environmental degradation on specific ecological processes, and bats can thus have important roles as ecological indicators. Bats can also be important environmental indicators because they are sensitive to a wide range of environmental stresses to which they respond in predictable ways (Fig. 1). Additionally, the wide range of food sources exploited by bats allows them to be used as indicators for a wide range of environmental stressors.

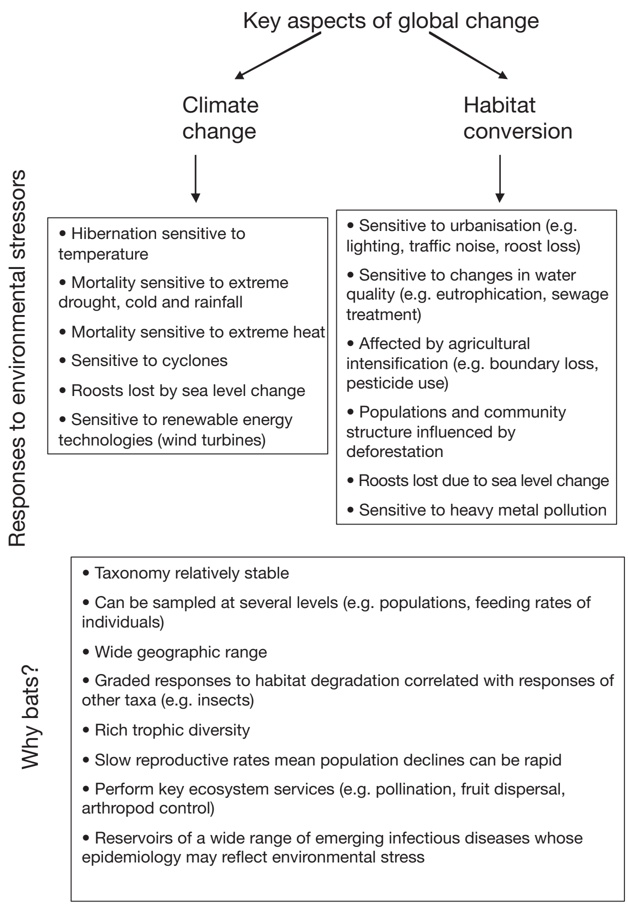

Fig. 1. Schematic outline of reasons for bats' excellent potential as bioindicators

Monitoring natural populations can have a variety of goals and the decision on which group of species to use as indicators must be influenced by the goals of the monitoring programme (McGeoch 1998, Caro & O'Doherty 1999, Moreno et al. 2007). Monitoring ecosystem health, for example, to identify the nature or source of pollution would require a different set of indicator species (environmental indicators) to those for monitoring the effects of habitat loss on patterns of species richness (biodiversity indicators) or on ecological processes (ecological indicators) (McGeoch 1998). Thus, before a monitoring programme begins and indicator species are selected, the goals and scale of the programme must be clearly formulated (McGeoch 1998, Caro & O'Doherty 1999, Moreno et al. 2007).

Biodiversity indicator species have characteristics that can be used as an index of attributes (e.g. presence/absence, population density and relative abundance) of other species comprising the biota of interest (Landres et al. 1988). Biodiversity indicator taxa are thus surrogates for an entire biota in which species richness or the lack of human resources (e.g. time, money and trained personnel) preclude monitoring the fate of all taxa (Moreno et al. 2007) as a means of monitoring human-induced environmental degradation. If indicator taxa are to be suitable surrogates for a diverse array of taxa, they should possess a suite of characteristics that are rarely found in any single species (Spector & Forsyth 1998). Thus, a small number of indicator species are often used as surrogates (Caro & O'Doherty 1999). These species collectively must have characteristics that make them easy to identify (stable taxonomy), be easy to sample, be widely distributed geographically, show graded responses to habitat degradation and these responses should be correlated with the responses of other taxa (Spector & Forsyth 1998, Moreno et al. 2007). They also represent the biota of interest as well as the variety of functional groups comprising it. Their natural history should be well-known so that the broader implications of changes in their abundance, and the significance of their correlations with other taxa or environmental variables, could be used to evaluate the status of the entire community (Moreno et al. 2007).

Characteristics of bioindicator taxa

Indicator species should have sufficient taxonomic stability (low rate of species invalidation through synonymy) to permit their accurate and consistent identification (Pearson & Cassola 1992). The tools and personnel associated with such identification (e.g. identification keys and taxonomists) must be reliable and readily available. It is essential that a significant portion of the population of an indicator species can be sampled quickly and, with reasonable effort, on a regular basis. Such sampling must yield relative or absolute abundance data so that a profile of the species assemblages can be compared (Spector & Forsyth 1998); presence/absence data will not provide information on the shifts in relative abundance necessary for monitoring environmental change (Spector & Forsyth 1998). It is also important that assemblage composition can be easily characterized in terms of species as well as guilds or ensembles (e.g. those associated with foraging, dietary habits or roosting) to isolate the ecological factors causing shifts in relative abundance.

Environmental degradation can occur over a variety of scales (e.g. changes in land use such as agricultural intensification) resulting in very localized or widespread impacts. Species with highly restricted ranges may be adequate to monitor such changes and would allow the location of the source of pollution or disturbance with greater accuracy (Caro & O'Doherty 1999). However, due to the globalization of human economic activity, threats to biodiversity are increasingly acting on a global scale. Monitoring the impacts of such threats through indicator species requires that the chosen species have broad geographic ranges (Spector & Forsyth 1998). Bats, as volant taxa, fulfill this criterion better than most other taxa.

As urbanization expands into previously unoccupied landscapes, habitat loss or degradation and its monitoring become increasingly important. Indicator species should thus be sensitive to habitat loss or degradation but should show a graded response over long time-periods (Spector & Forsyth 1998). Such indicator species allow the detection of disturbance while providing an opportunity to redress its cause. A graded response would also provide insight into the severity of the disturbance. Taxa that are too sensitive and become locally extinct over a short time are unsuitable because they would not allow the detection of changes in relative abundance and, at best, monitoring would only reveal presence at some time and absence at another. Indicator taxa that are too insensitive to habitat degradation, on the other hand, would show no change, even as sensitive species go extinct or their habitats become severely degraded.

Related to a sensitive and graded response is the correlation of the response of the indicator species with responses by other species (Spector & Forsyth 1998, Moreno et al. 2007). Such a response is essential for biodiversity indicator taxa, but not for environmental indicators. Response correlations may be positive or negative, but correct interpretation is dependent on knowledge of the natural history of the species involved (Moreno et al. 2007).

Taxa used as bioindicators

Invertebrates are most commonly used as indicators (McGeoch 2007, Moreno et al. 2007). Insects are favoured as indicator taxa because they comprise a large proportion of terrestrial species richness, are often habitat specialists, are sensitive to small-scale heterogeneity (Hill 1996, Niemela et al. 1996) and play a significant role in ecosystem functions (McGeoch 2007). However, the use of insects as indicator species is not always straightforward because many species remain undescribed or are in need of taxonomic revision (Spector & Forsyth 1998). Moreover, insects can be difficult to sample quickly and efficiently. Instead, entomologists have advocated the use of subsets of certain insect taxa, such as dung beetles, based on ease of sampling and response to habitat gradients (Spector & Forsyth 1998, McGeoch et al. 2002).

Birds are useful biological indicators (Gregory et al. 2005), especially at the edges of urban areas, because they are ecologically versatile and can be monitored relatively easily and cheaply (Koskimies 1989). They are also highly mobile and therefore can respond rapidly to changes in their habitat (Fuller et al. 1995a, Louette et al. 1995). It is at the edges of urban areas, where habitat structure is often highly fragmented, that relationships between humans and bird assemblages are easiest to study (Cody 1985). Thus, birds have long been used as both environmental (e.g. Kushlan 1993, Alleva et al. 2006) and biodiversity indicators (e.g. Reynaud & Thioulouse 2000).

Why bats?

Bats are excellent indicator taxa and thus have been used as ecological indicators of habitat quality (Wickramasinghe et al. 2003, Kalcounis-Rueppell et al. 2007). Bats are also sensitive to human-induced changes to ecosystems (Fenton et al. 1992, Estrada et al. 1993, Medellín et al. 2000, Moreno & Halffter 2000, 2001, Estrada & Coates-Estrada 2001a, b, Clarke et al. 2005a,b, Hayes & Loeb 2007, Kunz et al. 2007). However, in neotropical coffee plantations bats showed modification in their guild (or ensemble) structure, but the species composition did not change with the alteration of habitat from undisturbed cloud forest to coffee plantations. Species composition of both frogs and dung beetles changed across the same habitat gradients (Pineda et al. 2005). Similarly, although bat activity was significantly different between organic and conventional farms in southern England and Wales, species composition was not (Wickramasinghe et al. 2003). Thus, caution is necessary when selecting groups of species as indicators and sampling should be conducted at the appropriate level (i.e. species versus ensemble) and with appropriate units (i.e. activity versus species richness).

Insectivorous bats occupy higher trophic levels and would be excellent indicators owing to the relationship between contaminant and/or environmental disturbance and trophic levels (Alleva et al. 2006). Dietary accumulation and metabolic capacity increases at higher positions in the food chain, and insectivorous bats are likely to show the consequences of pollutants before organisms at lower trophic levels such as herbivorous insects or birds. The slow reproductive rates of bats mean that populations take a long time to recover from declines, and although population declines take longer to detect, trends are less subject to noise that may confound patterns in short-term studies of fast reproducing taxa such as insects. Although bat populations can be monitored directly to assess long-term population changes (Walsh et al. 2001), short-term impacts on insectivorous bats can be quantified by monitoring ‘feeding buzzes’ — increases in the rate of emission of echolocation calls as bats home in on insect prey (Griffin et al. 1960).

With respect to other criteria that make groups of species suitable indicators, the taxonomy of bats is mostly stable, at least at the species level. Although the genera of some bat species have been changed (Kearney et al. 2002, Simmons 2005), relatively few species names have been altered. However, several new cryptic species have recently been discovered (Jones & Van Parijs 1993, Kingston et al. 2001, Mayer & von Helversen 2001, Kiefer et al. 2002, Kingston & Rossiter 2004, Jacobs et al. 2006) and there are likely to be more as bat research increases. However, this problem is relatively minor (compared to insects or birds with their greater diversity) and is easily circumvented by the careful choice of indicator species.

Unfortunately, few studies have tested the suitability of bats as indicator species with respect to the other criteria (e.g. correlation of bat responses to habitat disturbance with those of other species). Thus it is important to appreciate that although bats may have great potential as indicator species, other indicator taxa that exploit ecosystem services in complimentary ways should also be incorporated in monitoring programmes (e.g. Pocock & Jennings 2008). Similarly, a variety of methods have to be used to sample bats efficiently and completely (Flaquer et al. 2007, MacSwiney et al. 2008) and sampling methods involving capture can be labour-intensive and time-consuming (Hayes et al. 2009, Kunz et al. 2009a). Cost-effectiveness can be an important criterion in determining the practical feasibility of long-term surveys of potential indicator taxa (Gardner et al. 2008). Although bat surveys can involve high capital costs and intensive training, advances in acoustic technology mean that acoustic monitoring of insectivorous bat assemblages should become increasingly efficient and affordable (Parsons & Szewczak 2009). Moreover, methods for surveying many species, including frugivorous and nectar-feeding taxa, involve low-cost trapping methods such as the use of mist-nets and harp traps (Kunz et al. 2009b).

Measuring bioindicator sensitivity

Attention should also be paid to how best to assess sensitivity. Sensitivity is often measured by quantifying differences in abundance or density, for example in disturbed versus non-disturbed habitats. However, abundance may not always be a suitable measure of sensitivity. If competition occurs for the best quality habitats (e.g. those that generate highest foraging returns) and they are limited in availability, a small number of highly competitive individuals may exist in the best habitats, with large numbers of subdominants relegated to lower quality areas (van Horne 1983). For example, the presence of large numbers of male bats at high elevation sites supports the hypothesis that the best quality lowland sites are monopolised by breeding females and perhaps by high-quality males (Barclay 1991, Russo 2002, Senior et al. 2005, Cryan & Veilleux 2007, Cryan & Diehl 2009).

Any study of bioindicators should assess whether abundance or density is a valid indicator of sensitivity (Hayes et al. 2009, Kunz et al. 2009a). Competitive effects may occur between as well as within species. For example, in forest fragments in French Guiana, the smaller *Artibeus obscurus* appears to be relegated to fragmented habitats by *A. jamaicensis*, which excludes *A. obscurus* from continuous forest (Henry et al. 2007). The sex ratio of *A. obscurus* is significantly male-biased in fragments, and haematocrits (a proxy of physiological condition) were significantly lower in fragments compared with continuous forest. Thus sex ratios and physiological measures may be better indicators of sensitivity to habitat disruption than measures of abundance or densities in some circumstances.

THE IMPORTANCE OF BATS IN ECOSYSTEMS

The extensive taxonomic and functional diversity of bats makes them well suited as bioindicators (Patterson et al. 2003, Simmons & Conway 2003). Indeed, bats are among the most diverse and geographically dispersed group of living mammals. They form some of the largest non-human aggregations of mammals, and may be among the most abundant groups of mammals when measured in numbers of individuals (Kunz 2003, O'Shea & Bogan 2003); only members of the order Rodentia exceed bats in number of species, and over 1116 species of bats have been described (Simmons 2005). Powered flight sets bats apart from other mammals, and this most likely has been an important factor contributing to their widespread distribution and diversity (Kunz & Fenton 2003). Living bats are known from all continents except Antarctica and their distribution ranges from the southern tip of South America to northern Scandinavia (Kunz & Pierson 1994, Willig et al. 2003). They are absent only from polar regions and some isolated oceanic islands. Powered flight has also contributed to their extraordinary feeding and roosting habits, reproductive strategies and social behaviours (Patterson et al. 2003, Simmons & Conway 2003). Roosting habitats include foliage, caves, rock crevices, hollow trees, crevices beneath exfoliating bark and an assortment of man-made structures (Kunz 1982, Kunz & Lumsden 2003, Kunz & Reynolds 2003). Their rich dietary diversity, which includes insects, fruits, leaves, flowers, nectar, pollen, seeds, fish, frogs, other vertebrates and blood, is unparalleled among the orders of living mammals (Kunz & Pierson 1994, Patterson et al. 2003, Simmons & Conway 2003).

Bats are important in terms of their ecological and economic roles. Because bats fill such a wide array of ecological niches, they offer an important multisensory role in assessing ecosystem health. Old World pteropodids and New World phyllostomids are important pollinators and seed dispersers for a number of ecologically and economically important plants (Fujita & Tuttle 1991, Kunz & Pierson 1994, Kunz 1996, Hodgkison et al. 2003). The New World plant-visiting bat *Leptonycteris curasoae* appears to be the major pollinator of 2 primary cactus species of the Sonoran Desert, the cardon and organ pipe cactuses (Fleming & Valiente-Banuet 2002, Molina-Freaner et al. 2004). The Old World bats *Rousettus aegypticaus*, *Epomophorus wahlbergi* and *Eidolon helvum* pollinate flowers of the baobab tree, an economically important species in the African savannah (Kunz 1996). On faunally depauperate oceanic islands, pteropodids are often the sole pollinators of plants that are known to have multiple pollinators on mainland areas, and they are often the only vertebrates large enough to carry large-seeded fruits (Fleming & Racey 2009). Thus, in these assemblages, plant-visiting bats may fulfill keystone roles in structuring local forest communities. As frequent dispersers of pioneer species such as *Solanum* and *Piper*, bats are important for the revegetation of cleared areas (Kelm et al. 2008). Over 186 paleotropical plant species utilized by flying foxes (*Pteropus*) have been identified as being of economic importance to people for a variety of products, including food, medicines, dyes, fibers, ornamental plants, and timber (Fujita & Tuttle 1991). For example, pteropodids are the primary pollinators of 2 plant species that are extremely important to the local economies of Southeast Asia, durian *Durio zibethinus* and petai *Parkia speciosa* and *P. javanica*, and thus play vital roles in both pollination and seed dispersal of a number of valuable timber species (Start & Marshall 1976).

Insectivorous species are the primary consumers of nocturnal insects. Given the relatively large volumes consumed (up to 100% of body mass per night, e.g. Kurta et al. 1989) and the long distances travelled (several km per night), these bats are thought to play a major role in suppressing nocturnal insect populations and transporting nutrients across the landscape, particularly from stream corridors to tree roosts (Pierson 1998). Indeed, experiments show that bat exclusion reduces the numbers of arthropods and hence limits herbivory more than bird exclusion in neotropical forests (Kalka et al. 2008). Similar exclusions also show that bats significantly reduce arthropod numbers in coffee plantations, especially during the wet season (Williams-Guillén et al. 2008). Although mosquitoes are often touted as an important dietary item of some insectivorous bats, the overwhelming numbers and diversity of insects eaten by bats are represented by other groups, namely lepidopterans, coleopterans, homopterans, hemipterans and trichopterans (Anthony & Kunz 1977, Whitaker 1993, 1995, Agosta 2002, Agosta & Morton 2003). Bats are predators on a number of economically important insects, including cucumber beetles, June bugs, corn earworm moths, cotton bollworm moths, tobacco budworm moths and Jerusalem crickets (Whitaker 1995, Lee & McCracken 2005), which are important agricultural pests on such crops as corn, cotton and potatoes (Whitaker 1993, Cleveland et al. 2006). Extrapolations based on data from the Winter Garden region of south-central Texas suggest that the presence of large numbers of Brazilian free-tailed bats *Tadarida brasiliensis* can reduce the influence of insect herbivory from cotton boll worms and corn earworms on a transcontinental scale. With a few exceptions, the model suggests that both genetically engineered (Bt) and conventional cotton production is more profitable when large numbers of insectivorous bats are present (Cleveland et al. 2006, Federico et al. 2008).

BAT POPULATIONS UNDER THREAT

Bat populations can be readily monitored over long time periods, as shown for example by the UK's National Bat Monitoring Programme (NBMP) implemented by the Bat Conservation Trust. This programme has been operating since 1995 and uses a combination of standardized counting methods — including roost counts, hibernation counts and bat detector surveys — to assess the relative abundance of a number of bat species in the UK (Walsh et al. 2001). The NBMP has shown that trends in bat populations can be statistically identified from data collected through standardized monitoring schemes.

Bat populations appear to be declining almost everywhere in the world, presumably in response to a series of environmental stresses, many of which are induced by humans. Several species have apparently become extinct, including the pteropodids *Pteropus brunneus* from Australia, *P. pilosus* from Palau, *P. subniger* from the Mascarene Islands, *P. tokudae* from Guam, *Mystacina robusta* from New Zealand and *Nyctophilus howensis* from Lord Howe Island (Kunz & Pierson 1994). For many other species, ranges are contracting, numbers are declining and only remnant populations remain. Species in decline probably include the pteropodids *Aproteles bulmerae* in Papua New Guinea, *P. mariannus* in Guam and *Emballonura semicaudata* on several Pacific islands, *Eumops glaucinus* in the USA, *Rhinolophus hipposideros* and *Rhinolophus ferrumequinum* in much of Europe (Kunz & Pierson 1994). *Coleura seychellensis* now has a population estimated at only 100 ind. in the Seychelles (Bambini et al. 2006). Other species usually considered abundant have also experienced declines. For example, the numbers of *Pipistrellus* sp., the most common bats in Britain, decreased by 62% according to roost counts between 1978 and 1987 (Stebbings 1988).

Hence bats are taxonomically and functionally diverse, often abundant, global in distribution and provide key ecosystem services. Population declines suggest that bats are affected by environmental stressors, and that monitoring of their populations may give insight into the importance of these stressors in a more general context. We now review specific case studies that illustrate the potentially important roles that bats can play as bioindicators, emphasizing mechanisms that might drive population declines.

ENVIRONMENTAL STRESSORS AFFECTING BAT POPULATIONS

Global climate change

There is broad consensus that we are currently in a period of rapid and global climate change, and that the impact of these changes can already be observed in a range of ecosystems (e.g. Parmesan & Yohe 2003). Not only are global temperatures increasing, some meteorological events are becoming more extreme, such as the number of days with exceptionally heavy precipitation in North America (Peterson et al. 2008). Global climate change is likely to have multiple impacts on bats. Newson et al. (2009) gave 3 examples of how monitoring bat populations could be used as effective indicators of the effects of climate change on migratory species. Monitoring bats in European hibernacula, populations of the straw-coloured fruit bat *Eidolon helvum* in Africa and Brazilian free-tailed bats *Tadarida brasiliensis* at maternity roosts in North America were considered to be valuable potential indicators of negative effects of climate change. Some specific effects of extreme climatic events are highlighted below.

Incremental increases in temperature: physiological impacts

The reproductive cycle of temperate zone bats is closely linked to their pattern of hibernation (Racey & Entwistle 2000). Temperate species mate in autumn and winter and spermatozoa are stored in the female reproductive tract until spring. If bats experience warm conditions and a supply of food in the second half of winter, they will arouse from hibernation prematurely, ovulate and become pregnant. Experimentally, the timing of births can be altered by up to 3 mo by manipulating environmental conditions (Racey 1972). Conversely, if bats experience periods of inclement weather associated with food shortages during pregnancy, they will become torpid and the gestation period is extended (Racey 1973, Racey & Swift 1981). The ability of bats to halt, speed up or slow down the rate of foetal growth is unique among mammals (Racey 1982). Given this extreme dependence on external temperatures and food supply, the timing of reproductive cycles of temperate bats is likely to be significantly affected by climate change. In greater horseshoe bats *Rhinolophus ferrumequinum*, birth timing was significantly correlated with spring temperature, with young being born earlier after warmer springs; births were approximately 18 d earlier when spring temperatures rose by 2°C (Ransome & McOwat 1994). To date, however, the only documented example of extreme disruption of the timing of reproductive events has been the pregnancies and births reported for the mouse-eared bat *Myotis myotis* in December in the Doñana Reserve in southern Spain. These occurred 6 mo before the usual birth period for this pan-European species (Ibáñez 1997).

In captivity, spermatozoa stored in the female reproductive tract lose their viability if the bats are not provided with conditions suitable for hibernation (Racey 1972, Racey & Entwistle 2000). If unsuitable hibernation conditions similarly affect bats in the wild, and males in particular (which also store spermatozoa in their epididymis), their reproductive success may be compromised.

The predicted decrease in frequency or even the disappearance of extreme cold winters may result in a reduced period of hibernation, increased winter activity and reduced reliance on the relatively stable temperatures of underground hibernation sites. An earlier spring would presumably also result in a shorter hibernation period and hence the earlier appearance of foraging bats. If sufficient food is available, an earlier emergence from hibernation may have no detrimental effect on population size. However, the occurrence of later periods of cold weather could inflict significant mortality. Over 2 decades ago, before climate change became a matter of concern, Avery (1985) showed that, over a 3 yr period, pipistrelles (*Pipistrellus* spp.) appeared over a fenland foraging site in every winter month and on a third of all winter nights. Many temperate bats species already feed regularly during the winter months, and are likely to adapt to warmer winters by increasing activity further. Such warmer weather may lead to increased availability of flying insects when the temperature rises above the threshold for insect flight (ca. 10°C). Climate change is predicted to change energetic demands during hibernation and hence alter the distribution of hibernating species (Humphries et al. 2002). Large die-offs (≤75% at some hibernacula) of bats in the genus *Myotis* have been reported in caves and mines in the northeastern USA, termed white-nose syndrome because a white fungus is apparent in the muzzle of dead and moribund bats (Blehert et al. 2009) (Fig. 2). The fungus is phylogenetically related to *Geomyces* spp. and grows on the muzzles, ears and wing membranes of affected bats. No causal pathogen ultimately responsible for the die-offs has yet been identified; however, unusually warm and erratic winters may have affected the food supply or hibernal cycle of these bats and pesticides may also be involved in weakening their immune system (Locke 2008). Bats, in this case, may be viewed as a mammalian analogue to the canary in a coal mine, warning of impending ecological stress (canaries were used to detect gases such as carbon monoxide in coal mines in Britain until 1986 because of their sensitivity to odourless but lethal carbon monoxide gas).

Incremental increases in temperature: range shifts

Climate change may also cause changes in the distribution of bats both at local and global levels. La Val (2004) analysed capture data for bats in the Monteverde Cloud Forest in the Tilaran Mountains of Costa Rica over a 27 yr period. Although capture rates did not change significantly, at least 24 species previously associated with the lowlands were recorded at high elevations during this period. La Val (2004) attributed this shift in distribution to climate change as well as forest clearance and an increase in area of secondary forest.

Pipistrellus kuhlii, a bat species typically associated with Mediterranean regions of Europe, has undergone a substantial northward range shift over the past 15 yr. The species is now found in several countries in central and eastern Europe, and its northward range expansion may be the result of sustained recent increases in global temperature (Sachanowicz et al. 2006). Because bats are volant they can potentially shift ranges relatively rapidly, and so changes in their distribution may be valuable indicators of climate change.

Extreme drought and cold: *Miniopterus bassani*

In 2006, South Australia experienced the driest year on record, with the lowest rainfall since records began in 1869, at less than half the annual average, and no surface water in any of the wetlands. This presumably reduced the insect food supply available to the southern bent-winged bat *Miniopterus bassani*, the entire population of which depends on 2 maternity sites in the area. In addition, the minimum ambient temperature in October 2006 fell below 5°C on 18 occasions, and on 7 of these it fell below zero. In November, temperatures fell to 5°C or below on 5 occasions and in December they fell to 2°C or below on 5 occasions. Over 300 pups were dead or dying in early December, and overall deaths were estimated at 500. Such mortality is likely to have a significant effect on the population, which had already declined from 100 000 to 65 000 since the 1960s (Bourne & Hamilton-Smith 2007).

Extreme heat: *Pteropus alecto* and *P. poliocephalus*

On 12 January 2002 in northern New South Wales, ambient temperatures of over 42°C resulted in the deaths of over 3500 individuals in 9 mixed-species colonies of *Pteropus alecto* and *P. poliocephalus*. In one colony alone, 5 to 6% of the bats present died from hyperthermia. The temperature extreme had a greater effect on the tropical black flying fox *P. alecto*, 10 to 13% of which died, compared with <1% of the more temperate grey-headed flying fox *P. poliocephalus*. Mortality mainly affected dependent young (23 to 49% of deaths) followed by adult females (10 to 15%) and <3% of adult males (Welbergen et al. 2008).

This closely observed event led to documentation of similar occurrences, and it became apparent that more than 30 000 *Pteropus* spp. have died during 19 temperature extremes, 24 500 of which were *P. poliocephalus* (listed as Vulnerable in Australia). *P. alecto* was relatively less affected because most die-offs occurred below its southern distribution limit. However, the fact that this limit is increasing southward also increases the likelihood of die-offs occurring in this species (Welbergen et al. 2008).

Cyclones

The increased frequency of extreme weather events (hurricanes and typhoons) in the tropics has a marked deleterious effect on bat populations, particularly those that roost in trees on islands, as a direct consequence of tree loss and by increased hunting by island inhabitants experiencing food shortages.

Cyclones in the western Indian Ocean have long threatened endemic pteropodids such as *Pteropus rodricensis* in the Mascarene Islands, the population of which was halved by a single cyclone (Carroll 1988). In the Samoan Islands, the populations of *P. samoensis* and *P. tonganus* declined by 80 to 90% as a result of cyclones in the early 1990s (Craig et al. 1994). These cyclones had a differential impact on the 2 species, reflecting differences in habitat use and susceptibility to hunting (Pierson et al. 1996).

Such differential effects also have been documented in the Caribbean where Hurricane Hugo (1989) significantly reduced populations of the dominant frugivore *Artibeus jamaicensis*, which were slower to recover than those of *Brachyphylla cavernarum*, so that the latter dominated the frugivore ensemble 5 yr after the hurricane (Pedersen et al. 2009). The species-specific effects of hurricanes are further revealed by Gannon & Willig (2009) for the bats of Puerto Rico. The rate of recovery of cave-roosting *A. jamaicensis* populations depended on the severity of the hurricane. Recovery occurred more rapidly after Hurricane Hugo (1989, category 5) than after Hurricane Georges (1998, category 3), likely because *A. jamaicensis* benefits from the proliferation of the pioneer plant species on which it feeds (Fig. 3). In contrast, populations of the tree-roosting *Stenoderma rufum* declined gradually after Hurricane Hugo and appeared to suffer far more from subsequent alteration of the habitat than from direct hurricane mortality.

Other possible effects of climate change

Bats may also be affected by other factors involved in climate change, although evidence to date is somewhat anecdotal. Extreme precipitation may depress foraging activity and lead to desertion of the young

Fig. 2. Cluster of little brown bats *Myotis lucifugus* showing symptoms of white-nose syndrome. The syndrome has been associated with recent mass deaths of bats in the northeastern USA, though it may be a secondary consequence of other environmental stressors. Signs of disease in bats may be indicators of environmental stress. Photo credit: Al Hicks, New York Department of Environmental Conservation

(Bat Conservation Trust 2007). Additionally, sea level rise may reduce access to some cave roosts, such as those on the Kenyan coast, where the entrances to coastal caves are presently partially submerged (McWilliam 1982).

Bat populations are likely to be affected directly by climate change, but may also suffer from indirect effects as changes in the means of energy production occur in response to the need to reduce carbon emissions. In particular, the development of wind energy facilities in Australia, Europe and North America has led to unexpectedly large numbers of migratory bats being killed (Brinkman 2006, Kunz et al. 2007, NRC 2007, Arnett et al. 2007, 2008, Baerwald et al. 2008).

Fig. 3. Bats are sensitive to the effects of habitat disturbance caused by major climatic events such as hurricanes. Populations of *Artibeus jamaicensis* (a) recovered more slowly after Hurricane Hugo in 1989 (b) than those of *Brachyphylla cavernarum*, so that the latter dominated the frugivore guild 5 yr after the hurricane. Photos: (a) T. Schountz; (b) NASA

Efforts are needed to find ways to reduce the impacts of these facilities on bats, either by developing acoustic deterrents or by increasing the turbine cut-in speed (the wind speed at which electricity enters the power grid) during migratory periods (Kunz et al. 2007, NRC 2007). Recent research in Canada and Germany has indicated that bat fatalities can be reduced significantly when turbine cut-in speeds are increased slightly (E. B. Arnett, R. M. R. Barclay, O. Behr pers. comm.).

Habitat and landscape change

Habitat change has affected bats in many ways. Below we review the roles of several of the key anthropogenic changes that have occurred recently, especially focusing on urbanisation, changes in water quality, agricultural intensification, forest disturbance and roost loss.

Urbanisation, industrialisation and heavy metal pollution

Changes in land-use practices may also affect the species composition of local and regional ecosystems, especially those associated with conditions and structures of urbanisation (Rydell 1992, Keeley & Tuttle 1999, Kunz & Reynolds 2003, Kunz et al. 2008). Light pollution might affect bats in different ways. For example, emergence may be extended and infant growth retarded by house lights in some slow-flying bat species adapted to more forested habitats (Boldogh et al. 2007). In contrast, some populations adapted to foraging in open spaces (e.g. *Pipistrellus* spp. in western Europe) may benefit from feeding on insects attracted to streetlights. Arlettaz et al. (2000) suggested that this increase may have contributed to the decline in *Rhinolophus hipposideros*, which rely on the same categories of insect prey — namely dipterans and lepidopterans. The increasing use of bridges and buildings, including houses designed specifically for bats, has led to changes in geographic distributions and local population densities of some bat species (Tuttle & Hensley 1993, Kunz & Reynolds 2003). Consequently, some species that formerly only roosted in caves and tree cavities on a seasonal basis have become more abundant and occupied some roosts on a yearly basis (Kunz 1982, Kunz & Reynolds 2003, Ormsbee et al. 2007). The long-term consequences of this shift in roosting habits on local species composition in temperate and tropical ecosystems remain to be determined, especially given the relatively ephemeral nature of these human interventions.

Bats may also be negatively affected by recent increases in road traffic. Greater mouse-eared bats *Myotis myotis* spend less time foraging when subjected to traffic noise in laboratory conditions, presumably because the noise masks rustling noises made by moving insects that these bats normally detect by passive listening (Schaub et al. 2008). Bats may also be killed by collisions with motor vehicles on busy roads (Russell et al. 2009, this Theme Section).

Pollution by heavy metals is often associated with urbanisation. Cadmium, lead and mercury are the most commonly reported heavy metals associated with toxic effects on wildlife (O'Shea & Johnson 2009). High concentrations of cadmium have been reported in the guano of gray bats *Myotis grisescens* in the USA (Clark 1988a,b). Several studies have reported mercury concentrations in insectivorous bats (O'Shea & Johnson 2009) but none have determined the concentration of methyl mercury. When methylated, often through microbial processes, mercury becomes highly toxic and concentrates through food webs to a greater extent than in its elemental form. Lead poisoning has been well-documented in both wild and captive Old World fruit bats based on lead concentrations in target organs, histopathology, morbidity and mortality (Zook et al. 1970, Sutton & Wilson 1983, Skerratt et al. 1998). Concentrations of other heavy metals and toxic elements have been reported in bats, but only in a few cases have shown harmful effects (O'Shea & Johnson 2009).

Water quality

Riparian habitats are prime foraging areas for insectivorous bats (e.g. Vaughan et al. 1996, Fukui et al. 2006); these rivers and lakes support large numbers of insects. However, deterioration in water quality may occur because of agricultural runoff and industrial pollution (Mason 1997). High input of organic matter and toxins such as ammonia into water courses from sewage treatment plants may lead to eutrophication that can in turn affect the invertebrate community in rivers. For example, the biomass and diversity of insects emerging from rivers is lower downstream of sewage outputs (Whitehurst & Lindsey 1990).

Vaughan et al. (1996) measured bat activity above and below sewage outfalls as a model system to test the hypothesis that widespread declines in water quality may reduce bat activity. Sites downstream of sewage outputs had overall 11% fewer bat passes and 28% fewer buzzes than upstream sites; the reduction in activity was especially noticeable in *Pipistrellus* (Vaughan et al. 1996). *Myotis* had higher feeding activity downstream (Vaughan et al. 1996), possibly reflecting the presence of pollution-tolerant insects such as some chironomid species that may benefit from eutrophication (Mason 1997). Vaughan et al. (1996) showed that deterioration in water quality can have negative impacts on bat activity and foraging, highlighting that bats can be used as bioindicators of water quality and long-term declines in water quality may have contributed to declines in bat populations in Britain.

Kalcounis-Rueppell et al. (2007) investigated the effects of effluent from a wastewater treatment plant (WWTP) on foraging activities of bats and insect abundance along urban streams in North Carolina, USA. More bat passes of *Eptesicus fuscus* (a habitat generalist) were recorded upstream of the WWTP, whereas activity of *Perimyotis subflavus* (a riparian habitat specialist) was higher downstream, suggesting that *P. subflavus* may be tolerant of or even benefit from anthropogenic input into the watershed which may increase the availability of some prey groups (Kalcounis-Rueppell et al. 2007).

There is little evidence that eutrophication of fresh waters is harmful to bats; in fact it may be responsible for the apparent increases in populations of *Myotis daubentonii* in Europe (Kokurewicz 1995). In a study designed to test this hypothesis, Racey et al. (1998) found little difference between the numbers of bats and insects foraging over a small eutrophic river and a large oligotrophic one.

Park & Cristinacce (2006) investigated the effect on foraging bats of phasing out percolating filter beds, which provide breeding opportunities for dipterans, in favour of activated sludge, for treating human sewage. They demonstrated that the biomass of insects and activity of *Pipistrellus* spp. were significantly higher at filter beds than at activated sludge systems, and suggested that the current preference for the latter is likely to reduce the value of treatment works as foraging sites for bats.

Agricultural intensification and pesticide use

Changes in agricultural practices are occurring worldwide, and intensification is ongoing as the human population increases in number. Most research on the effects of agricultural intensification has been performed in developed nations, though the impacts of intensification will no doubt be felt on a global scale.

Agricultural intensification is recognised as having had major detrimental effects on biodiversity in western Europe since the mid-20th century (Robinson & Sutherland 2002). The effects of agricultural intensification can be large in scale. For example, 76% of the land in Britain is currently used for agriculture. Intensification involves the increased production of agricultural commodities per unit area (Donald et al. 2001) and involves processes such as increased mechanisation and the use of synthetic chemical fertilizers and pesticides. Traditional rotations in farm management have declined, and hedgerows and field margins have been removed (Robinson & Sutherland 2002). The effects of agricultural intensification have been marked for granivorous birds: 24 of 28 farmland bird species declined between 1970 and 1990 (Fuller et al. 1995b). Increased pesticide use can further reduce food available for insectivorous bats, and the removal of hedgerows and field margins will take away valuable foraging and commuting habitats, as well as reducing the availability of important habitats for their prey (Fig. 4). Thus, it has been hypothesised that agricultural intensification is a major cause of the declines in bat populations in Europe during the latter half of the 20th century (Stebbings 1988).

Long-term historical data are not available to test this hypothesis directly, but an indirect test is possible by comparing the abundance of nocturnal insects and the activity and foraging rates of bats on contemporary organic and conventional farms. In organic farming, the use of synthetic fertilizers, pesticides, genetically engineered seeds, growth regulators and food additives for livestock are excluded. Comparisons between matched pairs of organic and conventional farms are therefore useful for investigating the impact of agricultural intensification on biodiversity.

Nocturnal insect abundance, species richness and moth species diversity were higher on organic farms than on their matched conventional counterparts (Wickramasinghe et al. 2004). Five of the major insect prey groups eaten by bats (carabid beetles, noctuid moths, geometrid moths and chironomid and ceratopogonid flies) were more abundant on organic farms (Wickramasinghe et al. 2004). These data suggest that the prey base of nocturnal insects available for bats is depleted on conventional compared with organic farms, thus, providing support for findings from other studies that show increased numbers and diversity of other insect taxa on organic farms (Bengtsson et al. 2005, Fuller et al. 2005, Hole et al. 2005). Moreover, bat activity was 61% higher and foraging activity (counts of feeding buzzes) was 84% higher on organic farms than on conventional ones (Wickramasinghe et al. 2003). Species composition was similar in both situations, although horseshoe bats *Rhinolophus* spp. were only detected on organic farms (Wickramasinghe et al. 2003). The study emphasised that bats are likely victims of agricultural change and important bioindicators of intensification that can also track changes in their ecologically important prey base. The finding of increased bat activity on organic farms was also determined in an independent study by Fuller et al. (2005).

Fig. 4. Bats are sensitive to the effects of agricultural intensification. Many hay meadows rich in plant species such as this one on an organic farm (a) have been replaced by intensively managed silage in Great Britain (b). Bat activity and counts of feeding buzzes were found to be higher on organic than conventional farms (Wickramasinghe et al. 2003), and horseshoe bats such as *Rhinolophus ferrumequinum* (c) were only recorded on organic farms surveyed. Photos: (a, b) N. Jennings; (c) G. Jones

Understanding the mechanisms contributing to these trends is important. Although the paired organic and conventional farms in the study by Wickramasinghe et al. (2003) were matched as closely as possible and were similar in their areas of pastoral, arable, woodland and water habitats, in habitat richness and in farm size, organic farms had significantly higher hedgerows. Thus, it was unclear whether hedgerow structure or agrochemical use was the important characteristic driving differences in bat activity and insect abundance between the 2 farm types. Notwithstanding, bats and their insect prey respond in similar ways to differences in agricultural practice, suggesting that changes in bat populations may reflect more widespread biotic change.

Possible mechanisms driving these differences were investigated further by Pocock & Jennings (2008) who documented differences in the sensitivity (measured by the difference of log counts at paired sites) of insectivorous mammals and their prey to proxies of intensification (representing use of agrochemicals, the switch in grass production from hay to silage and boundary loss). Bats were especially sensitive to boundary loss, suggesting that hedgerow differences may be an important driver of their reduced activity and feeding rates on conventional farms (Pocock & Jennings 2008). Hedgerows are important commuting routes for bats (Verboom & Huitema 1997, Downs & Racey 2006) and serve as shelterbelts where swarms of aerial insects congregate (Lewis & Dibley 1970), forming food patches for bats. Insects were more sensitive to increased agrochemical input than were their mammalian predators (including bats) (Pocock & Jennings 2008). The latter authors (2008) emphasised that different taxa respond in different ways to specific aspects of intensification, and the choice of suitable bioindicators should be made with care. Indeed, the sensitivity of a taxon to one aspect of intensification is often a poor predictor of its sensitivity to another. It is clear that no single taxon can be an indicator of all aspects of intensification, further indicating that bioindicator studies in response to agricultural intensification require studies involving multiple taxa (Pocock & Jennings 2008).

Pesticide use is also an important component of agricultural intensification. Although the primary purpose of agricultural pesticides is the reduction of insect numbers, direct evidence that such reduction in insect food supply limits the populations of insectivorous bats is not available. There is, however, direct evidence that agricultural pesticides ingested with insects carry sublethal levels that were responsible for heavy mortality of *Tadarida brasiliensis* in New Mexico (Geluso et al. 1976, 1979, Clark 1981). Pesticides are mobilized during lactation and transferred in the milk to the young that die as a result (Geluso et al. 1981).

Jefferies (1972) showed that bats taken from one of the most intensively farmed areas of the UK were more heavily contaminated with residues of DDT than were either insectivorous or carnivorous birds. Laboratory experiments showed that bats were more sensitive to DDT than were other mammals, and it was metabolized more slowly in bats than in passerine birds. Bats carried one-third of the lethal level of organochlorine insecticides, but this rose to close to lethal levels following hibernation. These results suggest that organochlorine residues could have caused population declines in bats (Jefferies 1972).

In the USA, many endangered *Myotis grisescens* were found dead with lethal brain levels of Dieldrin in 2 colonies (Clark et al. 1978a), and high levels of DDT found in skin samples have been linked to the decline of *Tadarida brasiliensis* at Carlsbad Caverns, New Mexico during the 1950s and 1960s (Clark 2001). In Australia, high tissue levels of DDT were detected in *Miniopterus schreibersii*, even in young bats that had not left the maternity roosts. Such high levels of DDT were the suspected cause of several mass die-offs in this species (Dunsmore et al. 1974). However, in Spain, Hernández et al. (1993) found that chlorinated hydrocarbon residues in bats were at much lower concentrations than the estimated lower lethal levels.

Historically, chlorinated hydrocarbons were used to exclude bats from buildings in the USA, but this increased mortality of adults and volant young when fat stores were metabolized (Kunz et al. 1977, Clark et al. 1978b). Similarly, these pesticides have been used as remedial timber treatments within roof spaces and have led to the deaths of bats roosting there (Voûte 1981, Racey & Swift 1986). In the USA and the UK, owing largely to pressure from conservationists and environmentalists, most of these highly toxic chemicals have been replaced by synthetic pyrethroids and other alternatives with much lower mammalian toxicity (Racey 2000). Although Clark (1981, 1988a,b) suggested that pesticides might have subtle but important effects on bat physiology, the sublethal effects of chlorinated hydrocarbons have rarely been documented (Swanepoel et al. 1999). The residues of such pesticides are also commonly found in the tissues of bats in the developing world (McWilliam 1994).

In recent years, synthetic pyrethroid insecticides have become increasingly used to control insect pests (Hirano 1989, O'Shea & Clark 2002). Pyrethroid compounds were initially extracted from chrysanthemum flowers in the 1800s, but most are now manufactured in several different synthetic forms. Most are lipophilic, highly toxic to aquatic organisms and are rapidly metabolized. They appear to exhibit low toxicity in laboratory mammals (Peterle 1991). Pyrethroids are neurotoxic and the mode of action resembles that of the organochlorine DDT. However, some pyrethroids may persist in the environment and adversely affect bats, particularly chlorinated forms such as cypermethrin (Clark & Shore 2001). Apart from the work of Racey & Swift (1986) there has been little research on the effects of pyrethroids on bats or their insect prey. With the growing use of these compounds, research should be undertaken to explore their direct impact on bats and the insects upon which bats feed (O'Shea & Johnson 2009).

Deforestation

Rapid rates of deforestation are of major conservation concern, especially in tropical environments (Ewers 2006). Most research on the effects of disturbance on bats in tropical forests has been conducted in the neotropics, and some of the key findings are highlighted below.

Latitudinal gradients of biodiversity in New World bats are quite steep with regard to taxonomic (Willig & Selcer 1989, Willig & Sandlin 1991, Stevens & Willig 2002), functional (Stevens et al. 2003) and phenetic (Stevens et al. 2006) components, all attaining maxima in equatorial regions. The family Phyllostomidae differentially contributes to these patterns, as it is the most diverse bat family in the neotropics (Rex et al. 2008). Phyllostomids eat nectar, pollen, fruit, insects, small vertebrates and even blood (Gardner 1977). Their diversity and differential dependence on forested environments potentially makes them key indicators of disturbance in neotropical forests (Fig. 5).

Fenton et al. (1992) captured species in the subfamily Phyllostominae (whose species eat mainly animals, though sometimes they eat more fruit than animals) more often in forested than in deforested sites in Mexico, and considered phyllostomine bats as suitable indicators of habitat disruption caused by deforestation. They also related vegetation structure to the richness and diversity of bat communities in Mexican rainforests, and showed that species richness, the number of rare species and diversity were all positively associated with vegetation indices that were suggestive of low levels of forest disturbance. These results corroborate the value of the species in this subfamily as bioindicators of habitat disruption in neotropical forests. Indeed, many phyllostomine bats are specialised in dietary and roosting habits, and thus a large number of species may reflect a wider range of niche dimensions than are available in undisturbed habitats (Kalko et al. 1996, Kalko 1998, Medellín et al. 2000, Kalko & Handley 2001, Patterson et al. 2003).

Willig et al. (2007) documented population-level responses of 24 common phyllostomid bats to habitat alteration in lowland Amazonia in the environs of Iquitos, Peru. In this region, like in much of the western Amazon, human disturbance (Maki et al. 2001) primarily parallels navigable rivers and roads, where understory vegetation is removed and most of the trees are felled and burned prior to planting with pineapple, plantain or manioc. The resultant agricultural clearings (chacras) are generally small in extent (~1 ha). They are farmed until the soil is no longer fertile, after which they are abandoned and regenerate into early successional forest (purma). Frugivorous species dominated chacra, purma and undisturbed forest habitats (Willig et al. 2007). Nonetheless, 8 phyllostomid species responded to habitat conversion. Four (*Phyllostomus discolor*, *Sturnira lilium*, *S. tildae*, and *Uroderma bilobatum*) attained highest abundances in chacra. Two species (*Tonatia saurophila* and *Mesophylla macconnelli*) attained highest abundances in mature forest, and *Carollia benkeithi* was most abundant in purma. *Carollia* sp. attained higher abundances in purma and chacra than in mature forest. In a comparison of temporal activity among the 3 habitat types for the 8 most common phyllostomids, Presley et al. (2009) found no differences between closed forest and purma, but significant differences between agricultural (chacra) and forested (purma and closed canopy site) areas for 5 species (*Artibeus lituratus*, *A. obscurus*, *A. planirostris*, *C. perspicillata* and *R. pumilio*). Taken together, these results suggest that bats maybe sensitive bioindicators of anthropogenic activities because their abundances and behaviours are affected by disturbance and recovery processes even at small spatial scales.

It is important to appreciate that the level of disturbance may affect patterns of species richness and diversity in neotropical forests, and probably in other ecosystems as well. Moderate levels of disturbance in some neotropical forests may increase habitat heterogeneity and thus may increase bat diversity (Gorresen & Willig 2004). Responses to fragmentation also differ among guilds: in Guatemala large frugivorous bats formed a higher proportion of the nightly catch in continuous forest, whereas small frugivores were proportionally more abundant in fragments. Thus, the relative abundances of these 2 ensembles, which feed on large fruits of mature trees and small fruits that occur in early successional changes respectively, may allow a rapid assessment of forest disturbance (Schulze et al. 2000). More recently, Klingbeil & Willig (2009) showed that population-level responses to fragmentation in lowland Amazonia (peri-Iquitos area) by frugivorous bats (e.g. stenodermatines) differed from that of gleaning animalivores (e.g. phyllostomines). Frugivores responded to compositional metrics (i.e. forest cover, patch density, mean patch size and patch diversity), whereas gleaning animalivores responded to configurational metrics (i.e. edge density, mean patch shape, mean proximity, mean nearest neighbour distance). Moreover, indices of community structure (e.g. species richness, evenness, dominance, diversity and rarity) only responded to configurational metrics.

Studies of bats suggest that low impact logging in lowland Amazonia (Tapajos National Forest of Brazil) might represent a sustainable use of tropical forests for timber extraction without appreciable negative effects on the bat fauna (Castro-Arellano et al. 2007, Presley et al. 2008). Although compositional (species abundance distributions) and structural (rank abundance distributions) aspects of assemblages differed between cut and control forests, most of the differences could be attributed to the decrease in relative abundance of *Carollia perspicillata* and the increase in relative abundance of *Artibeus lituratus* in cut forest compared to control forest. However, the number of rare species in cut forest was much less than that in control forest (i.e. loss of 13 species). If sufficient primary forest exists in close vicinity to these managed areas, rescue effects will likely countermand local extinctions. Thus, these studies document the differential responses of bats at the level of populations, ensembles and assemblages to anthropogenic disturbance, and suggest that population and community metrics would be useful as bioindicators of even subtle changes associated with the removal of <19 m^3 of tree biomass per hectare.

Roost loss

Timber harvesting and agricultural practices have adversely affected bat populations in many parts of the world (Lacki et al. 2007). Clearing of rainforests or temperate-zone old-growth forests (with selective harvesting of snags) has resulted in the loss of crevice, cavity and foliage roosts, as well as important foraging habitats. Consequences are likely to be most serious for species such as the neotropical *Vampyrum spectrum* or the North American *Lasionycteris noctivagans*, which appear to require tree hollows for roosting (Kunz & Lumsden 2003, Barclay & Kurta 2007). Several species that in the past most likely occupied hollow trees now regularly use man-made structures, where they are

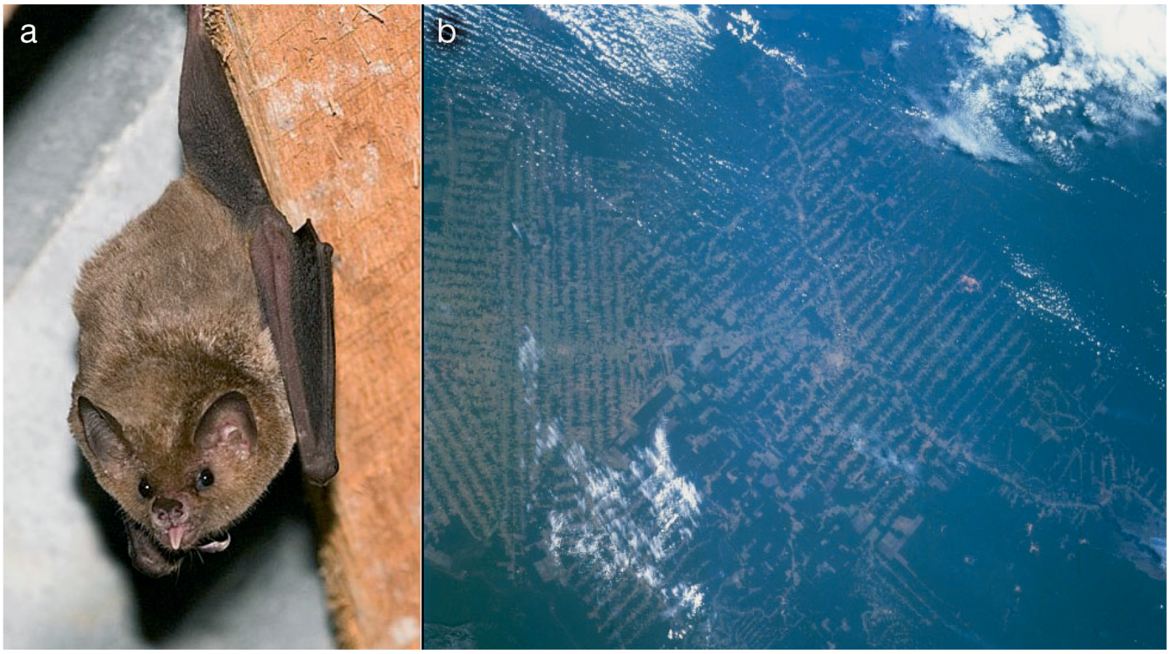

Fig. 5. Bats are indicators of habitat disturbance in neotropical rainforests. The phyllostomid *Glossophaga soricina* (a) prefers small agricultural clearings (chacras) in the lowland Amazon of Peru. Deforestation and fragmentation of forest patches is a major problem in the neotropics. The satellite image (b) illustrates the deforested frontier in Rondonia State of west-central Brazil, showing a patchwork of clearcut swaths (light areas) expanding into the Amazon rainforest (darker patches). The forest here is cleared for ranching and timber. Photos: (a) G. Jones; (b) NASA

often not welcome and may face exclusion or eradication. Man-made structures such as barns are being converted into living spaces at a rapid rate (Kunz & Reynolds 2003), and caves and mines often experience high levels of disturbance from tourism.

Fig. 6. Bats are indicators of the pressures of overhunting for bushmeat. These fruit bats were in a confiscated consignment of bushmeat from Africa. Photo: US Fish and Wildlife Service

Hunting

Although hunting of pteropodids for food is widespread (Mickleburgh et al. 2009), there have been few attempts to harvest bats sustainably (Halstead 1977). Overhunting has resulted in the extinction of *Pteropus subniger* in Mauritius and Réunion (Cheke & Dahl 1981) and has contributed to the local extinction of a dozen other congeners from Indo-Pacific islands (Rainey 1998). Hunting continues to be a key threat to pteropodids (Fig. 6), including species on islands in the Indian and Pacific Oceans such as *P. rufus* (Racey et al. 2009, Wiles & Brooke 2009).

Human consumption remains a major factor affecting bat populations on Indo-Pacific islands and in adjacent areas of Asia, a practice that has led to international trade in fruit bats into Guam and the adjacent Commonwealth of the Northern Marianas (CNMI) (Rainey 1998, Wiles 1992). Hunting by Guamanians reduced the population of *Pteropus mariannus* on the island to a few hundred individuals within the confines of the US military base and, perhaps, contributed to the extinction of *P. tokudae*. In Palau, *P. mariannus* was intensively harvested until 1994, with between 10 000 and 16 000 bats exported annually to Guam and the CNMI (Wiles et al. 1997). Brooke & Tschapka (2002) documented the unsustainable hunting of *P. tonganus* on Niue Island in the South Pacific, stemming from the belief of islanders that taboo areas on the island, which they did not enter, harboured an inexhaustible supply of bats, >1500 of which were shot when the population was estimated at between 2000 and 4000 ind. Jenkins & Racey (2008) reported that although the endemic *Pteropus rufus*, *Eidolon dupreanum*, *Rousettus madagascariensis* and *Hipposideros commersoni* were the most commonly eaten bats in Madagascar, a wide range of small insectivorous bats also are taken, and the high harvesting represents a serious threat to local populations. The killing of the molossid *Cheiromeles torquatus* for food in Borneo is also causing serious concern (Hutson et al. 2001), and the unsustainable exploitation of insectivorous bats for food in Laos has been described by Francis et al. (1999), with thousands of *Tadarida* being harvested during exit from a cave and then subsequently smoked for sale. In one instance, 3000 ind. were sold to occupants of a single passing truck.

Disease

High fatalities observed in bats, if associated with diseases, may provide an early warning of environmental links among contamination, disease prevalence and mortality. Increased environmental stress can suppress the immune systems of bats and other animals, and thus one might predict that the increased prevalence of diseases is a consequence of altered environments. Bats are reservoirs of several pathogens whose spread may be related to physiological stress associated with habitat loss or alteration (Fenton et al. 2006). The recent die-offs of bats presenting with white-nose syndrome (Blehert et al. 2009) may relate to increased levels of environmental stress, perhaps as a consequence of increased arousals and hence energetic stress during hibernation, rendering the bats susceptible to fungal infection.

In their comprehensive review of viral infections of bats, Messenger et al. (2003) noted that infectious disease has rarely been documented as a large-scale cause of mortality in any bat population and thus is seldom mentioned as a major issue. This contrasts with the situation in birds where, for example, the impact of West Nile virus on North American populations has recently been documented (LaDeau et al. 2007). Messenger et al. (2003) noted the few documented cases of bat mortality in which disease has been implicated. For example, several thousand *Tadarida brasiliensis* died in Carlsbad Caverns, New Mexico in August 1955 and 1956; the fact that half of the 20 bats sampled in 1955 were rabies-positive led to the hypothesis that rabies was the overall cause of mortality (Burns et al. 1956). However, inclement weather during migration was subsequently linked to the deaths in 1956 (Constantine 1967). The only other mass mortality attributed to rabies was several hundred *Epomops dobsoni* in southern Africa, 10 to 15% of which were confirmed to be infected with Lagos bat virus (King et al. 1994).

Pierson & Rainey (1992) described episodes of apparent epidemic disease in Pacific flying fox populations, including mass deaths of *Pteropus mariannus* in Micronesia in the 1930s at the same time as measles affected the human population. An epidemic of unknown aetiology was also suspected of depleting populations of *P. tonganus* in Fiji during the 1940s. More recent episodes occurred on the Admiralty Islands when many *P. neohibernicus* were found dead in 1985 (Flannery 1989); a similar incident involved *P. rayneri* in the Solomon Islands.

Since Messenger et al. (2003) reviewed the subject, Calisher et al. (2006, 2008) have updated the list of viruses isolated from bats, Breed et al. (2006) have reviewed the association between henipariviruses and bats, Harris et al. (2006) have reviewed the prevalence of European bat lyssaviruses and Demma et al. (2009) have summarized recent information on the prevalence of rabies and other diseases associated with bats. Other studies have reported the occurrence of antibodies to SARS-like coronaviruses in several species of rhinolophids in China (Lau et al. 2005, Li et al. 2005) and to Nipah, Hendra and Tioman viruses in the 3 endemic Malagasy pteropodids (Lehlé et al. 2007). Evidence of asymptomatic Ebola virus infections has been found in 3 species of pteropodids in West Africa (Leroy et al. 2005). Most of these studies have been driven by concerns about the health of humans, great apes or livestock and little evidence has emerged about the effects of virus infections on the bats themselves, although some fitness costs must be assumed. The most important fact to emerge, however, is that the same bats may be seropositive to rabies-like viruses in successive years and the disease is not necessarily fatal in these animals (O'Shea & Bogan 2003, Amengual et al. 2007).

Bats represent a potential epidemiologic reservoir of transmission of leptospirosis to humans, especially in the tropical Amazon. Indeed, a diverse group of leptospires occurs in peri-Iquitos bat populations including *Leptospira interrogans* (5 clones), *L. kirschneri* (1 clone), *L. borgpetersenii* (4 clones), *L. fainei* (1 clone) and 2 previously undescribed leptospiral species (8 clones) (Matthias et al. 2005). The detection in bats of the *L. interrogans* serovar Icterohemorrhagiae, a leptospire typically maintained by peridomestic rats, suggests a rodent–bat infection cycle in Iquitos. The maintenance of a genetically diverse group of leptospires in bats suggests that they may be capable of transmitting leptospirosis to humans, and thus species of public health concern in the tropics (Bharti et al. 2003).

Mass deaths of *Miniopterus schreibersii* were reported in caves across southern France in 2002, extending into Spain and Portugal. Although the extent of mortality was thought to have reduced the population by 60 to 65%, the cause was unclear, although herpes virus was isolated from bat lungs (Roue & Nemoz 2004). Other bat species inhabiting the caves were thought to be unaffected (Roue & Nemoz 2004). More recently, 8 novel herpes viruses have been isolated from 7 European bat species (Wibbelt et al. 2007). Although half the bats examined showed signs of pneumonia, none of the viruses could be related consistently to a pulmonary lesion, although an aetiological association between the 2 could not be excluded. Bats are reservoirs of several diseases that can be fatal to humans, including rabies and Ebola (Messenger et al. 2003). Bat populations may come into increasing contact with humans as habitat is destroyed and human populations encroach into pristine habitats, increasing the risk of spillover of infections into humans. An increased incidence of disease in bats may therefore be an important bioindicator of habitat degradation in general.

CONCLUSIONS

Bats are excellent indicators of human-induced changes in climate and habitat quality. They show functional and taxonomic diversity and are widely distributed. Many bats fulfill vital ecosystem services, and declines in bat populations often reflect features of habitat deterioration that have impacts on a wide range of taxa. Bat populations show responses to environmental stressors ranging from alterations in habitat quality to climate change as well as direct exploitation. They are reservoirs of a wide range of diseases whose spread and spillover may be related to habitat deterioration and climate change. Bats have taxonomic stability, and can be monitored by a range of methods (Kunz & Parsons 2009). The importance of bats as bioindicators is already being recognised. For example, in May 2008 the UK government adopted bats into their suite of biodiversity indicators of the sustainability of lifestyles to meet targets under the Convention on Biological Diversity. EUROBATS has a 'Bats as Indicators' Intersessional Working Group that aims to take forward opportunities to use bats as biodiversity indicators. It is now time to 'seize the night' and to develop a global monitoring programme for bat populations, involving standardised methodology that can be applied in both New and Old World situations, so that the value of bats as bioindicators can be fully realised.

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Perspective

Do We Need to Use Bats as Bioindicators?

Danilo Russo *, Valeria B. Salinas-Ramos, Luca Cistrone, Sonia Smeraldo, Luciano Bosso * and Leonardo Ancillotto

Wildlife Research Unit, Dipartimento di Agraria, Università degli Studi di Napoli Federico II, Via Università, 100, 80055 Portici, Italy; valeria.salinasramos@unina.it (V.B.S.-R.); luca.cistrone@gmail.com (L.C.); sonia.smeraldo@unina.it (S.S.); leonardo.ancillotto@unina.it (L.A.)

* Correspondence: danrusso@unina.it (D.R.); luciano.bosso@unina.it (L.B.)

Simple Summary: Bioindicators are organisms that react to the quality or characteristics of the environment and their changes. They are vitally important to track environmental alterations and take action to mitigate them. As choosing the right bioindicators has important policy implications, it is crucial to select them to tackle clear goals rather than selling specific organisms as bioindicators for other reasons, such as for improving their public profile and encourage species conservation. Bats are a species-rich mammal group that provide key services such as pest suppression, pollination of plants of economic importance or seed dispersal. Bats show clear reactions to environmental alterations and as such have been proposed as potentially useful bioindicators. Based on the relatively limited number of studies available, bats are likely excellent indicators in habitats such as rivers, forests, and urban sites. However, more testing across broad geographic areas is needed, and establishing research networks is fundamental to reach this goal. Some limitations to using bats as bioindicators exist, such as difficulties in separating cryptic species and identifying bats in flight from their calls. It is often also problematic to establish the environmental factors that influence the distribution and behaviour of bats.

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Abstract: Bats show responses to anthropogenic stressors linked to changes in other ecosystem components such as insects, and as K-selected mammals, exhibit fast population declines. This speciose, widespread mammal group shows an impressive trophic diversity and provides key ecosystem services. For these and other reasons, bats might act as suitable bioindicators in many environmental contexts. However, few studies have explicitly tested this potential, and in some cases, stating that bats are useful bioindicators more closely resembles a slogan to support conservation than a well-grounded piece of scientific evidence. Here, we review the available information and highlight the limitations that arise in using bats as bioindicators. Based on the limited number of studies available, the use of bats as bioindicators is highly promising and warrants further investigation in specific contexts such as river quality, urbanisation, farming practices, forestry, bioaccumulation, and climate change. Whether bats may also serve as surrogate taxa remains a controversial yet highly interesting matter. Some limitations to using bats as bioindicators include taxonomical issues, sampling problems, difficulties in associating responses with specific stressors, and geographically biased or delayed responses. Overall, we urge the scientific community to test bat responses to specific stressors in selected ecosystem types and develop research networks to explore the geographic consistency of such responses. The high cost of sampling equipment (ultrasound detectors) is being greatly reduced by technological advances, and the legal obligation to monitor bat populations already existing in many countries such as those in the EU offers an important opportunity to accomplish two objectives (conservation and bioindication) with one action.

Keywords: biodiversity; Chiroptera; climate change; environment; foraging; forest; habitat; river; urban

1. Introduction

The scientific literature is crowded with definitions for "bioindicator". According to the Oxford Dictionary of Zoology, an indicator species is "a species of narrow amplitude with respect to one or more environmental factors and that is, when present, indicative of a particular environmental condition or set of conditions" [1]. An even more general definition, which we adopt for the goals of this paper, might include processes beyond organisms and see bioindicators as "any biological entity (taxon or process) that responds in some way to environmental characteristics or their alteration".

Many bioindicator subcategories have been proposed according to the information conveyed by such responses. For instance, [2] distinguished between environmental, ecological, and biodiversity indicators. While ecological bioindicators are used to detect and monitor the effects of a stressor on the biota, environmental indicators allow detecting and monitoring changes in a given environmental state, and biodiversity indicators make it possible to identify and monitor species diversity in a certain region [2].

However, since many organisms respond to environmental characteristics and their changes, it is clear that the number of bioindicator candidates is potentially extremely high—thousands, at least—which complicates their selection. Choosing the "right" bioindicator is by no means trivial because its use will affect policy and management decisions, and undoubtedly, using too many bioindicators may generate contrasting results and be confusing (e.g., [3]). What bioindicator should be used is a sensitive matter that too often leads to partisan arguments, as well as to attempts to "sell" a given organism as a bioindicator because raising its public image in terms of "usefulness" would support its protection. Although this is understandable, it is also unethical because of the decision-making implications of choosing a given bioindicator.

To help prevent such problems, well-established criteria have been formulated, and several proposals exist or have been adopted by the scientific community. For instance, [4] identified a seven-step path that is still valid. Perhaps the most important aspect is that, as established in step 1, the user needs should be determined before developing a list of candidate indicators. It is, then, important to define screening criteria against which indicators should be scored, summarise the results of the scoring process, decide how many indicators are needed and, on such bases, make a final selection [4].

With 1440 species currently known to science, bats are the second most diverse order of mammals and provide a substantial contribution to global vertebrate diversity (Mammal Diversity Database, [5]). There is mounting evidence that bats provide crucial ecosystem services, including suppression of agricultural pest arthropods, pollination, and seed dispersal of an impressive number of plant species, among which several are of high economic value [6,7]. Being sensitive to human action, many bat populations are imperilled; hence, they are legally protected in many regions of the world [8].

Discussion about the use of bats as bioindicators is at least over two decades old. In a 2009 seminal paper, five international bat specialists presented well-grounded arguments on why bats are potentially valuable bioindicators [9]. At least for European bat specialists and conservationists, another two landmarks are represented by the International Symposium on the importance of bats as bioindicators, held in Granollers (Barcelona) in 2012 [10], and a special issue of the journal "Mammalian Biology" devoted to the topic [11]. From the policy viewpoint, EUROBATS (The Agreement on the Conservation of Populations of European Bats, currently binding 37 States Parties on bat conservation) adopted Resolution 6.13, titled "Bats as Indicators for Biodiversity" (https://www.eurobats.org/official_documents/meeting_of_parties/resolutions, consulted on 5 May 2021). In a nutshell, this resolution urges parties to develop national, regional, and pan-European bat biodiversity indicators, facilitate the incorporation of bat data within multi-taxa indicators, support the objective of gathering the data for these indicators and forge cooperation platforms to facilitate data exchange.

In this article, we present the state-of-art of using bats as bioindicators, showing that only a limited number of studies addressed the topic comprehensively and that bats appear to be promising bioindicators, at least in certain environmental contexts. We also highlight limitations and advantages and identify future research and applications, with a special focus on temperate regions.

2. Testing Bats as Bioindicators: Where Are We Now?

Despite the considerable attention received by the topic, relatively few attempts have been made to test real-world bioindication applications, and much of the debate on bat sensitivity to environmental changes relies on conservation biology studies showing how bats react adversely to anthropogenic stressors. Few examples of bat-based bioindication schemes are available. In the UK, a "bat index" is part of a suite of organisms used to estimate temporal trends of biodiversity across the country [12]. The index comprises ten bat species trends (two of which are combined), and its recent increase was taken as evidence for a recovery of some bat species after considerable 20th-century population declines [12]. Although this index, along with the others used in the assessment, is highly important to provide a picture of UK biodiversity and its trends (and supposedly indicate "sustainable development"), it does not make it possible to identify the environmental changes that produce the recorded index variation, nor may bats alone summarise the biota responses to human-induced stressors. Hence, in this case, too—one of the few real-world examples of bat bioindication—the use of bats as ecological, or environmental bioindicators appears to be quite limited.

Likewise, an ambitious project that has so far involved nine European countries aimed at developing an index that assesses bat conservation status in the European continent [13]. In that case, a prototype indicator was built from national trends of 16 bat species from nine countries for which hibernacula counts were systematically available. Data were summarised as regional trends and indices, which led to identifying species trends and indices for Europe eventually summarised as a European indicator. As in the UK case, this is a remarkable attempt to reach a good understanding of bat trends in the continent which may inform bat conservation and management. However, the very causes of such trends may be hypothesised but are extremely difficult to be objectively identified: they can be many and waive a tapestry of complex interactions with bat populations, ultimately resulting in the observed responses.

Despite the interest of policymakers and conservationists in employing bats as bioindicators, research lags, and relatively few cases of explicit testing of bat indication performances are available. For example, a simple Scopus search (on 31 January 2021) made using "bats" and "bioindicators" as keywords retrieved 103 documents. Of these, 42 documents addressed the topic in some way, while others were either not strictly relevant or regarded monitoring techniques. In some cases, claiming that bats are useful bioindicators appears more an attempt to emphasise their societal and ecological values and promote conservation than a sound scientific statement based on well-grounded evidence.

Below, we discuss environmental contexts, processes, and management practices for which bats may likely be used as effective bioindicators based on current knowledge.

2.1. River Quality

Many studies showed that rivers often provide rich bat species assemblages with key foraging opportunities and that both water quality and riparian vegetation affect food availability [14]. Biological assessment of river quality is among the main bioindication goals worldwide, and it is therefore somewhat surprising that even this highly promising bat bioindication opportunity has not been tested thoroughly. The few studies published showed contrasting results, yet at least some of them suggest that bats might be useful bioindicators of river quality. In a paper [15] set in England and Wales, the authors developed a predictive model of Daubenton's bat (*Myotis daubentonii*) distribution and abundance at waterway sites based on available monitoring acoustic data. This species is strictly associated with riparian habitats, being perhaps one of the most habitat-specialised bat species in Europe. The model included terms such as biological water quality, waterway width, mean annual discharge, and the presence of trees [15]. The activity was predicted to be higher on larger waterways with abundant woodland nearby but a high amount of site-specific variation was found. The activity was also related to aquatic macroinvertebrate diversity (associated with good chemical water quality). Overall, *M. daubentonii* activity could be predicted from habitat and water quality data, but precision was somewhat too low to apply the model routinely for river quality evaluation. The authors of [16] worked on the same species, this time in the Iberian Peninsula, where they explored correlations between bat activity, as established from monitoring data that had been summarised in the "QuiroRius" index, and two common indices used to characterise river quality (macrobenthos, IBMWP; vegetation, QBR). The weak correlations found showed little agreement among indices, which questions the use of the QuiroRius index for bioindication. This was instead seen as a complementary index that cannot be used alone [16].

Another study [17], carried out in North Carolina, showed more promising results when several bat species were taken into account based on acoustic surveys. Using state-wide water quality information from official biological assessment surveys and urban land cover data, [17] found that bats responded to water quality and urbanisation independently, that responses were species-specific, and that those recorded at the local scale were evident at a landscape scale. The authors concluded that water quality may be used as a predictor for the presence of species of conservation concern, but the study also shows some potential for bat-based bioindication of water quality independent of other landscape stressors such as urbanisation.

Finally, [18] showed that assemblages of foraging bats along Italian rivers were associated with environmental status and quality (Figure 1).

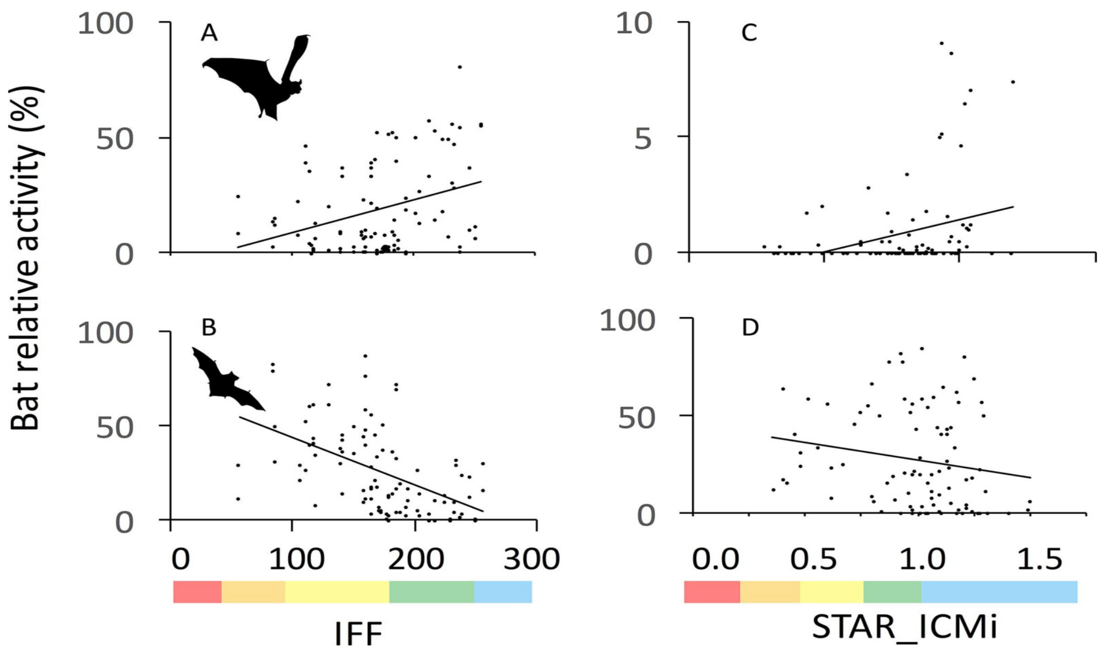

Figure 1. In a study carried out in Italy, bat communities showed significant responses to river quality. The figure shows the relationship between % activity for groups of bat species and the two bioindication indices. (**C**) is a group characterised by similar echolocation calls made of two genera (*Nyctalus* and *Eptesicus*) which were not separated for the purpose of the study; (**A**), (**B**), and (**D**) were groups made by associating species that showed similar responses ("shopping basket" approach) to improve bioindication performances. (**A**) = *Pipistrellus pipistrellus* + *Myotis emarginatus* + *M. nattereri* + *Nyctalus/Eptesicus serotinus* + *Barbastella barbastellus*; (**B**) = *Miniopterus schreibersii/Pipistrellus pygmaeus* + *P. kuhlii*; (**C**) = *Nyctalus/Eptesicus serotinus*; and (**D**) = *M. schreibersii/P. pygmaeus* + *M. daubentonii/capaccinii*. The Fluvial Functionality Index (IFF) is shown on the left, while the macroinvertebrate-based STAR_ICMi index is on the right. River-quality ranges (increasing from left to right) associated to index values are shown below the plots as follows: red = bad, orange = poor, yellow = moderate, green = good, blue = excellent. Reprinted from [18]. Copyright (2018), with permission from Elsevier.

River quality was established according to two officially adopted indices, one (STAR_ICMi) based on macrobenthic invertebrate assemblages and another, the fluvial functionality index (IFF), including a suite of biotic and abiotic features to capture river ecosystem health.

In that study too, bat activity was measured acoustically. Higher activity levels were recorded for some species as the values of quality indices increased, while the activity of other species declined; thus, [18] opportunistically pooled together species showing the same trends, which strengthened the indication performances. These results are encouraging; however, as for the others mentioned above, locally adapted bat populations might show different responses in other geographic regions, so the findings of this study warrant confirmation over a broader geographic range.

2.2. Farming Practices

Many bat species occur in farmland, and despite the well-known influence of farming practices on bat richness and activity suggesting that these mammals might act as suitable bioindicators in agroecosystems (see [19,20] for a review), few studies have explored this issue. Overall, bats show contrasting reactions to low-intensity vs. conventional farmland, probably because the former management category provides resources and conditions that are more generally favourable to a broad range of wildlife [19,20]. This shows, at least, that bats have the potential to be employed as both ecological and environmental indicators of farming practices. One of the big issues to cope with, however, is that bat responses may potentially be due to many factors, often involving different spatial and temporal scales, and are likely influenced by landscape effects. Difficulties in controlling factors acting "beyond plot" as well as "within-plot" variation (hedgerow network size, the spread of pesticides, water availability, cultivation types, etc.) may help explain the contrasting results obtained when comparing bat activity or species richness between organic vs. conventional cultivations. For instance, out of eight studies specifically designed to pursue this goal, four found more bat species or higher activity at organic sites [21–24], one detected a few bat species that were more abundant at organic sites, and three found no difference between organic and conventional farmland [25–27]. However, after rigorously controlling for the characteristics of landscapes surrounding their study sites, [24] found that organic soybean cultivations had higher bat and insect abundance than conventional ones. Noticeably, insect abundance and dry weight (i.e., food availability) only partly explained differences in bat activity, probably because other factors such as the use of pesticides at conventional sites may have had a substantial influence [24].

2.3. Forest Structure and Management

Bats are mostly forest mammals. Many species roost and/or forage in the forest, or use forest patches and corridors for commuting and migration stopovers. The presence and activity of bats in the forest are highly influenced by the forest age and structure, and, in turn, forest management. For example, the availability of suitable tree roosts (and cavities) is highly affected by forest management, which also influences forest heterogeneity, such as the presence of edges, clearings, and undergrowth—features providing foraging opportunities to different bat species, depending on their hunting strategies [28]. For example, coppice (in which trees are cut to ground level and regrow agamically) is a form of management that implies high tree density and small tree diameters, making the forest unsuitable for both roosting and foraging at its core. However, it also generates clearings and edges, which favours feeding by edge specialists such as, in Europe, pipistrelle bats [29]. Well-preserved high forest, hosting many veteran or dead trees rich in cavities and enough space for core foraging, is exploited by many tree-roosting species and ground or foliage gleaners [29]. Therefore, it is expected that bats will exhibit species-specific responses to forest management and that this will concern both roosting and foraging behaviour, setting the scene for the use of these mammals as indicators of forest management. Despite the overwhelming literature that is available on the ecology of forest bats and their conservation implications (e.g., [30]), explicit attempts to use bats as bioindicators in this context are surprisingly rare. In one of such cases, not only were bats found to respond clearly to different management options applied to a range of forest types and structures, but such effects were detected on total bat activity expressed as the sum of all bat passes recorded [31]. This offers a robust, taxonomy-independent approach to bioindication in forest ecosystems. There is also mounting evidence that bats exhibit responses to wildfires [32–34], so bats may offer considerable potential for bioindication of after-fire recovery patterns.

2.4. Urbanisation

Urban areas filter out many mammal species, including bats [35]. Notwithstanding this impact, bats still represent the most numerous urban-dwelling order of mammals, with ca. 80 species out of the over 1400 currently described [35]. At the landscape level, there is a clear negative relationship between the amount of urban space in the landscape and bat richness, and bat richness typically declines along gradients of increasing urbanisation. Although urban areas provide several bat species with considerable roosting opportunities in buildings, prey is often scarce—it is mostly concentrated in green or blue spaces (e.g., [36])—and artificial illumination repels most bat species, apart from a handful of species that exploit insects attracted at lights [37]. Moreover, anthropogenic noise [38] and predation by opportunistic animals such as domestic cats also have adverse effects on bats. As for farmland, singling out the specific drivers that elicit responses by bats can be tricky, but also in urban habitat, there is great potential for bat bioindication, and species richness or community composition are likely to prove effective, at least to highlight urbanisation gradients or urban sustainability.

2.5. Bioaccumulation

Bats typically accumulate chemicals such as pesticides and heavy metals from their food, which is a threat to bat survival but also offers an important opportunity for bioindication [39,40]. For example, flying foxes in Australia proved to be excellent bioindicators of environmental metal exposure: kidney and fur lead concentrations in recent specimens were lower than those recorded in samples taken in the early 1990s. Likewise, insectivorous bats in China were used to study mercury bioaccumulation [41]. In aquatic ecosystems, contaminants are transferred from freshwater sediments to bats through their insect prey, and a water habitat specialist such as *M. daubentonii* provides compelling evidence about bat bioindication potential in this context. Fur samples from this species were taken before and after remediation work (sediment dredging) was carried out at a German pond [42]. Measures made on the sediment after remediation showed only a weak decline in heavy metal content, while a pronounced decline was recorded from bat fur analysis, confirming that this bat species is an effective bioindicator of metal contamination in aquatic ecosystems [42]. The possibility of carrying out analysis on fur makes the approach non-invasive, thus being applicable to mammals at risk, such as bats.

2.6. Climate Change

Bats are widespread across the globe and their physiological requirements are greatly influenced by ambient temperature, which affects life cycle characteristics such as hibernation and reproduction [43]. Bats are therefore likely to react to climate change, yet responses have so far been recorded only in a few species (e.g., [44]). The bat's large body surface makes dehydration a considerable risk that must be prevented by drinking nightly, so climate change-driven disappearance of drinking sites poses a further threat to bats. This dependence upon climate makes bats excellent candidate organisms to indicate biotic responses to climate change, as proposed by [45]. This idea is pursued by the CA18107 COST Action "ClimBats" (www.climbats.eu, accessed on 10 May 2021), a European-Union funded action that, among its several goals, aims at designing monitoring networks spread across Europe to monitor compositional changes in bat assemblages such as to reflect responses to climate change.

2.7. Surrogate Taxa

Surrogate taxa (or biodiversity indicators) are groups of organisms whose species richness may effectively indicate the species richness of other taxa [46] providing a cost-effective way of capturing overall diversity and informing conservation planning, such as in establishing priorities for the selection of areas to be protected. Several groups may also be pooled together to strengthen their bioindication power, in a so-called "shopping basket" approach [47]. It is a common (anecdotal) experience that greater numbers of bat species are found in well-preserved sites where the overall biodiversity of animal communities is also high, whereas degraded environments tend to host a much lower number of bat species [48]. On such bases, using bats as a surrogate taxon would be tantalising; however, while few studies have tested their performances in this respect, such studies also provided contrasting results.

Perhaps the most promising results regard a study carried out in Denmark which used a comprehensive (434) species dataset available from atlases of bats, butterflies, birds, amphibians, reptiles, large moths, and click beetles [49]. In that study, bats and large moths proved as the most robust taxa in selecting grid cells that included the greatest richness of other taxa. In French forests, however, although bats were the most congruent taxon for alpha-diversity with bryophytes and ground beetles, they were classified as a low-cost yet inefficient surrogate group [50]. Likewise, [51] examined four tropical forest types in the Philippines and restricted their analysis to bats, birds, and trees, showing results that discourage the use of bats as a surrogate taxon in those contexts at moderate (100 $\times$ 35 km) spatial scales. Similarly, in Amazonian tropical forests, bats did not show good performances as biodiversity indicators, possibly—as the authors put it—because of bats' specific responses to land-use change and high mobility. In Germany, bats also showed limited potential to predict hotspots of phylogenetic (rather than taxonomic) diversity across species groups including dragonflies, grasshoppers, butterflies, and birds [52]. The study advised against using one taxon as a surrogate for others and highlighted that phylogenetic diversity correlated negatively with the amount of broadleaf forest, probably because specialised forest bats are closely related (such as those in the genus *Myotis*).

All the above-mentioned studies considered different geographic regions, ecosystem types, spatial scales, taxonomic assemblages, data sources or sampling methods, and sometimes even tackled varying goals, which may explain why they led to contrasting findings and, overall, provided a confused general picture.

3. Potential Limitations to the Use of Bats as Bioindicators

The use of bats as bioindicators has pros and cons (Figure 2). The authors of [5] identified eight points on which bases bats would represent excellent bioindicators.

These comprise: (a) relative taxonomic stability; (b) wide geographic ranges; (c) rich trophic diversity; (d) provision of key ecosystem services, (e) graded responses to environmental alteration correlated with those of other biodiversity components, such as insects; (f) rapid population declines due to slow population growth; (g) possibility of measuring several variables (population size, feeding activity, etc.); and (h) the role of bats as reservoirs of emerging infectious diseases whose epidemiology could reflect environmental stress.

Such criteria are therefore a mix of intrinsic features of bat natural history, their correlation with anthropogenic stressors, and practical sampling aspects. While this analysis provides a general picture of the potential value of bats as bioindicators, some of these aspects, as well others, merit further discussion, especially in light of new knowledge on bat biology, ecology, and technology applied to sampling.

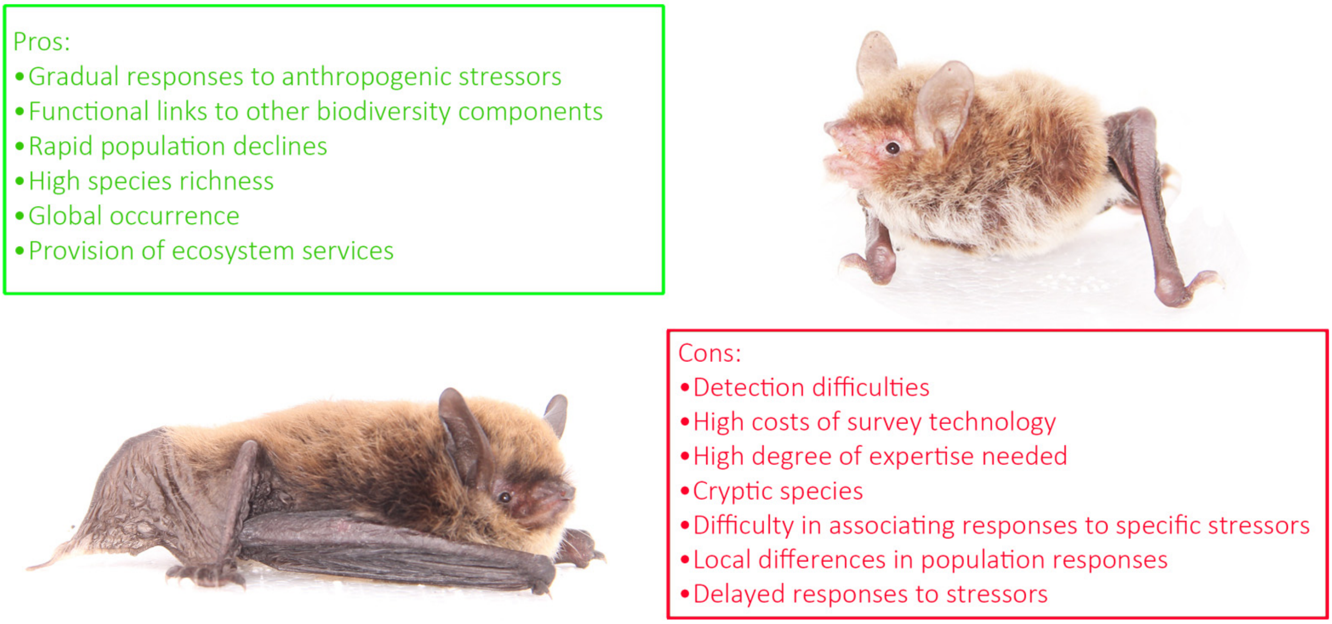

Figure 2. A schematic list of pros and cons of using bats as bioindicators.

3.1. Taxonomical Issues

Bats show relative taxonomic stability compared with many other animal taxa; however, in the last years, their taxonomy has proven relatively fluid due to the advent of molecular approaches that have resolved phylogenetic relationships and revealed many cryptic species (e.g., [53,54]). Even if we limit our analysis to the European region alone, many new cryptic species appeared on the scene in the last few decades. One of the most striking examples is offered by an abundant and widespread European species, the former "common pipistrelle" *Pipistrellus pipistrellus*, which in 1997 was split into two valid species (also differing in echolocation, behaviour, and ecology yet highly similar in morphology), *P. pipistrellus stricto sensu* and *P. pygmaeus* [55]. Since then, molecular analysis revealed the existence of several other cryptic species in Europe, including new *Plecotus* and *Myotis* species [56]. The difficulty of telling apart cryptic species in the field may hinder their usefulness as bioindicators. For example, in the UK biodiversity index, the two cryptic *Myotis* species *M. mystacinus* and *M. brandtii* are lumped together into a single taxon trend due to the difficulty of field distinction between them [12]. Of course, this tendency may not be representative of species-specific population trends because a population decline of one species might be masked by an increase of the other. Moreover, a general consideration for cryptic species pairs or groups is that despite their high morphological similarity, they often show marked ecological differences [57], which leads to different responses to environmental stressors. Using such bat species for bioindication would therefore require reliable identification, a task that may be too specialised, time-consuming, or expensive for large-scale sampling or monitoring.

3.2. Sampling Limitations

Several variables may indeed be measured from bats, which increases their usefulness as bioindicators. However, from a technical viewpoint, bats are not easy to sample. They may be observed directly in their roosts or captured in foraging or drinking sites, as well as along commuting routes, but they are nocturnal, elusive, often evade capture, and are also highly sensitive to disturbance [29]. For this reason, in most countries, permits are needed for bat capture and handling. Capture is necessary to obtain the bat's DNA, normally from skin tissue sampling, and identify confidently cryptic species (e.g., [58,59]. Bat capture and field identification require well-trained personnel, which limits the involvement of volunteers, rangers, and other non-specialised staff. A widespread alternative to capture is acoustic surveying and monitoring, in which echolocation (and, sometimes, social calls) are recorded for subsequent species identification [60]. Variables such as feeding rates may be inferred from counting "feeding buzzes", sequences of echolocation calls broadcast by bats on prey approach [61]. Bat echolocation calls, however, show high intraspecific and even intraindividual variation, while call design converges among species in response to overlapping sensory and ecological requirements [62]. This is the reason why not all species can be recognised with confidence, and despite the advent of automatic classification, it is still wise to refrain from identifying all calls to species. From the bioindication viewpoint, species misclassification is a serious concern, and lumping together similar echolocation calls that cannot be classified to the species level might not provide meaningful information [63]. In other words, acoustic identification may not always provide taxonomic sufficiency, i.e., the degree of identification requested to detect differences in community composition or relative activity that characterise different environmental conditions [64]. Acoustic surveys require the employment of ultrasound detectors and recorders, as well as specialised software for sound analysis, whose costs are still not negligible.

3.3. Disentangling Cause-Effect Relationships

A highly desirable (yet not always necessary) property of a bioindicator is a narrow ecological niche so that the organism will be present (or absent) only under certain environmental conditions, providing discrete responses. For example, among aquatic arthropods, Ephemeroptera, Plecoptera, and Trichoptera (EPT) are highly intolerant to water pollution, so in many cases, their presence can be used to characterise high water quality, and they tend to be absent in polluted rivers [65], albeit with some exceptions (e.g., [66]). As for bats, this is, in many cases, not possible. First, relying on species presence may lead to errors due to limited detectability: bats evading capture or weak echolocators overlooked in acoustic surveys may lead to false absences [67]. Second, especially when using acoustic data, the resulting often-coarse taxonomic resolution may hinder species-specific associations to certain habitats, environmental conditions, or landscape management practices. Even more importantly, most bat species are multiple-habitat specialists [68] that occur in a relatively broad spectrum of environmental conditions. This holds even for relatively specialised bat species, let alone generalists such as, e.g., pipistrelles [69]. For example, the barbastelle bat (*Barbastella barbastellus*), often regarded as a forest specialist, finds optimal reproductive habitat in the unmanaged high forest, so one might be tempted to use barbastelle presence to indicate relatively undisturbed forest (e.g., [70,71]). However, barbastelle bats also frequently occur in logged forests and may even be found on rocky islands with little woody vegetation [72] or in forestless clay badlands ([73]; Figure 3). The species shows *continuous* rather than *discrete* responses to forest structure and management, such as changes in the sex ratio or density of reproductive groups [74].

Although such continuous responses may still be employed for bioindication, value ranges should be defined, and categorisation might be arbitrary and unlikely to remain valid across broad geographic regions or environmental gradients. Variables such as species richness, however, can be more easily used to categorise responses to habitats, land-use change, or environmental stressors, such as urbanisation gradients [75]. Moreover, bats fly over long distances, so they may often cross unsuitable habitats to reach their roosting or foraging sites—one more reason why detecting a given bat species in a certain habitat or under a specific environmental condition might tell us little.

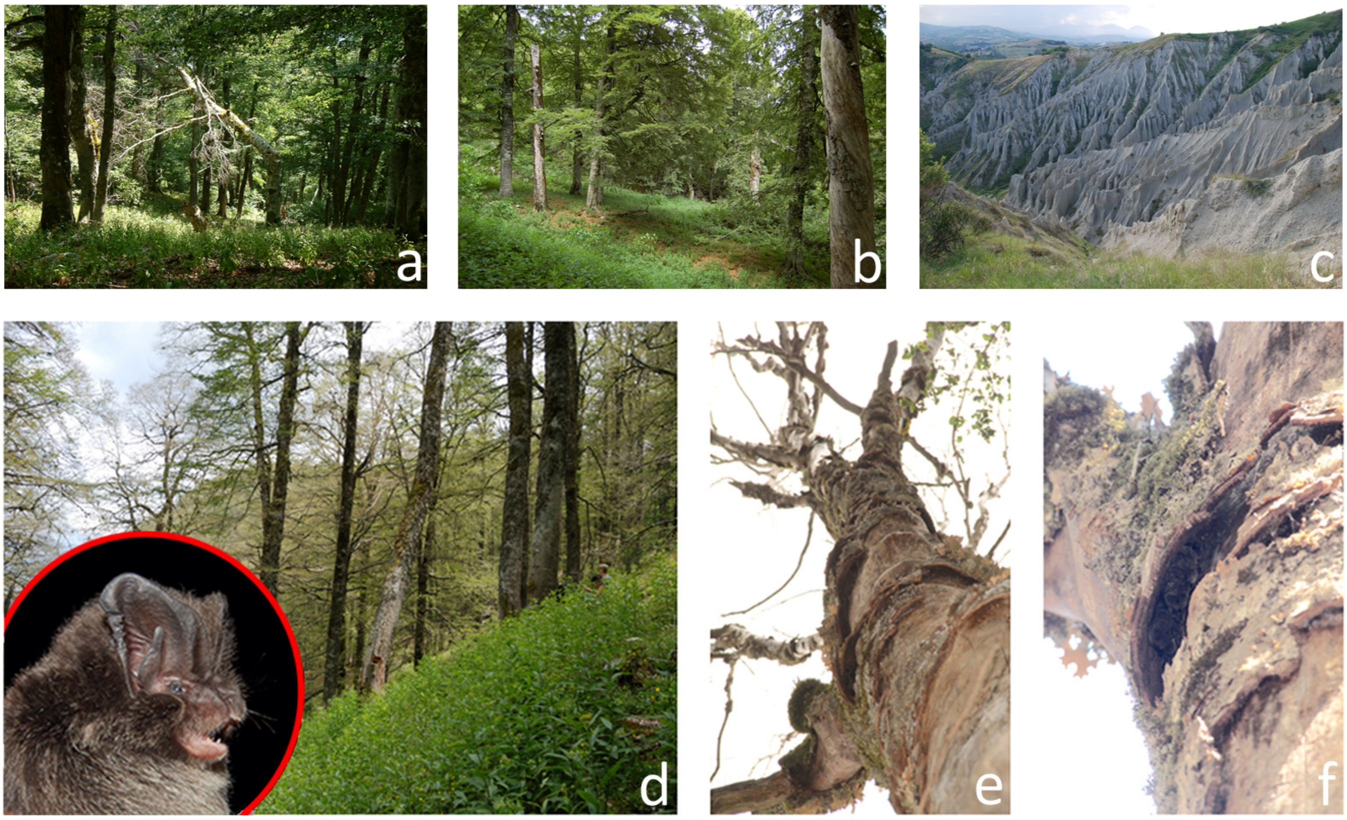

Figure 3. Barbastelle bats (*Barbastella barbastellus*), often deemed forest bats typically associated with unmanaged forest (**a**), may in fact occur in logged sites (**b**) or even in clay badlands (**c**) characterised by few or no trees. The species is sensitive to multiple spatial scales, from landscape/habitat (**d**) to tree (**e**) and cavity (**f**) types. In (**f**), a small reproductive group can be noticed roosting underneath the flaking bark of a beech snag.

Bats find their resources in a range of habitats: roosts, food, and water may occur in separate habitats, so bats may show responses to alteration of any such habitats. Responses to habitat changes may occur even if alteration concerns non-bat habitat. Bat commuting routes, such as those connecting roosts with foraging sites, often cross habitat that contains no bat resource but is still vital to bats to support their movement. Human action may sever commuting routes, for instance, through light pollution [37], and this may have adverse effects on the bat energy budget and ultimately fitness, even if the affected habitat does not contain any resource. Insectivorous bats normally only feed on adult insects, whose abundance will depend on prey reproductive success and larval survival [76]. Therefore, if larval and imaginal stages of prey occur in a different habitat, bats might be affected by the alteration of habitat they do not use directly, provided the latter is important for prey reproduction [77]. Furthermore, bats are sensitive to multiple spatial scales. Following with the example of the above-mentioned barbastelle bat, its habitat requirements span over a broad spatial range (Figure 3), from large-scale connectivity (forest corridors connecting the main roosting areas and mountain ridges delimiting the latter) to specific features of the habitat around the roost tree, the tree itself and the roost cavity [70,71,78–80].

However, why is all this a problem for bioindication? Effective bioindication requires clear reactions to well-identified causes, i.e., a clear picture of which environmental factor or stressor will cause an observed response. Therefore, despite bats' high sensitivity to changes in environmental factors, disentangling the rich tapestry of stressors that often act synergically on bat activity and/or population size is a difficult exercise. Although statistical models such as GLMMs may cope with multiple-variable systems, for instance taking into account the role of several spatial scales (e.g., [81]), the results are often not sufficiently straightforward to translate into a practical bioindication approach. Bat activity is also highly influenced by factors such as temperature [82], wind speed [83], and, according to some authors [84], even moon phase, so that it may vary substantially even between consecutive days or within hours. On a cold spell, bats may even not show up, resulting in false absence. Models testing activity responses need to accurately include such factors.

3.4. Responses May Be Influenced by Local Adaptations

Finally, bat species often cover wide geographic ranges, which is, in principle, a desirable bioindicator quality [5]. However, this does not mean that intraspecific responses to environmental stressors will stay equal across a species' whole distribution. For example, intraspecific differences in bat climatic tolerance may be due to local adaptation and result in different population-scale responses [85]. Extrapolating the interpretation of observed responses (and bioindication applications) to different areas within a species' geographic range may therefore be misleading, which prevents geographic generalisation of bat bioindication approaches.

3.5. Delayed Responses to Environmental Stressors?

Ideal bioindicators should exhibit prompt responses to environmental conditions and their changes, which allow decision-makers to take action swiftly to reverse the trend if needed. From this viewpoint, bats are promising since their low reproduction rates make demographic recovery slow and population declines conspicuous (e.g., [86]). However, one study carried out in Hokkaido (Japan) showed that current bat activity was influenced by past landscapes, i.e., bats adapted to hunt in open space (a "25 kHz" phonic group) were more active where the broadleaved forest was scarcer in the 1950s, and open spaces used to be dominant [87]. This would represent a legacy of once optimal (open-space) sites to which bats remained faithful despite subsequent habitat transformation. On such bases, [87] suggested that bats may undergo time-lagged effects of past environmental conditions, but the study did not control for other factors that might potentially affect the bat population size and activity.

4. Conclusions

There is an ever-growing number of biologists and ecologists who are uncomfortable with proposals of new organisms as bioindicators because sometimes the proposers seem to oversell a certain bioindicator to raise its public profile and achieve better protection rather than to respond to real indication needs. This is risky because it weakens the usefulness of bioindicators and their credibility. Therefore, we should first establish what questions bats can answer, or in which habitats they may act as bioindicators. For example, based on what we discussed, bats are promising bioindicators in riverine systems, and their practically constant presence along rivers, where they act as top predators, fully highlights this potential. The bat's high position in the trophic chain also makes bats especially useful to monitor the presence of contaminants such as pesticides or heavy metals. Bats are protected, so killing them for science poses conservation and ethical problems and is illegal in many countries [88]; however, as we discussed, the presence and concentration of heavy metals may be assessed humanely. Moreover, using bats that die in rehabilitation centres or are killed by, e.g., windfarms provide useful material to carry out measurements of heavy metals or pesticides in bat organs [88].

Bats also offer promising responses to forestry or farming practices, and the main problem of disentangling the specific management factors that cause responses may likely be overcome through ad hoc research [9]. The high sensitivity of bats to temperature changes and water availability also makes bats potentially excellent indicators of climate change. In our view, however, identifying habitats and processes where bats may do well, or better than other organisms as indicators needs new research perspectives, shifting from conservation biology studies to specifically designed protocols that may assess bat responses and standardise their measurement and interpretation. Moreover, networking among researchers is crucial in covering large geographic regions and accounts for location-biased responses that might hinder general patterns. The academic pressure for "novelty" in scientific articles may seriously discourage researchers from replicating studies carried out elsewhere in the geographic regions where they work, but this is an obstacle that the research environment needs to eliminate to test the bioindicator properties of bats. Standardising methods will be another key step towards using bats as bioindicators, at least within indicator types or habitats, perhaps appreciating that bats might in some cases be useful indicators on a small but not large geographic scope.

Other problems that hinder a standardised use of bats as bioindicators are related to the costs of the technology involved in (especially acoustic) bat surveys and the often-coarse taxonomic resolution provided by echolocation call analysis. The former problem is likely to be greatly mitigated, if not solved soon, by the advances in survey technology [89,90]. Taxonomic insufficiency, however, will be overcome only by developing robust indicators, for instance, by testing responses by broader "phonic types" (groups of species sharing similar calls) or overall bat activity: this would circumvent all taxonomic issues. Otherwise, indication applications should be restricted only to species that are identified with confidence.

As many bat species are at risk, their systematic monitoring is mandatory in many countries to assess population trends, and in the EU, bat monitoring is an obligation arising from Article 11 of 92/43/EEC "Habitats" Directive. Therefore, developing monitoring methods that may both estimate bat conservation status and provide applications to bioindication would be a cost-effective approach to accomplish two objectives with one action.

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RESEARCH ARTICLE

Renewable energies and biodiversity: Impact of ground-mounted solar photovoltaic sites on bat activity

Elizabeth Tinsley[redacted] | **Jérémy S. P. Froidevaux**[redacted] | **Sándor Zsebők**[redacted] | **Kriszta Lilla Szabadi**[redacted] | **Gareth Jones**[redacted]

[1]School of Biological Sciences, University of Bristol, Bristol, UK; [2]Biological and Environmental Sciences, Faculty of Natural Sciences, University of Stirling, Stirling, UK; [3]Centre d'Ecologie et des Sciences de la Conservation (CESCO), Muséum National d'Histoire Naturelle, Centre National de la Recherche Scientifique, Sorbonne Université, Concarneau/Paris, France; [4]Department of Systematic Zoology and Ecology, ELTE Eötvös Loránd University, Budapest, Hungary; [5]Centre for Ecological Research, Institute of Ecology and Botany, Vácrátót, Hungary and [6]Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary

Correspondence
Elizabeth Tinsley
Email: [redacted]

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Abstract

1. Renewable energy is growing at a rapid pace globally but as yet there has been little research on the effects of ground-mounted solar photovoltaic (PV) developments on bats, many species of which are threatened or protected.
2. We conducted a paired study at 19 ground-mounted solar PV developments in southwest England. We used static detectors to record bat echolocation calls from boundaries (i.e. hedgerows) and central locations (open areas) at fields with solar PV development, and simultaneously at matched sites without solar PV developments (control fields). We used generalised linear mixed-effect models to assess how solar PV developments and boundary habitat affected bat activity and species richness.
3. The activity of six of eight species/species groups analysed was negatively affected by solar PV panels, suggesting that loss and/or fragmentation of foraging/commuting habitat is caused by ground-mounted solar PV panels. *Pipistrellus pipistrellus* and *Nyctalus* spp. activity was lower at solar PV sites regardless of the habitat type considered. Negative impacts of solar PV panels at field boundaries were apparent for the activity of *Myotis* spp. and *Eptesicus serotinus*, and in open fields for *Pipistrellus pygmaeus* and *Plecotus* spp.
4. Bat species richness was greater along field boundaries compared with open fields, but there was no effect of solar PV panels on species richness.
5. *Policy implications*: Ground-mounted solar photovoltaic developments have a significant negative effect on bat activity, and should be considered in appropriate planning legislation and policy. Solar photovoltaic developments should be screened in Environmental Impact Assessments for ecological impacts, and appropriate mitigation (e.g. maintaining boundaries, planting vegetation to network with surrounding foraging habitat) and monitoring should be implemented to highlight potential negative effects.

Jérémy S.P. Froidevaux and Gareth Jones contributed equally as senior authors.

KEYWORDS
Chiroptera, echolocation calls, energy-wildlife conflict, environmental policy, farmland, green energy, photovoltaic panels, solar farm

1 | INTRODUCTION

Renewable energy is growing at a rapid pace globally, bolstered by almost all countries having renewable energy support policies in place (REN21, 2022). Renewable technology currently contributes an estimated 11% to global "total final energy consumption" with the potential to supply two thirds of total global energy demand, and Europe has the highest proportion of renewable energy and fastest growth in its use globally (Gielen et al., 2019; REN21, 2020; Singhal et al., 2015; Xu et al., 2019). Three technologies contribute the most capacity to global renewable power (3146 GW): hydro-electric (1195 GW 44%), wind (845 GW 25%) and solar photovoltaic (PV) (942 GW 24%), with solar PV increasing by 25% in 2021, the largest annual capacity increase recorded to date (REN21, 2022). The development of solar PV sites within the British rural landscape has grown over the last 10 years from virtually zero capacity in 2010 to over 13 GW capacity in 2020, with the majority of solar installations (92%) being <4 kW developments scattered throughout the landscape (Department for Business Energy and Industrial Strategy, 2021).

Renewable technologies are important in meeting energy demands sustainably, particularly with the associated benefits of favourable economics, low carbon footprints, ubiquitous resources, scalable technology and significant socio-economic benefits (Gielen et al., 2019). In the UK, solar PV has become recognised as the most popular renewable energy technology available to landowners due to opportunities for supporting environmental improvements, such as contributing to sustainable energy, while cutting business costs and providing substantial additional incomes through subsidies and ground rent (Chel & Kaushik, 2011; Jones et al., 2014; Mbzibain et al., 2013). In addition, the solar PV developments are temporary, with a 25–40 year life span, so once decommissioned the installation site can be restored to its original use almost immediately if necessary (Hernandez et al., 2014; Jones et al., 2014).

At present in Europe ground-mounted solar PV developments do not automatically trigger the scoping process for an Environmental Impact Assessment (EIA) (European Commission, 2021). The lack of formal assessment is a concern, as ground-mounted solar PV installation is permissible in undesignated ecologically sensitive areas (Gove et al., 2016). Conservation implications must, therefore, be given consideration when solar PV sites are in development, operation and during decommissioning to ensure any impacts are minimised and mitigated (Gibson et al., 2017). Renewable technologies such as hydro-electric and wind energy are already associated with detrimental effects on wildlife, leading to advice that improved policy and complex trade-off metrics are required to balance biodiversity impacts when planning for meeting energy demands (Holland et al., 2019; Kuvlesky Jr et al., 2007; Popescu et al., 2020). The need to balance wider impacts sparks a complex "green-green" dilemma, where the two desirable goals of clean energy and improved biodiversity have conflicting and potentially unresolvable effects on each other's success (Straka et al., 2020).

A well-considered and applicable decision support tool has been developed in the UK to assess Solar Park Impacts on Ecosystem Services but currently the focus of this is on localised ecological management for co-benefits rather than the initial appropriate and sensitive siting of developments within the ecological landscape (Randle-Boggis et al., 2020). Making this initial assessment is important to ensure that strategic decisions for land allocation align with energy policy (Popescu et al., 2020). This is particularly important as ground-mounted solar PV may have mixed to negative impacts on biodiversity.

On one hand, ground-mounted solar PV sites have the potential to positively influence biodiversity across the agricultural landscape where the existing land management does not consider ecology, and biodiversity is poor. For example, when properly sited, sensitively designed with biodiverse planting beneath and surrounding the panels, and carefully managed with ecological preservation in mind, the assigned land has the potential to develop a habitat network for pollinating species at a landscape scale and provide ecosystem services, including pest management to local crop production (Armstrong et al., 2021; Blaydes et al., 2021; Semeraro et al., 2018). This network approach could also make it possible to compensate for any cumulative and potentially detrimental impacts of developments near each other.

On the other hand, and despite the benefits of renewable energy in tackling energy demand and climate change, utility-scale solar PV developments are considered to potentially cause negative effects on biodiversity (Gielen et al., 2019). The alteration of land use, land cover, soils and water resources result in changes to microclimate and hydrological conditions, which have direct and indirect impacts on ecosystems (Hernandez et al., 2014; Pizzo, 2011). The resultant change can cause three key ecological effects: habitat loss and fragmentation, microclimate changes, and behavioural alterations, all of which may introduce barriers to relatively sedentary species by disrupting gene flow, while also reducing habitat availability for wide-ranging species which may disperse beyond the development sites (Hernandez et al., 2014; Pizzo, 2011), such as flying animals.

Bats are valuable bioindicators of change in ecological systems, as well as providing ecosystem services such as pest suppression, particularly in agricultural landscapes (Aguiar et al., 2021; Boyles et al., 2011; Jones et al., 2009; Kemp et al., 2019; Russo & Jones, 2015; Russo et al., 2018, 2021). This is in part due to their wide-ranging distributions and their position at the top of food chains, meaning they are affected by factors which have altered the prevalence of other species, such as habitat loss and fragmentation that may decrease the availability of invertebrate prey (Jones et al., 2009; Park, 2015; Russo & Jones, 2015). In the UK, 18 bat species comprise a third of all mammal species (Mathews et al., 2018). As such understanding the interactions of bats with solar PV installations is crucial in ensuring their protection, and to determine any effects on ecosystem health and services.

Parallels can be drawn between land development for solar PV and for wind turbines, especially in terms of habitat modification. Bats have been studied extensively in relation to wind energy, encompassing fatalities at turbines potentially caused by collision, flight paths affected by vortices, turbines being mistaken for roosts, used as mating sites and because insect prey can be attracted to turbines (Baerwald et al., 2008; Cryan, 2008; Cryan & Barclay, 2009; Cryan et al., 2014; Dahl et al., 2012; de Jong et al., 2021; Horn et al., 2008; Rydell et al., 2016; Voigt et al., 2022). Wind turbines also cause habitat loss due to bats avoiding surrounding wind turbines farms (Barré et al., 2018, 2022; Minderman et al., 2012, 2017). Successful mitigation has been developed accordingly, including curtailment and using acoustic deterrents (Adams et al., 2021; Arnett et al., 2013; Baerwald et al., 2009; Mitchell-Jones & Carlin, 2014; Weaver et al., 2020).

The potential implications of solar PV developments on bat species in Britain, as well as other wildlife, segments into direct and indirect impacts (Chock et al., 2021). A key potential direct impact is that bats may collide with solar panels, as bats perceive smooth, horizontal surfaces as water, and will approach such surfaces attempting to drink (Greif & Siemers, 2010; Greif et al., 2017; Russo et al., 2012). The indirect impacts of solar panels on bats may be subtler, with panels potentially increasing reflective temperature at night following a day of hot weather and also altering microclimate by blocking sunlight, rainfall and affecting drainage potentially reducing the availability of invertebrate prey (Froidevaux, Louboutin, et al., 2017; Horváth et al., 2010; Pizzo, 2011). In addition bats may actively avoid solar PV sites, as a consequence of habitat loss and fragmentation as solar energy can require large land footprints (Pang et al., 2014). A recent comparison of bat activity in solar farms and adjacent habitats in Hungary indicated that while some bat species may exploit solar farms others avoid them (Szabadi et al., 2023).

Despite the potential impacts solar PV sites could have on bats, there is no empirical evidence to inform their appropriate siting or informed mitigation because the effects of solar PV panels on bats have not been tested empirically yet. Thus, the aim of the study was to assess the potential impacts of ground-mounted solar PV sites on bat activity and bat species richness. More specifically, our objectives were to investigate species-specific bat activity and bat species richness in different habitats (field boundaries and open fields) within ground-mounted solar PV sites in the UK in simultaneous comparison with matched sites nearby that did not contain solar PV panels (control sites). Due to bats generally avoiding anthropogenic alterations, we predicted reduced activity and species richness at ground-mounted solar PV sites (Bender et al., 1998; Coleman & Barclay, 2013). We also predicted that bat species would be mainly affected at their foraging/commuting habitats, that is open space foragers will show reduced activity in fields containing solar PV panels, whereas species that utilise edge and cluttered habitats would be more affected along boundary habitats.

2 | MATERIALS AND METHODS

2.1 | Sampling design

We implemented a paired study design across 19 solar PV sites to assess whether bat species richness and activity were higher in fields and along boundary habitats that contained PV panels, compared with "empty", matched control sites. This resulted in 19 sampling points for solar boundary habitat, 19 for solar open habitat, 19 for control boundary habitat, and 19 for control open habitat. All sites were located in south-west England, where the highest concentration of solar PV sites and greatest bat species richness in the UK coincide (Department for Business Energy and Industrial Strategy, 2021; Mathews et al., 2018). Where private land was entered, permissions were granted by land owners and the relevant solar farm companies. No ethical approval was required for this study as we passively monitored bats through acoustic recordings.

The control sites were within the same land management boundary as the solar PV site, and matched as closely as possible in plot size, habitat type, land use and boundary habitats. There was no difference in the average size of solar PV and control fields (solar PV mean = 59.6 ha, SD = 32.0; control mean = 53.2 ha, SD = 28.4; paired *t*-test: $t(18) = 1.3$, $p = 0.203$) (see Appendix S3 in Supporting Information). All solar PV sites were on grassland that was either grazed or managed through mowing or were on cut arable crops. Field boundaries corresponded to hedgerows, treelines, woodland or vegetated ditches and were exactly matched. The paired fields were a minimum of 500 m apart and not adjacent to each other to maximise the chances of obtaining independent data within comparable landscapes (Froidevaux, Louboutin, et al., 2017).

2.2 | Bat echolocation call recording and species identification

Fieldwork was completed between July and October 2019 and the same period in 2020. Bat activity was monitored for seven consecutive nights at each site (30 min before sunset to 30 min after sunrise), simultaneously across the four locations (open and boundary habitats within the field with solar PV panels and paired control). Recordings were made using SM3 bat detectors (Wildlife Acoustics, Inc.). All detector microphones (SMM-U2f [frequency response +/− 6 dB 20–100 kHz see [redacted] Wildlife Acoustics) were elevated to 1.27 m using identical tripods. Detectors were set to auto trigger between 8–120 kHz and 1–88 dB and recorded for a maximum of 10 s (384 kHz, sampling rate). A detector was placed within the centre of the control and solar fields, and along the associated boundary habitats of the control and solar fields. Detectors recording the open and boundary habitat within the solar and control field were a minimum of 50 m apart.

Sampling took place during optimal weather condition for bats to forage (i.e. no rain, low wind speed and temperature >10°C). The mean (±SD) temperature at dusk over the recording period was 16.2 ± 3.1°C [redacted]

Sound files were analysed using zero crossing software Kaleidoscope Pro (v. 5.4.1, Wildlife Acoustics, Inc.) with Bats of Europe Classifiers (United Kingdom) (v. 5.4.0) selected. All 10 s recordings were automatically scanned and the call sequences were identified and then manually checked to confirm the species (*Barbastella barbastellus*, *Eptesicus serotinus*, *Pipistrellus nathusii*, *P. pipistrellus*, *P. pygmaeus*, *Rhinolophus ferrumequinum* and *R. hipposideros*) or species group (*Nyctalus* spp., *Myotis* spp., *Plecotus* spp.). The grouping of *Myotis* spp. is widely used due to the difficulty of separating the echolocation calls of the different species (Russ, 2012). Similarly *Nyctalus noctula* and *N. leisleri*, as well as *Plecotus auritus* and *P. austriacus* could not always be separated so these calls were grouped as *Nyctalus* spp. and *Plecotus* spp., respectively. All files which Kaleidoscope Pro could not automatically assign a species to were identified manually (Russ, 2012).

All files which Kaleidoscope Pro classified as "Noise" (195,375 files) were run through the full spectrum software Bat Classify [redacted] This was to ensure no call sequences within the large number of "Noise" labelled files were missed. Following analysis, 0.5% of labelled files were randomly checked to ensure that the automated identification was reliable (Rowse et al., 2018). For all call sequences with >80% certainty in the automated identification, the classification to species was accepted, except for *Myotis* species where >50% certainty was accepted to ensure call sequences were not excluded from the dataset. These parameters were designed to apply a precautionary approach based on the Precision-Recall metric of the Bat Classify software [redacted]

2.3 | Statistical analysis

All analyses were performed in R statistical software v.4.1.1 (R Core Team, 2021) and all statistical tests were considered significant at $p < 0.05$. We performed generalised linear mixed-effect models (GLMMs) with "GLMMTMB" package (Brooks et al., 2017) to assess the effects of PV panels on species-specific bat activity and bat species richness in agricultural landscapes. Echolocation call sequence data were pooled by site and location over the seven-night period, and we defined bat activity as total number of bat call sequences for species or species groups. Due to their low occurrences (<40% of the sites), *R. hipposideros* and *P. nathusii* were disregarded for the analysis on species-specific activity. GLMMs on bat species were fitted with a Gaussian distribution (since diagnostic plots were largely unsatisfactory with Poisson or negative binomial distributions) and we applied a squared transformation to the response variable to meet the normality assumption. GLMMs on bat activity were fitted with a negative binomial distribution and we employed zero-inflated models when necessary. We included the presence/absence of PV panels (treatment: solar vs. control site) in interaction with the habitat type surveyed (boundary vs. open field) as explanatory variables while pair ID were considered as random factors to account for the paired-sampling design.

We also included in the models landscape variables that could potentially affect bat activity in agricultural landscapes, including the proportion of urban, arable land, grassland and broadleaf woodland, and the Euclidean distance to the nearest watercourse. For area-based landscape variables, we considered eight spatial scales (buffers ranging from 250 m to 10 km radii) to qualify local habitats around each site, and to encompass the wide foraging ranges of the bat species studied (Laforge et al., 2021). Landscape variables were derived in QGIS using the Land Cover Map (Environmental Information Data Centre, 2019) (20 m resolution) supplied by the Centre of Ecology and Hydrology. When comparing solar PV sites with control sites no statistical differences occurred in the distance to the nearest water source, or in cover of arable land, grassland, broadleaved woodland or urban areas at the different spatial scales with the exception of cover of grassland and arable habitat surrounding the control and solar PV site at the 250 and 500 m scales (Appendix S2). To reduce the number of landscape variables and avoid model overparameterisation, we assessed independently the relationships between the response variables and each landscape variable using GLMMs with the same model structure as described above (i.e. including the same random effect and the interaction and using the same distribution family). We compared the second-order Akaike information criterion (*AICc*) of each model with the model that included the interaction only and retained in the final models only landscape variables at their best scale of effect (Martin, 2018) that led to lower *AICc* (i.e. $\Delta AICc \geq 2$) (Burnham & Anderson, 2002). For highly correlated variables (Spearman coefficient correlation $|r| > 0.7$), we retained the one leading to lower *AICc*. From the final full models, we finally ran post hoc pairwise comparisons corrected for multiple testing using the Tukey method in the "LSMEANS" package (Lenth, 2014). Residual diagnostics were checked with the "DHARMA" package (Hartig, 2022). We also checked for multicollinearity, overdispersion, influential outlier and zero inflation with the "PERFORMANCE" package (Lüdecke et al., 2023).

3 | RESULTS

3.1 | Bat acoustic sampling

A total of 133 nights of recording took place simultaneously on each of the four bat detectors across 19 different sites, resulting in 532 individual nights of recording. This produced a total of 51,464 call sequences, comprising 10 species or species groups. The bat species most frequently recorded was *P. pipistrellus* (24,017 call sequences) with over twice the number of recordings of any other species or species group. The species most infrequently recorded were *P. nathusii* and *R. hipposideros* (106 and 170 call sequences, respectively). All species or species groups were recorded at each of the treatments (solar vs. control site) and habitat features (boundary vs. open field) (Table 1).

3.2 | Effect of solar PV panels on the activity of bats

Overall, we recorded more bat activity at the control sites than the solar PV sites, and more bat activity at the boundary habitats compared to the open field (Table 1). We found statistical evidence that the activity of six of eight species/species groups (i.e. *E. serotinus*, *Myotis* spp., *Nyctalus* spp., *P. pipistrellus*, *P. pygmaeus* and *Plecotus* spp.) were negatively affected by solar PV panels (Table 2 and Figure 1). For all these taxa, our full models on bat activity that included the presence/absence of solar PV site in interaction with the habitat type were more informative than the null one ($\Delta AICc > 2$; Appendix S1 in Supporting Information).

The effects of solar PV panels on bat activity were largely dependent on the habitat type investigated. Only *P. pipistrellus* and *Nyctalus* spp. were significantly, negatively affected by solar PV panels regardless of the habitat type considered. For other taxa, our models indicated a significant negative effect of solar PV sites on *Myotis* spp. and *E. serotinus* along the boundary habitats at the solar sites compared to control ones while *P. pygmaeus* and *Plecotus* spp. were significantly less active in the open habitat at solar sites compared to control ones (Table 2 and Figure 1). Finally, we found no difference in bat species richness between habitats at the solar sites and matched control ones.

3.3 | Effect of habitat type and landscape variables on the activity of bats

Regardless of the presence/absence of solar panels, all species/species groups (except *Nyctalus* spp. and *Plecotus* spp.) were significantly more active along field boundaries compared with open fields ($p < 0.05$). Similarly, there was greater bat species richness at field boundaries compared with open fields (See Appendix S1).

Arable land cover at the largest scale (10 km) positively influenced *B. barbastellus* activity and urban area at the largest scale had a positive effect on *P. pipistrellus* (See Appendix S2 in Supporting Information). Grassland cover had a significant positive effect on *E. serotinus* activity (500 m radius scale) and *Nyctalus* spp. activity (1 km radius scale). The number of species recorded was greater on farms located near freshwater sites.

4 | DISCUSSION

Our predictions regarding bat activity were largely supported, though species-specific differences were apparent. For several species, there was lower activity in fields with solar PV panels, in both open and boundary habitats, compared to matched fields without solar PV panels. Specifically, solar PV sites had a

TABLE 1 The number of bat call sequences recorded at boundary and open habitats at matched control and solar photovoltaic (PV) sites. Totals are for seven consecutive nights of recording at 19 habitat replicates in each column. [Correction added on 23-Aug, after first online publication: The values for "*Myotis spp.*" have been updated in this version.]

Species	Control, boundary	Solar PV, boundary	Control, open	Solar PV, open	Total
Barbastella barbastellus	314 (2.36 ± 3.6)	437 (3.29 ± 6.3)	31 (0.23 ± 0.6)	28 (0.21 ± 0.52)	810 (1.52 ± 3.88)
Eptesicus serotinus	1569 (11.8 ± 34.8)	457 (3.44 ± 12.31)	316 (2.38 ± 4.53)	155 (1.17 ± 3.73)	2497 (4.69 ± 19.1)
Myotis spp.	5816 (43.73 ± 103.92)	2529 (19.02 ± 39.85)	915 (6.88 ± 15.26)	755 (5.68 ± 6.68)	10015 (18.83 ± 58.16)
Nyctalus spp.	1283 (9.65 ± 13.65)	899 (6.76 ± 9.56)	1463 (11 ± 15.14)	773 (5.81 ± 7.24)	4418 (8.3 ± 11.98)
Pipistrellus nathusii	29 (0.22 ± 1.13)	25 (0.19 ± 0.95)	37 (0.28 ± 0.93)	15 (0.11 ± 0.81)	106 (0.2 ± 0.96)
Pipistrellus pipistrellus	11,855 (89.14 ± 163.04)	7156 (53.8 ± 121.64)	4404 (33.11 ± 96.48)	602 (4.53 ± 5.46)	24,017 (45.14 ± 116.45)
Pipistrellus pygmaeus	4176 (31.4 ± 138.77)	1219 (9.17 ± 16.65)	781 (5.87 ± 12.64)	250 (1.88 ± 5.48)	6426 (12.08 ± 70.96)
Plecotus spp.	472 (3.55 ± 4.4)	462 (3.47 ± 8.07)	941 (7.08 ± 13.13)	265 (1.99 ± 2.25)	2140 (4.02 ± 8.28)
Rhinolophus ferrumequinum	182 (1.37 ± 3.51)	565 (4.25 ± 16.84)	38 (0.29 ± 0.78)	80 (0.6 ± 2.52)	865 (1.63 ± 8.82)
Rhinolophus hipposideros	100 (0.75 ± 2.13)	62 (0.47 ± 1.24)	3 (0.02 ± 0.15)	5 (0.04 ± 0.23)	170 (0.32 ± 1.27)
Total	25,796 (193.95 ± 327.67)	13,811 (103.84 ± 160)	8929 (67.14 ± 120.64)	2928 (22.02 ± 19.31)	51,464 (96.74 ± 201.9)

Means ± SDs of bat passes/night/site are presented in brackets after the totals, with 7 nights at each of 19 habitat replicate sites.

TABLE 2 Results of the post hoc pairwise comparisons applied to the GLMMs relating the effects of the presence/absence of solar photovoltaic panels (treatment: solar vs. control site) in interaction with habitat type (boundary vs. open field) on species-specific bat activity and bat species richness.

Dependent variable	Pairwise differences: Control versus solar	Est. & SE	*t* value	*p*
Species richness[a]	Boundary	−0.35 ± 4.82	−0.07	0.942
	Open	5.23 ± 4.82	1.09	0.282
Barbastella barbastellus activity	Boundary	0.06 ± 0.31	0.15	0.836
	Open	0.11 ± 0.41	0.26	0.795
Eptesicus serotinus activity	Boundary	1.23 ± 0.44	2.79	0.007**
	Open	0.74 ± 0.46	1.62	0.109
Myotis spp. activity	Boundary	0.69 ± 0.30	2.26	0.027*
	Open	0.14 ± 0.31	0.44	0.661
Nyctalus spp. activity[b]	Boundary	0.55 ± 0.22	2.54	0.013*
	Open	0.46 ± 0.21	2.19	0.032*
Pipistrellus pipistrellus activity	Boundary	0.80 ± 0.37	2.17	0.033*
	Open	1.31 ± 0.43	3.06	0.003**
Pipistrellus pygmaeus activity	Boundary	0.51 ± 0.42	1.21	0.232
	Open	0.93 ± 0.42	2.22	0.030*
Plecotus spp. activity	Boundary	0.23 ± 0.29	0.77	0.446
	Open	0.90 ± 0.30	3.02	0.004**
Rhinolophus ferrumequinum activity	Boundary	0.17 ± 0.60	0.28	0.782
	Open	0.81 ± 0.71	1.14	0.257

[a]Species richness was modelled using a Gaussian distribution. We applied a squared transformation to the response variable to meet the normality assumption.

[b]We employed a zero-inflated model to account for excess zeros in the response variable.

Est.: estimate, SE: standard error of the estimate. $^{**}p \le 0.01$, $^{*}p \le 0.05$, $p \le 0.10$.

significant, negative effect on six out of the eight bat species and species groups analysed. *Eptesicus serotinus* and *Myotis* spp. had significantly lower activity along the boundary habitats at solar PV sites, compared to equivalent features at control sites. *Pipistrellus pygmaeus* and *Plecotus* spp. had significantly less call sequences recorded in the open habitat at solar PV sites compared with the centre of control fields. *Pipistrellus pipistrellus* and *Nyctalus* spp. were negatively affected by solar PV sites in both habitats (open and boundary habitats).

Hedgerows and connective features are important commuting and foraging features for bats (Froidevaux, Boughey, et al., 2017; Leroux et al., 2022). The significantly reduced numbers of *E. serotinus* and *Myotis* spp. along boundaries bordering PV solar sites suggests that the panels may be causing some bats to alter their flight paths, potentially resulting in further fragmentation of the ecological landscape. The reduced number of *P. pygmaeus* and *Plecotus* spp. in the open habitats suggests that solar PV is resulting in habitat loss for these species. *Nyctalus* spp. and *P. pipistrellus* were the only species found to be significantly affected at both open and boundary habitats.

We found that bat species that feed in both cluttered (some *Myotis* species) and edge habitats (*E. serotinus*) were affected along boundary habitats, and that species that feed in open space (*Nyctalus* spp.), cluttered (*Plecotus* spp.) and edge habitats (*P. pipistrellus*, *P. pygmaeus*) (Denzinger & Schnitzler, 2013) were negatively affected by the presence of solar panels in the open fields. *Barbastella barbastellus* and *R. ferrumequinum* activity did not differ between any of the sampling locations, which compliments results found in a similar study of solar farms. This may be due to the smaller sample size for these species providing low statistical power, their foraging strategies meaning the sampling habitat was not favourable, or because the panels where inconsequential for these species. The impacts of solar PV on bat activity are therefore best assessed on a species-specific basis, rather than trying to pool risk categories as has sometimes been done for other renewable energy technologies such as wind farms (Scottish Natural Heritage et al., 2021).

Our findings share some similarities with a recent study from Hungary (Szabadi et al., 2023), where *P. pygmaeus* (compared with open grasslands) and *Myotis* spp. (compared with both open

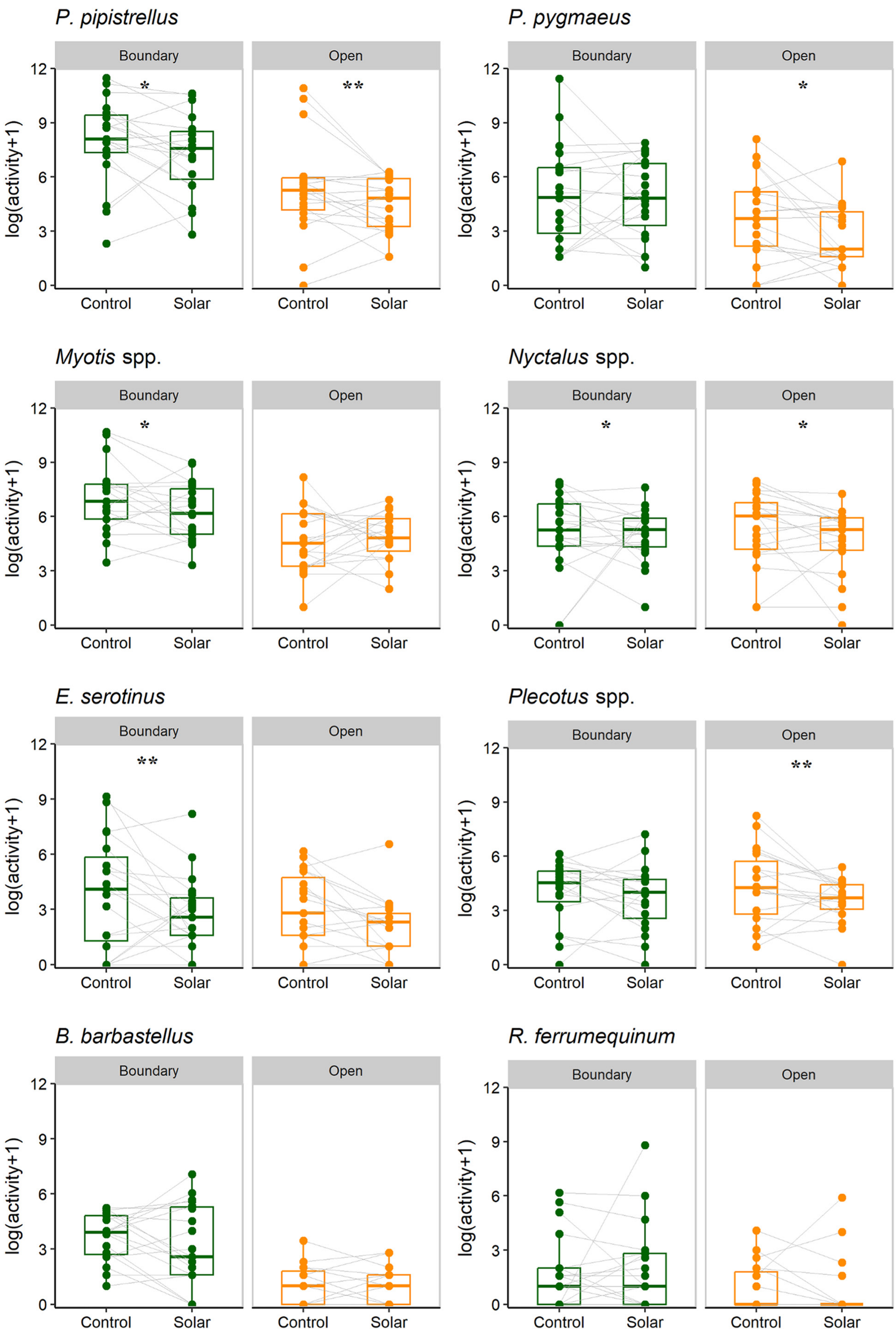

FIGURE 1 Boxplots showing medians and interquartile ranges of species-specific bat activity (i.e. total number of bat call sequences per site on a logarithmic scale to the base 2) at control and solar PV sites. Dots represent raw data with paired sites linked with a grey line. $^{**}p < 0.01$ and $^{*}p < 0.05$.

grassland and forest) showed lower activity at solar PV sites. Hence, solar PV sites may reduce bat activity over broad geographical scales.

The implications of these findings for bat conservation are considerable and understanding why solar PV sites are negatively affecting bat species is crucial, as has been done for other renewable energies (Frick et al., 2020). Bats are known to be affected by anthropogenic noise (Jones, 2008; Luo et al., 2014, 2015; Schaub et al., 2008), development associated with urbanised environments (Jung & Threlfall, 2016), the presence of smooth surfaces (Greif & Siemers, 2010; Greif et al., 2017; Ingeme et al., 2018) and habitat fragmentation (Meyer et al., 2016) all of which can be associated with ground-mounted solar PV sites.

There has been a "lack of consistency among evaluation or assessment methods" when assessing the ecological footprint of solar panels and other renewable energies (Burger & Gochfeld, 2012), as well as a disconnection between energy models and ecological assessment in policy which is well established in economic and emission modelling (Pang et al., 2014). In Europe, under legislation (The Conservation of Habitats and Species Regulations, 2017) it is an offence to deliberately disturb wild animals including bat species (Regulation 43, (1b)) and to affect significantly the local distribution or abundance of the species (Regulation 43, (2b)). The potential significant direct and indirect disturbance caused by solar PV on British bats foraging and commuting habitats, means that their impacts on bats should be assessed under legislation (The Town and County Planning (Environmental Impact Assessment) Regulations, 2017). This is in line with wind turbine developments and other energy generation projects.

Under this process, we suggest appropriate effort should be given to assess the presence of bats roosting, foraging and commuting within close proximity to the proposed development location due to the known risks of bats not tolerating anthropogenic disturbance, as detailed above. Where necessary, mitigation to support bats should be designed and activity should be monitored over extended periods. Mitigation may include, but is not limited to, reducing the density of panels within the site footprint, ensuring boundary habitat is maintained and improved in its area and diversity, and ensuring appropriate planting to improve foraging resources for those species identified as being at risk from the development (Boughey et al., 2011; Olimpi & Philpott, 2018). This should take place both within the solar PV sites and in the surrounding area. Where a solar PV site is proposed in proximity to a roost, or on a known important commuting route, of the species which have so far been identified as affected, then consideration should be given to whether alternate siting of the development, at a less sensitive location within the ecological landscape, would be more appropriate.

Further research is required to assess bat behaviour at and in proximity to solar PV sites to understand why some bats avoid solar PV sites, for example for example whether prey sources are negatively affected by solar PV developments or potentially panels are creating a collision risk with bats attempting to drink from them (Greif & Siemers, 2010; Greif et al., 2017; Horváth et al., 2010; Russo et al., 2012). Further work should be for the purposes of ensuring focused and effective mitigation that can be implemented and monitored through the EIA process.

Our study identifies some detrimental effects of solar PV sites for bat activity, and as such we conclude that assessing, mitigating and monitoring bat activity needs to be factored into solar PV development planning and operation. As highlighted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services and the Intergovernmental Panel on Climate Change biodiversity loss and climate change will continue to mutually reinforce each other unless tackled simultaneously (Pörtner et al., 2021). Successful mitigation measures at solar PV developments will be an opportunity to manage climate change while supporting biodiversity.

AUTHOR CONTRIBUTIONS

Elizabeth Tinsley, Gareth Jones and Jérémy S. P. Froidevaux conceived the ideas and designed methodology; and Elizabeth Tinsley collected the data; Elizabeth Tinsley and Jérémy S. P. Froidevaux analysed the data. Elizabeth Tinsley, Gareth Jones and Jérémy S. P. Froidevaux led the writing of the manuscript. All authors contributed critically to the drafts, including Sándor Zsebők and Kriszta Lilla Szabadi, and gave final approval for publication. *Statement of inclusion*: we include authors who contributed towards writing from a country outside of where the study was conducted.

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CONFLICT OF INTEREST STATEMENT

The authors do not have a conflict of interest.

DATA AVAILABILITY STATEMENT

Data are available via the Dryad Digital Repository [redacted] (Tinsley et al., 2023).

ORCID

Elizabeth Tinsley [redacted]
Jérémy S. P. Froidevaux [redacted]
Sándor Zsebők https://orcid.org/0000-0003-4463-4753
Kriszta Lilla Szabadi [redacted] 1
Gareth Jones h [redacted]

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. Table S1. Outputs of the full GLMMs relating the effects of the presence/absence of solar photovoltaic panels (treatment: solar vs. control site) in interaction with habitat type (boundary vs. open field) on species-specific bat activity and bat species richness. Marginal and conditional R^2 as well as delta *AICc* between the full and the null models are given. Delta *AICc* >2 indicates that the full model was more informative than the null one. Est., estimate; SE, standard error of the estimate.

Appendix S2. Table S2. The mean area (ha) of different landscape variables found around each of the recording sites/distance (km) to water to the control and solar study sites. Habitats were identified as per the UK Land Cover Map 2020. Pairwise comparisons were conducted using the Wilcoxon test for paired data. Significant differences are indicated in bold.

Appendix S3. Table S3. The approximate area (m^2) of the solar and control field at each site, with the corresponding open and boundary habitat where the bat detectors were placed. Open habitat management type: 1 grazed, 2 mown, 3 arable, Boundary habitat type: 4 hedgerow, 5 treeline, 6 woodland, 7 wet ditch.

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