GI Base 2.0: Database of Scotland's Green Infrastructure plants

Project Final Report

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1 Executive summary

We are currently witnessing a revolution in the way we gather and use evidence: for example, in the fields of medicine and aviation, our planes and drugs have become safer and more effective because statistical tools can be deployed to quickly apply new findings to practice (Sutherland, 2023), and we have the potential to see a similar leap in green infrastructure. Green infrastructure comprises all the plants we find in human-modified landscapes, from those planted as solitary street trees and integrated in sustainable drainage schemes to semi-natural habitats. Together, these plants form networks that provide critical ecosystem services and to this end, this leap is urgently needed: the biosecurity and climate risks of using ill-fitted plants are well known, and recent research (Watkins et al., 2022) has found that fewer than a quarter of landscape developments are planted with the density and diversity of species that are approved by the local authority, presenting major blind spots in our understanding of the ecosystem dynamics in our green infrastructure.

Optimising plant selection in Green Infrastructure for ecosystem service delivery and biosecurity is now fundamentally a procurement challenge: our research shows that the ecological principles that underpin ecosystem functioning are increasingly understood by practitioners, and the barriers to progress are a lack of high quality, evidence-based data, compounded by supply chain issues. As such, the commercial horticulture sector has a performance gap both in the technical resources to select the best plants and the means by which contracts and skills are handled between clients and contractors.

Responding to these twin needs, we carried out the following steps to develop an evidence base that meets the demands of specifiers and suppliers, and a process for structuring curated data on plant performance in ways that fit with emerging digital design workflows.

Steps taken in this report	**Key finding**
We surveyed professionals across the Green Infrastructure sector, investigating the processes of plant selection and perspectives on recently developed schemes for managing plant health.	There is a growing demand amongst practitioners for high quality data to inform plant selection and decision-making.
Using the Planning Portals, we updated GI Base 1.0 by reviewing soft landscape proposals submitted by developers in Scotland, and identified the species diversity and abundance of plants used in Green Infrastructure projects across the country.	GI professional outputs are weighted towards securing planning permission rather than details and specifications, resulting in a homogenisation of urban habitats across Scotland.
We undertook a horizon scan of invasion debt amongst the plants grown in horticulture in England, Wales and Scotland, and identified species of concern that are not currently assessed by the Non Native Species Secretariat.	Plants recognised in law and policy as invasive or likely to become invasive are routinely specified in GI projects in Scotland.

We assessed the Defra Plant Health Risk Register and re-engineered it so that it could be searched by plant host, and then built a composite score for biosecurity risk of the species and genera in the Risk Register.	There are opportunities to make the PHRR more accessible to GI practitioners.
In the final step, we developed a template for organising plant data in generated in (3) and (4) that can be integrated within the digital workflows of each sector in the Green Infrastructure industry.	Software-agnostic digital tools and resources can be developed that would align the information used by GI industries to specify and procure plants, representing an opportunity to manage biosecurity risks at scale.

As a consequence, this report sets out a way of achieving a step change in the resilience and functioning of Scotland's urban habitats, with a cross-sector framework for the implementing next steps. In particular, this report highlights the importance of embedding the Plant Health Strategy for Scotland in the Green Infrastructure industry through the development of complementary training and tools that can be used by all sectors. This will require closer working between the appropriate Scottish Government directorates and the industry bodies, and taking advantage of the increasing use of digital services to design, grow and procure plants.

We identify several steps that would enable this transformational change to be implemented:

- The evidence base that is used for decision making can be significantly improved:
  - Plant Health Risk Register maintained by Defra should be accessible in two formats, organised from the perspectives of pests and the plants that they are associated with, and then revised to fill in gaps in coverage.
  - Plant performance data that integrates plant physiology, biosecurity risk, invasiveness traits, ecosystem service delivery, climate fitness and aesthetic criteria should be standardised across the Green Infrastructure sectors.
- Within the design and procurement process, a suite of software-agnostic digital resources that organise these data should be agreed and maintained by an industry body.
- At a national level, the introduction of a planning condition that requires the submission of a Biosecurity Management Plan (e.g. for five years) before construction can start would be a relatively light touch means for embedding a cross sector approach to managing plant health at landscape scales. The submitted plan should include:
  - The maintenance phase where any plant health or invasive species issues can be flagged and reported as they arise.
  - A responsible person checking plants as they arrive to make sure that they are the specified species and that they are healthy.
  - Maintaining the integrity of planting designs to prevent specified plants being swapped out at the time of planting due to supply chain issues. If plans are able to include a ranked list of suitable replacement species, this can also help limit the chance of an INNS species being used.

    - Standard definitions of provenance should be included to take into account local adaptation and the possibility of maladaptation of introduced provenances.
    - A template assessment to help developers evidence that their plan will deliver positive effects for biodiversity.
    - Consideration needs to be given to enforceability due to the differing legislation in England and Scotland.
- The above will require significant biosecurity and invasive species awareness raising and training for professionals so that plants aren't misidentified and plant health issues can be spotted and reported as soon as they develop. This could be along the lines of existing guidance such as "be plant wise", but tailored to a professional audience.
- Key recommendations of the Plant Health Strategy for Scotland (e.g. "build on existing engagement mechanisms to reach all sectors and citizens" and "explore strengthening biosecure procurement… and potential to improve plant health awareness within industry supply chains") should be followed to address the unique types of habitat fragmentation, disturbance and biological novelty that are associated with urban environments, and in turn, biosecurity risk.
- Collaboration between Scottish Government directorates (Rural and Environment Science and Analytical Services and the Planning, Architecture and Regeneration Directorate) on three areas:
    - Development of a requirement for a Biosecurity Risk Management Plan for major projects as a condition of Planning Approval.
    - Engagement with the construction and horticulture sectors, to secure cross-sector support for standardised data that can be used by all parties in supply chains and digital design workflows.
    - Review of the potential for using GIBase in risk forecasting and targeted engagement with the construction industry.
- Development of CPD materials specifically for Green Infrastructure professionals, raising awareness of the new data resources and capabilities of the digital assets.

A core finding from this project is that conceptually, a re-framing of the Plant Health Risk Register so that a comparative understanding of plant hosts is accessible to GI and lay audiences is feasible and necessary, but that a significant degree of research and development will be needed to achieve this. To this end, the Cumulative Mitigated Risk Rating presented here and in Appendices should be seen as hypotheses awaiting further data to refine them.

2 Introduction

The roles that ornamental plants play in our towns and cities are documented in more detail and are better understood than ever before: we can categorise their benefits using the ecosystem services framework, quantify these services using natural capital accounting and then set policy targets and establish public payments based on natural capital delivery. But these benefits are only part of the picture: just as progress is made in understanding the value of these plants, we see more clearly the challenges presented by climate change and urbanisation. The causes and impacts of biosecurity risk and climate change can be seen in our urban environments, with habitat fragmentation, landscape surfaces and urban layout all contributing to the creation of novel plant communities, interrupted hydrologies and urban heat islands and in turn, the increasing levels of stresses that plants experience. These existential threats to our urban environments are compounded by biosecurity risk, with plants more vulnerable to the pests and diseases that are part of the natural environment (aside from novel introductions) as a result of these new and increased stresses. The concept of Green Infrastructure is increasingly recognised as a way of integrating the designed networks of natural and semi natural habitats in legal, planning and design professions, and although this concept has different but overlapping interpretations between professions and internationally (Matsler *et al.*, 2021), it remains a useful framework for navigating the shifting political landscape. At the same time, public momentum and international policy for positive environmental change has never been stronger, presenting an opportunity to set and reach ambitious goals.

The question of how we deliver this change is the motivating force behind this research. Studies show that species vary significantly in their ability to deliver ecosystem services (Goodness *et al.*, 2016) but the Green Infrastructure (GI) sector currently lacks effective tools to select the species that exhibit the characteristics they need. When it comes to designing with plants, it is too easy for a designer to see the outward characteristics of a tree: for example, the white bark of *Betula utilis var. jacquemontii* or the clusters of orange fruit of *Sorbus* 'Joseph Rock', rather than the physiological processes that determine the tree's ability to adjust to soil water deficits or atmospheric humidity. There are exceptions: Chapter 4.2 of the National House Building Council Standards (NHBC, 2024) requires housing developers to consider the relative differences between trees in terms of water uptake and as a consequence, their potential influence on subsidence near new houses but it also does a number of other, less desirable things at the same time. The Standards force designers to think about plants at the level of the genus, prioritises a single characteristic above all others and constrains our ability to harness and respond to multiple criteria. In this study, we found that prioritising water uptake by trees over ecosystem service provision, fitness, or contribution to landscape character has led to short-lived, often out-of-scale trees such as *Prunus* 'Amanagowa' and *Betula pendula* becoming the cornerstone species in the UK's urban landscapes, demonstrating the unintended consequences and outsize impacts of a single piece of regulation on an entire industry.

The fundamental challenge that the GI sector is faced with is resolving constraints on industry-scale change. Chapter 4.2 of the NHBC Standard is one of many resources that exist to aid decision making, yet many of the concerns expressed about the diversity and resilience of urban forests thirty years ago (Johnston, 2012) continue to be researched today, and although the demand for greater species diversity is increasing, it is not yet clear that the public momentum behind environmental enhancement is translating into change in species selection at an industry level. This may be in part a result of confusion amongst professionals about how to interpret the available guidance, which draws on a range of heuristic and research perspectives. For example, the widely used 10:20:30 rule (Santamour, 1990) was drawn up with the aim of increasing urban forest diversity by focusing on taxonomic criteria, whilst horticultural (Bassuk *et al.*, 2009) and autecological frameworks (Sjöman *et al.*, 2010) have also been proposed. Alongside these different conceptual frameworks, there are numerous research strands active at present, considering species selection from the perspective of individual traits such as pollution interception (Blanuša *et al.*, 2020), invasiveness or flower colour (Conway, 2016), and guidance that aims to provide a whole-tree perspective on plant functioning (Hirons and Sjöman, 2018) or using climate-matching tools to inform species selection (Watkins et al, 2020a). However, these many different types of resource point to an underlying problem that has yet to be articulated or addressed: that each of these resources assumes that species selection is a design challenge, whereas in practice, specification is part of a much wider procurement and management process that includes design, bringing together many different professional expertises and value systems.

Preliminary studies carried out in PHC2019/05 showed that there are major blindspots in GI design and planting: only 24% of Scottish development schemes are delivered in accordance with the proposals that are approved by local planning authorities, whilst planting palettes are shown to rely on small species diversity (5 tree species make up 50% of all tree species chosen by designers) and do not reflect Local Plans or Landscape Character Assessment guidance (Karlsdottir et al., 2021). These issues are emphasised by the findings of PHC2019/05 and the subsequent follow-up project (Marzano et al., 2023), which demonstrated the difficulties of engaging with the hard-to-reach sectors of the supply chain, making new guidance slow to be implemented.

To overcome this, GIBase 1.0 was developed as part of PHC2019/05. This database recorded the plants specified in a sample of large scale green infrastructure projects planned in England and Scotland, with the aim of providing industry and policy makers with a resource that could be used to understand the abundance and diversity of plants being specified in industry. Such a resource has multiple applications, from building a picture of the national, cumulative consequences of decisions made at local scales, to providing insights into biosecurity risk and ecosystem service delivery.

Since the publication of GIBase 1.0 we have undertaken extensive industry consultation to explore how the findings might lead to change in the procurement and supply of plants for planting. Anecdotal evidence from this engagement identified that further work was needed to develop a suite of tools that could be used by industry to better specify plants, and to meet this need, this report undertook five steps to build an evidence base and propose a solution to the challenges the industry faces:

1. We surveyed professionals across the Green Infrastructure sector, investigating the processes of plant selection and perspectives on recently-developed schemes for managing plant health.
2. Using the Planning Portals, we updated GI Base 1.0 by reviewing soft landscape proposals submitted by developers in Scotland, and identified the species diversity and abundance of plants used in Green Infrastructure projects across the country.
3. We undertook a horizon scan of invasion debt amongst the plants grown in horticulture in England, Wales and Scotland, and identified species of concern that are not currently assessed by the Non Native Species Secretariat.
4. We assessed the Defra Plant Health Risk Register and re-engineered it so that it could be searched by plant host, and then created an example method to build a composite score for biosecurity risk of the species and genera in the Risk Register.
5. In the final step, we developed a template for organising plant data generated in (3) and (4) that can be integrated within the digital workflows of each sector in the Green Infrastructure industry.

This report presents an updated version of the GIBase database, complemented by extended research into the biosecurity risks associated with the plants used in green infrastructure (note: this project relies on used 'major development' applications on Scottish local authority planning portals as its data source, e.g. larger housing or commercial building developments, and therefore does not include activities such as woodland creation or habitat restoration projects that are not primarily managed through the planning process). Chapter 3 provides a brief review of research into the ways in which plants are specified in the GI industry, and Chapter 4 sets out the methods and results used to gather and analyse data that describe how plants and plant health issues are managed across the GI industry, including the gathering and analysis of plant specification data, stakeholder engagement, and analysis of recent policy developments. In Chapter 5, we set out how the GI database is structured, with references to the database itself, which is attached as an Appendix to this report. To ensure that the information in GIBase 2.0 is accessible to all users and professionals working in GI, it is essential to present the information in ways that are compatible with industry-specific workflows. In GI design, Building Information Modelling holds significant promise and has demonstrated considerable benefits in civil engineering and architecture, but is constrained in the professional fields relating to plant specification: the issue is that product information is much easier to set out for inert materials like bricks or utilities services than it is for living organisms, such as plants. To this end, we produced data sheets (Product Data Templates - PDTs) for a sample of plants used in urban planting schemes in Scotland that can be incorporated into the GI designer's digital workflow. Finally, in Chapter 6, we set out next steps for implementing industry-scale change and provide a concluding summary of the report in Chapter 7.

3 Industry perspectives on the plant selection process

In spite of the industry emphasis on 'the right tree for the right place', it is not necessarily the case that green infrastructure projects achieve this in a consistent way. Figure 1 illustrates the different criteria considered by landscape architects when considering tree selection (Watkins et al., 2020b). The answers highlight the importance placed by green infrastructure designers on performance (e.g. ecosystem service provision, stress tolerance), even though there is little guidance available that provides information about these criteria. The question of whether these are the right selection criteria is a different, separate question that is under-acknowledged in the design sectors: in order to deliver policy goals, for example, the first questions that a designer needs to ask of a plant is whether it will survive under current or future conditions, alongside whether a particular plant poses biosecurity risks. Only once satisfactory answers are found should the potential benefits delivered by a plant be assessed: this is at odds with the selection literature and value systems of most landscape architects, who consider the potential ecosystem services to be the most important characteristic of a plant. This situation is widely acknowledged as a problem within the industry but until now, has yet to be addressed directly. This survey (Watkins et al., 2020b) identified a further potential issue for the professions working in green infrastructure, which is that language is often used to mean different things: an ecologist and a nursery worker would have very different interpretations of terms such as 'provenance' or 'hardiness', highlighting the need for a shared vocabulary that provides a common basis for decision making.

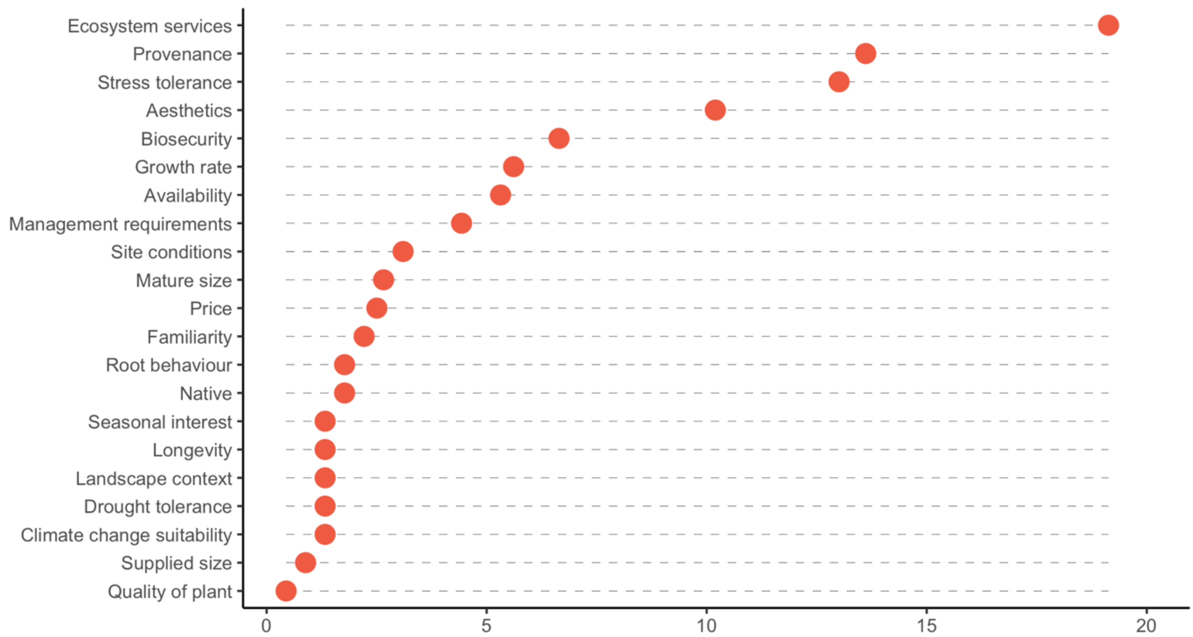

Figure 1. *The relative importance of species selection criteria considered by landscape architects in the UK (x axis shows percentage of responses). 136 responses; taken from Watkins et al., 2020b.*

Having identified the value systems embedded in the plant selection process, we looked at the context that these decision are made in by asking green infrastructure professionals how their time is allocated during a project contract. Figure 2 assesses the amount of time spent in practice on different stages of a project by landscape architects. This finding illustrates that most landscape architects spend most of their time working on the early stages of a project, carrying out landscape assessments and securing planning permission. This entails thinking at a high-level of abstraction in terms of spatial layout and material selection, and as such, a different type of knowledge and experience is often used to that needed for effective species selection, and the aim at these early stages is to set the criteria for a detailed design rather than actually resolving those details at that stage. This process is relatively straightforward for hard landscape materials: it is much easier, for example, to establish criteria for paving to have a specific level of recycled aggregate content and be of a specific colour, texture and dimension at an early stage of the design process (i.e. before the planning application is submitted) and then work with a supplier to match those criteria, than it is to establish criteria for a range of ecosystem service provision, aesthetic criteria and landscape fitness and then find taxa that meet those criteria in later stages of the design process.

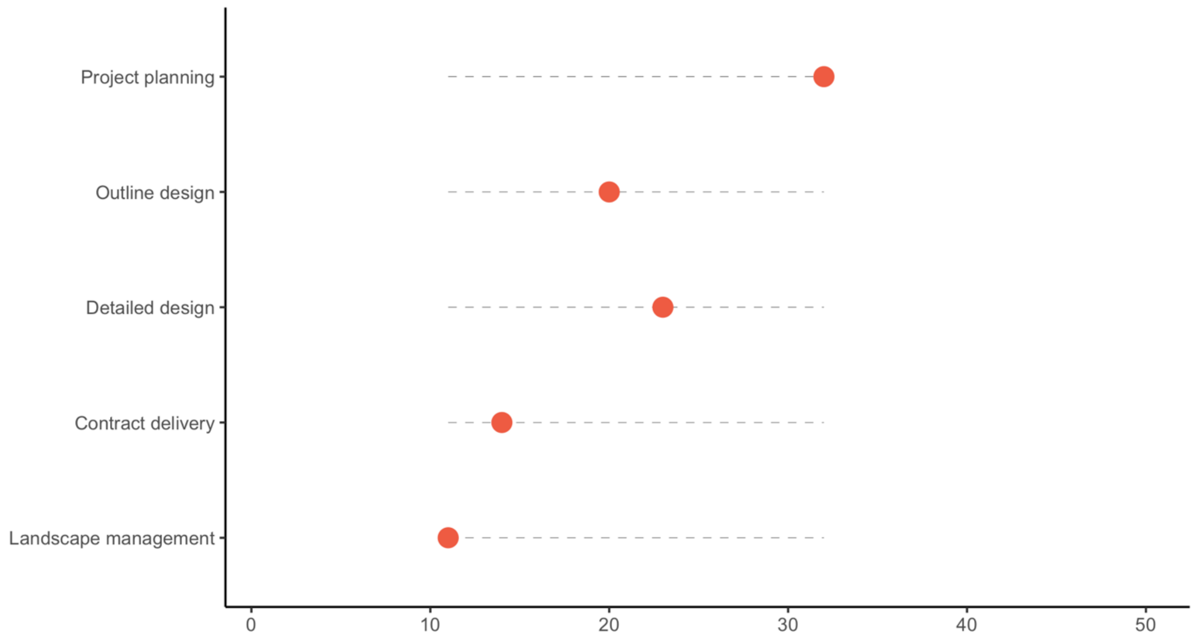

Figure 2. *The proportion of time spent on each stage of work by landscape architects. 138 responses; taken from Watkins et al., 2020b.*

Figure 3 shows which types of literature are most commonly used by designers. In spite of the poor quality of much of the heuristic literature, designers tend to rely upon specification guides provided for free by nurseries or horticultural sources such as encyclopaedias. However, these sources are inherently poorly-suited to the task for which they are used: the horticultural literature is intended to be used by gardeners with ample time and resources to spend on cultivation, whilst nursery catalogues are largely intended to sell plants, rather than provide robust and independent information.

By contrast, the academic literature tends to be niche and difficult to access, resulting in a poor transfer of knowledge between researchers and practitioners, whilst the design softwares are the least well-used, in spite of their unique advantage of being specifically designed for use by the sector.

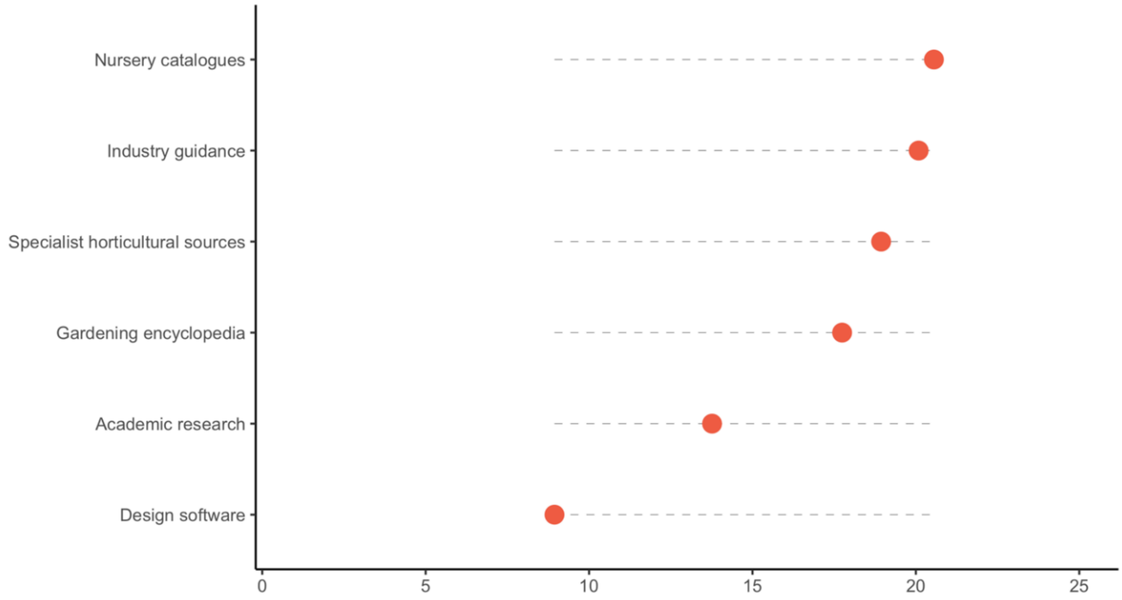

Figure 3. *The species selection literature used by landscape architects (x axis shows percentage of responses). 178 responses, taken from Watkins et al., 2020b*

The development industry relies on complex design, procurement and management systems which are often subject to changing commercial objectives and team composition. In a study carried out for Plant Health Centre Scotland (Karlsdottir et al., 2021) we explored the consequences of the practices identified in the Fitter Flora scoping report (Watkins et al., 2020b). Common to almost all development projects in the UK is a requirement for Planning Permission to be granted by the Local Planning Authority (LPA) before construction can begin; in order for Planning Permission to be granted, a developer is required to submit information about their project, detailing the types, quantities and design of materials that will be used in the project in a way that complies with the objectives of the LPA. For public transparency and engagement, this information is required to be stored in publicly-accessible formats. As such, the Planning Portals which store this information hold considerable promise for studying the large-scale and detailed trends in landscape decision-making; by accessing these portals to download landscape specifications we were able to compare the specifications drawn up by developers with the planting practices that are actually realised, finding that only 24% of schemes approved by local authorities comply with the approved details in the planning documents.

Numerous initiatives and research exercises are being undertaken to try to address some aspects of the questions relating to supply and procurement but building a regional or national picture of trends and practice until this point has proved difficult. This is partly a result of the complexity of the development industry (Awwad, Shibani and Ghostin, 2020) but the professionals working in this industry (eg landscape architects, contractors, planners, developer clients) have for a long time been difficult to engage with (Watkins and Brace, 2018), and the number of stakeholder engagement exercises being conducted in the recent past has led to stakeholder fatigue, exacerbating the challenge. Karlsdottir et al., 2021 showed significant differences between the designs that are approved by Local Authorities and the specifications of the plants that are actually planted, leading to a number of urgent recommendations being made to policy makers. To ensure that the data generated through this study could be accessed by researchers and practitioners as well as policy makers, we published GIBase, a database of plants specified in developments in the UK using data derived from Planning Portals across England and Scotland (Watkins et al., 2021).

4 Methods and Results

4.1 Plant selection in practice: extending GI Base

4.1.1 Methods

The first iteration of the Green Infrastructure database (GIBase 1.0; Watkins et al., 2022) provides data on the plants that are specified in large scale green infrastructure projects in England and Scotland. The data in this version were sourced from detailed drawings and plant specifications held on UK planning portals maintained by local authorities, as part of their function to record information that is submitted during the planning process.

In the first instance, the aim for GIBase was to provide policy makers with a snapshot of the abundance and diversity of plant species that are selected by the green infrastructure industry, which is to say, to provide a national-level understanding of the cumulative decisions that are taken by consultants and professionals. The database can therefore be used to address questions such as the risk of outbreaks from pests and pathogens, ecosystem service delivery, plant invasion risk, or variation of planting design in response to landscape character or location.

GIBase 1.0 considered a relatively small sample of projects from across England and Scotland (22 sites) and in this project we focused the sampling on local authorities in Scotland and repeated the methods to include 126 projects from across 24 local authorities. The full methods are set out in the original database publication (Watkins et al., 2022) but in brief, this entailed conducting searches of planning portals using keywords, eg 'soft landscape', 'landscape', 'general arrangement', 'layout plan' and 'green infrastructure' and assembling a dataset of technical drawings. Results were screened to include only those applications submitted within the past five years (2018-2023); the relevant documents were then downloaded and the plant data transcribed and anonymised with location recorded as decimal latitude and longitude to two decimal places.

4.1.2 Results

The results presented in GIBase 2.0 provide a high resolution understanding of the plants that are specified in Scottish green infrastructure projects, with some exceptions. The principal issue we came across was that local authorities in Scotland vary greatly in the types of information required from developers (or their agents) to discharge planning permission consents: in some instances, the specifications and drawings were detailed and consistent, meeting the level of resolution set out in Stage 4 of the RIBA Plan of Works, whilst others accepted outline specifications that are more generally consistent with stages 2 or 3 (which only provide indicative species names and quantities). We aimed to identify at least six projects within each local authority, although this was not possible in all cases (see Table 1).

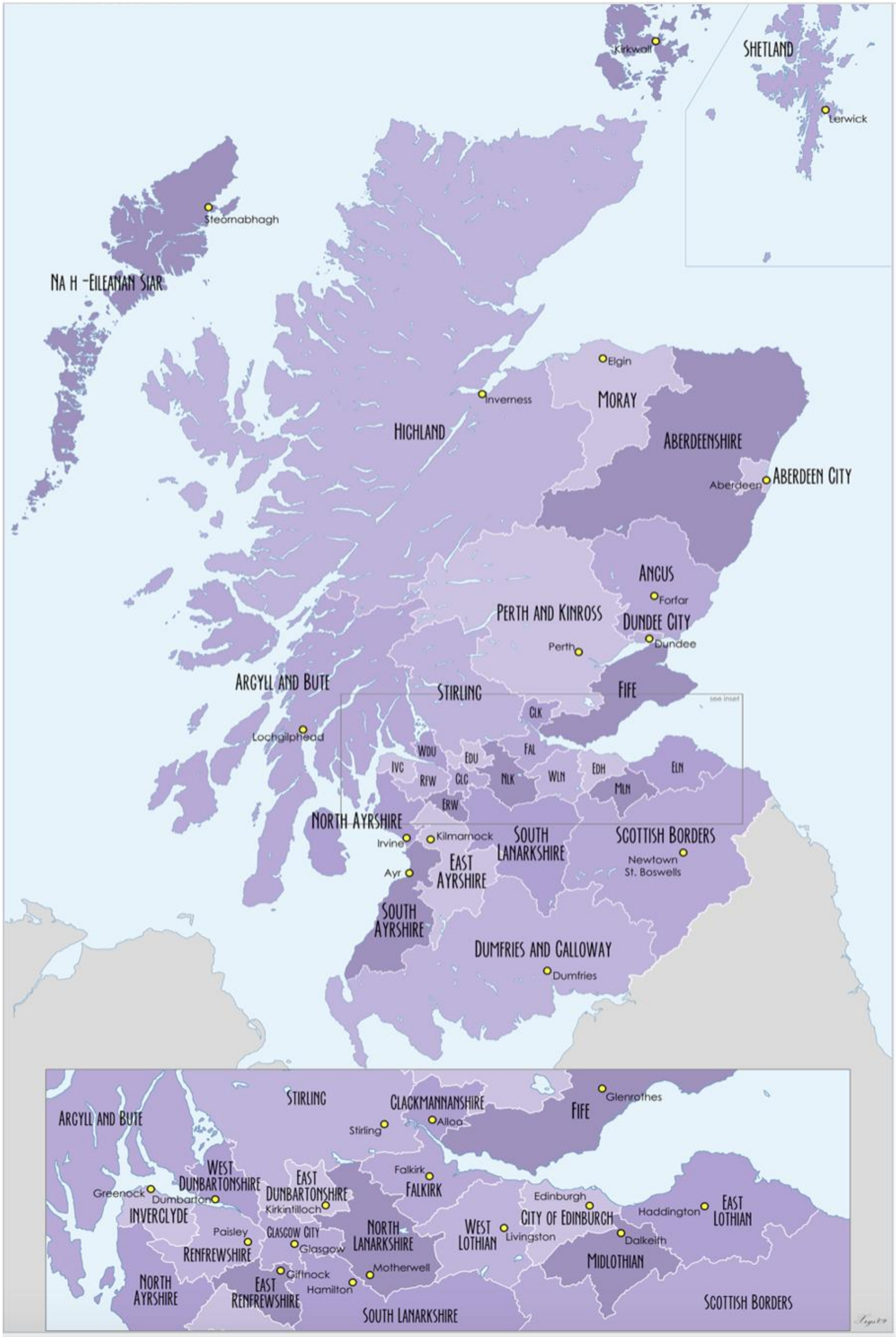

Figure 4. Local authorities included in GIBase 2.0

Nevertheless, the data contained in v2.0 represents a major step forward, with 126 projects included and over 687,500 plants, highlighting the major role that urban green infrastructure plays in Scotland's habitats. For reference, during the period considered in this study, planning applications for a total of 1,351 major developments were submitted in Scotland (Scottish Government, 2024), meaning that c. 10% of all developments were assessed as part of the project.

Table 1. Number of projects included in GIBase 2.0 for each local authority

Council	Number of projects included in GIBase 2.0
Aberdeen City Council	6
Aberdeenshire Council	6
Angus Council	6
Argyll and Bute Council	1
City of Edinburgh Council	6
Clackmannanshire Council	3
Comhairle nan Eilean Siar	0
Dumfries and Galloway Council	6
Dundee City Council	6
East Ayrshire Council	6
East Dunbartonshire Council	5
East Lothian Council	0
East Renfrewshire Council	3
Falkirk Council	4
Fife Council	6
Glasgow City Council	6
Inverclyde Council	2
Midlothian Council	6
North Ayrshire Council	6
North Lanarkshire Council	6
Orkney Islands Council	0
Perth and Kinross Council	6
Renfrewshire Council	6
Scottish Borders Council	2
Shetland Islands Council	0
South Ayrshire Council	4
South Lanarkshire Council	6
Stirling Council	4
The Highland Council	3
The Moray Council	6
West Dunbartonshire Council	0
West Lothian Council	1

The full data are set out in Appendix 1 and a summary of the most widely specified plants is provided in Tables 3-9. These highlight a number of important findings, including:

- The requirements for plant specifications vary significantly in specificity between local planning authorities, making it difficult for nurseries and contractors to manage planting stocks and respond efficiently to tender queries.
- This is compounded by numerous instances of historic nomenclature, spelling errors, and inconsistent practices for setting out planting quantities and densities.

- The diversity of plants used by designers remains low: the ten most frequently specified shrubs account for 47% of all shrub species and the top ten trees account for 77% of all trees.
- The range of plants selected suggest that designers rely on habit to select species when choosing between closely-related similar plants. For example, we found specifications for 514 for *Amelanchier canadensis* vs *A. laevis* (6), *Euonymus alata* (1) vs *E. fortunei* (6,304), and *Crataegus laevigata* (24) vs *C. monogyna* (38,128).
- Small trends in plant selection were found, with a decrease in usage of *Lonicera nitida* and *L. pileata*, found in comparison to GIBase 1.0 for example.
- Some species used widely by other sectors which use plants for planting such as forestry, agriculture or domestic horticulture (eg, within the genera Abies, Picea and Platanus) were not widely used in green infrastructure.
- The selection of plants does not appear to vary by location or project type, with no strong or significant correlations found in ANOVA studies.

Tables 3-9. The most frequently specified tree species in Scotland, separated by life forms.

Top 10 climbing species (5 taxa total)	**Qty of plants**	**% of total climbers specified**
Hedera helix	6,883	79%
Parthenocissus tricuspidata	1,223	14%
Hedera colchica	432	5%
Parthenocissus henryana	110	1%
Hydrangea anomala	19	<1%

Top 10 fern species (12 taxa total)	**Qty of plants**	**% of total ferns specified**
Polystichum setiferum	4,718	23%
Dryopteris wallichiana	3,401	17%
Dryopteris filix-mas	3,273	16%
Polypodium vulgare	3,107	15%
Polystichum polyblepharum	2,569	13%
Dryopteris affinis	1,894	9%
Polystichum aculeatum	549	3%
Dryopteris cristata	294	1%
Matteuccia struthiopteris	294	1%
Polystichum munitum	209	1%

Top 10 geophyte species (21 taxa total)	**Qty of plants**	**% of total geophytes specified**
Galanthus nivalis	21,049	31%
Crocus speciosus	12,800	19%
Narcissus Yellow Trumpet	10,435	15%
Narcissus pseudonarcissus	8,873	13%
Hyacinthoides non-scripta	6,164	9%
Galanthus elwesii	3,115	5%
Fritileria meleagris	2,500	4%
Crocus vernus	1,225	2%

Crocus chrysanthus	334	<1%
Crocus tommasinianus	167	<1%

Top 10 graminoid species (43 taxa total)	**Qty of plants**	**% of total graminoid plants specified**
Stipa tenuissima	5,159	28%
Carex elata	1,711	9%
Luzula nivea	1,323	7%
Miscanthus sinensis	1,075	6%
Luzula sylvatica	1,016	6%
Calamagrostis x acutiflora	926	5%
Deschampsia cespitosa	865	5%
Festuca glauca	813	4%
Molinia caerulea	781	4%
Lolium perenne	677	4%

Top 10 herbaceous perennial species (182 taxa total)	**Qty of plants**	**% of total herbaceous plants specified**
Geranium pratense	4,249	5%
Teucrium scorodonia	3,960	4%
Liriope muscari	3,664	4%
Anemone nemorosa	3,553	4%
Alchemilla mollis	3,240	4%
Blechnum spicant	3,233	4%
Persicaria bistorta	3,156	4%
Geranium Dragon Heart	2,750	3%
Erythronim spp.	2,500	3%
Geranium macrorrhizum	2,408	3%

Top 10 shrub and hedge species (240 taxa total)	**Qty of plants**	**% of total shrubs specified**
Crataegus monogyna	38,128	12%
Photinia x fraseri	20,017	6%
Prunus spinosa	18,637	5%
Corylus avellana	16,425	5%
Prunus laurocerasus	15,734	4%
Escallonia CF Ball	11,851	3%
Ligustrum vulgare	9,963	3%
Rosa canina	9,918	3%
Ilex aquifolium	8,952	3%
Prunus lusitanica	8,489	3%

Top 10 tree species (122 taxa total)	**Qty of plants**	**% of total trees specified**

Fagus sylvatica	64,181	40%
Carpinus betulus	17,510	11%
Pinus sylvestris	14,572	9%
Sambucus nigra	9,293	6%
Sorbus aucuparia	9,113	4%
Betula pendula	5,978	3%
Acer campestre	5,387	2%
Alnus glutinosa	3,895	2%
Taxus baccata	3,868	2%
Quercus petraea	3,004	2%

4.2 Biosecurity risk assessment in green infrastructure: invasive non-native species

4.2.1 Methods

GIBase 1.0 found that the invasive species listed in Schedule 9 of the Wildlife and Countryside Act (1981) were routinely included in green infrastructure projects and to this end, having assembled a database of plant diversity and abundance in urban green infrastructure, we undertook a horizon scan of invasion debt amongst the plants grown in horticulture in England, Wales and Scotland with two objectives:

- Identify the range of non-native species grown in UK horticulture that are available to green infrastructure designers.
- Identify 'functional hotspots' for potentially invasive non-native plants that would benefit from further research.

To carry this out, we assembled a dataset of plants from databases held by botanic gardens and plant collections. Having filtered these data for plants known to be able to grow outside in the UK in terrestrial conditions, we retained 6,880 plant taxa for study. We then accessed the TRY database (Kattge et al., 2020; a curated repository of functional trait data) to download information relating to reproduction (propagule pressure, represented by the trait 'Seed mass') and whole organism metabolic pace (represented by the trait 'Specific Leaf Area'). By creating a two dimensional scatter plot of the pace of growth and the ability to reproduce quickly (Figure 5), we were able to understand the high level functional characteristics of cultivated plants available to specifiers in relation to the traits of those that are known to be invasive.

4.2.2 Results

Figure 5 shows that both the non-native species available for green infrastructure and the species identified as being potentially invasive by the Invasive Non-native Species Secretariat are distributed across the wide range of trait spectra. This highlights the fact that invasion risk is embedded within a range of plant functional strategies and that greater understanding of physiological tipping points in response to climate change pathways is urgently needed, combined with guidance and training programmes for specifiers.

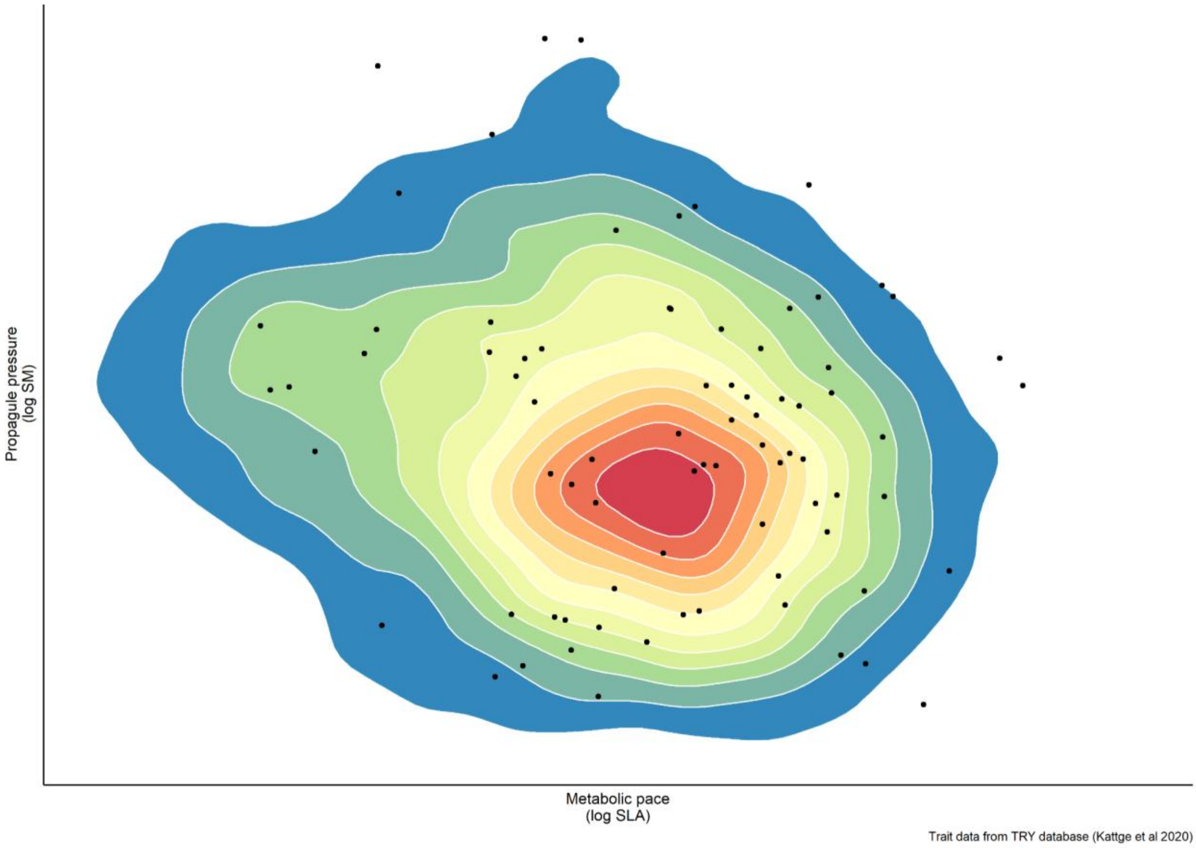

Figure 5. The traitspace of 6,880 non-native species grown in UK horticulture (density represented by shaded contours) in relation to species of concern (black dots).

To better understand the environmentally sensitive and diverse range of habitats that are created in green infrastructure, understanding the conditions in which these species might become invasive is therefore critical so that invasion risk can be better assessed.

To this end, Figure 6 investigates the trait space of species that are invasive in Scotland further, showing that species traits can be used to create a risk-based approach to species selection and habitat monitoring.

Figure 6. The identification of niches occupied by species of concern used in the GI industryin relation to their evolutionary strategies.

4.3 *Review of the Plant Health Risk Register from the perspective of plant users*

4.3.1 *Methods*

To extend the capability of GIBase to provide guidance to decision-makers and policy audiences on the biosecurity risks posed by green infrastructure plants in terms of their capacity to be hosts or vectors for pests, we used the Plant Health Risk Register (Defra, 2023 and subsequent version releases) to create a Cumulative Mitigated Risk Rating (CMRR) for plant species.

Whilst the Plant Health Risk Register is a powerful resource for tracking and managing the risks presented by pests and pathogens, there are numerous barriers to use in the green infrastructure sector. Aside from the domain-specific technical information contained within and visibility of the Register, the principal challenge for the green infrastructure is that the data are organised by reference to the pest or pathogen: whilst a number of initiatives are being carried out to refine the PHRR and adapt its presentation or ease of use and interpretation (eg, Elliot and Yeomans, 2024), at the time of writing, it is currently impractical to search the Register for particular plant genera or species and therefore impossible to use as a comparative tool for decision making – firstly, because the PHRR is a large .csv file that requires a degree of familiarity, secondly, hosts are referred to by multiple levels of taxonomic nomenclature (e.g. Fagaceae, *Quercus*, *Quercus robur*), and thirdly, if a user enters e.g. 'Quercus' in a search field, an extensive number of cells are returned. For the types of decisions that need to be made by those in the GI sector (confirmed through multiple rounds of consultation), this is not a practical resource at present.

The CMRR was created by re-coding the Register in the R language so that plant species became the data key. Following this, the Mitigated Risk Rating for each plant species or genus over a value of 30 was then summed to create a 'cumulative' score for each taxon (Mitigated

Risk Ratings range from '80' for the most severe risks, ie *Hymenoscyphus fraxineus*, *Ips typographus* and *Phytophthora ramorum*, to '0' or 'unrated' for those that are either remote risks or successfully controlled). The cut-off of 30 was used on the basis that pests and pathogens are part of a functioning environment and that a level of persistent but non-critical risk to plant health will need to be accepted both for pragmatic and technical rationales.

In a final step, we filtered the dataset for trees, shrubs and geophytes found in GIBase 2.0 and produced a Relative Risk Rating for urban woody plants by multiplying the CMRR by the frequency of use in green infrastructure projects for each of the species.

4.3.2 Results

The results of this exercise are set out in Appendix 2, with summary tables set out below (Tables 10-11). Coding the Plant Health Risk Register by plant taxa highlighted a number of challenges for current usage and opportunities for future development:

- Plants are recorded in the Risk Register as both species and genera, making it difficult to comparatively assess plant – pest relations.
- There was a significant difference in the range in mitigated risk rating between species and when comparing species to genera.
- Further, some plants were recorded in non-standard nomenclature. Analysis of these fields highlighted the limited utility of these terms, with "coniferous trees" having a CMRR of 350, whereas "deciduous trees" had a Rating of 50.
- The pace of horticultural development is difficult to capture in the Risk Register. For example, the genus Ulmus has a high score in spite of the fact new hybrids are being bred and introduced that are resistant to key pests. A similar picture may be expected of the genus Fraxinus in the coming years as new hybrids are developed.
- It appears that sampling bias plays a significant role in determining the frequency of plant taxa being included in the Plant Health Risk Register, and in turn, the CMRR. For example, there were few ash species recorded in the Risk Register (3) whilst Cotoneaster is dealt with at the genus level only, with no species level information.

The core finding from this process is that conceptually, a re-framing of the PHRR so that a comparative understanding of plant hosts is accessible to GI and lay audiences is feasible and necessary but that a significant degree of research and development will be needed to achieve this. To this end, the CMRR presented here and in Appendices should be seen as hypotheses awaiting further data to refine them. We note that the UK mitigated risk scores used to generate the CMRR include economic value of the host industry, and therefore there is bias towards host plants with greater national economic significance than would have been the case if the PHRR likelihood × impact scores were used instead.

Table 10. The 'top 10' Cumulative Mitigated Risk Rating of plant genera recorded in the Plant Health Risk Register.

Host genus	**Cumulative mitigated risk rating**
Prunus	2429
Malus	2303
Pinus	2293

Citrus	2137
Quercus	1652
Rosa	1507
Fragaria	1504
Solanum	1448
Picea	1324
Larix	1299

Table 11. The 'top 20' Cumulative Mitigated Risk Rating of plant species recorded in the Plant Health Risk Register.

Host full name	**Cumulative mitigated risk rating**
Solanum lycopersicum	4105
Solanum tuberosum	4081
Capsicum annuum	2724
Vitis vinifera ssp. vinifera	2248
Zea mays	2192
Solanum melongena	2187
Prunus persica	2004
Malus domestica	1721
Nicotiana tabacum	1695
Prunus domestica ssp. domestica	1693
Prunus avium	1571
Phaseolus vulgaris	1532
Glycine max	1511
Cucumis sativus	1487
Lactuca sativa	1367
Beta vulgaris	1292
Medicago sativa	1182
Fragaria ananassa	1125
Prunus armeniaca	1049
Pinus sylvestris	1025

Table 12. The 'top 25' Cumulative Mitigated Risk Rating of plant taxa recorded GIBase 2.0.

Species name	**Plant form**	**Relative risk (qty x mitigated risk rating)**
Prunus lusitanica	Shrub	70.47
Fagus sylvatica	Tree	67.97
Pinus sylvestris	Tree	66.44
Rosa arvensis	Shrub	59.05
Prunus avium	Tree	56.5
Corylus avellana	Shrub	56.4
Carpinus betulus	Tree	55.3
Prunus laurocerasus	Shrub	53.73
Prunus Otto Luyken	Shrub	52.94

Quercus robur	Tree	52.17
Viburnum davidii	Shrub	51.22
Cornus alba	Shrub	51.11
Quercus petraea	Tree	49.89
Narcissus Yellow Trumpet	Geophyte	49.41
Salix lanata	Shrub	48.64
Betula pendula	Tree	48.61
Narcissus pseudonarcissus	Geophyte	48.54
Prunus spinosa	Shrub	48.38
Lavandula angustifolia	Shrub	48.18
Salix cinerea	Shrub	47.95
Prunus 'Amanogawa'	Tree	47.9
Ilex aquifolium	Shrub	47.14
Euonymus fortunei	Shrub	46.63
Hyacinthoides non-scripta	Geophyte	46.6
Salix viminalis	Tree	46.6

4.4 Analysis of the introduction of biosecure procurement requirements on the green infrastructure supply chain

In 3.1 we reviewed analyses of the professional practices in contemporary green infrastructure, and then in 4.1we extended the GIBase to provide the greater understanding of the demand for individual plant species.

4.4.1 Methods

In this final stage of the research, we assessed where policy interventions could be most effective in reinforcing the green infrastructure supply chain. In particular, we focused on a cross-sector responses to the proposed introduction of Biosecure Procurement Requirements. We conducted semi-structured interviews that offered opportunities for informal and expansive conversations, drawing out anecdotal reflections on the green infrastructure industry and biosecurity risk management.

A longlist of nineteen stakeholders was developed and interviews scheduled; a common feature of the process was the challenge of securing commitments from stakeholders to be interviewed and the subsequent difficulty of scheduling interviews. In total, seven interviews were held with professionals from a range of sectors, with anonymity assured for each party:

Profession and core market focus	**Role**	**Number of interviewees**
Landscape architects working for SMEs, engaged on urban development and large-scale green infrastructure projects	Responsible for the specification of plants, their procurement and their management	2
Landscape contractors specialising in commercial projects (eg housing developments)	Responsible for implementing hard and soft landscape works, and landscape maintenance	2

Landscape manager employed by a national conservation charity	Responsible for maintenance of public green space	1
Developers (over 1,000 homes and associated mixed use buildings and landscape)	Commission and deliver large scale projects	2

The key points from the interviews were noted and the points of alignment and divergence synthesised in a structured process, with the results set out in the sections below.

4.4.2 Results

4.4.2.1 Understanding of how biosecurity relates to green infrastructure

The landscape manager, the landscape contractors and one of the landscape architects reported a relatively confident understanding of the importance of managing biosecurity risk, and identified principles that their practices have and policies that affect their work. In these introductory stages, a common example used was Ash Dieback and the importance of species selection in relation to the type of green infrastructure project.

The other interviewees (a landscape architect and the developers) were aware of the term 'biosecurity' but not able to use it with confidence, at times using it interchangeably with 'biodiversity'. These interviewees did not see biosecurity risk management as part of their roles, identifying landscape contractors (ie those responsible for the construction and planting) and ecologists (ie those responsible for site surveys and habitat assessments before development) as being the parties most closely associated with this issue.

A common theme amongst most interviews was the perception that selecting native plant species (irrespective of the country of cultivation or supply) was the most effective strategy to manage biosecurity risk: the roles of risk assessment (eg through consultation of the Plant Health Risk Register), nursery standards, transport or site management practices rarely arose unless prompted.

However, in a number of interviews it emerged that practices were being researched or were at early stages of implementation that would manage biosecurity risk, even if biosecurity was not the prime reason for them. For example, one developer described a recently-implemented Sustainability Framework, published by their organisation: although the Framework only mentions the word 'biosecurity' once, it sets out ambitions for contract growing of trees and shrubs. In this instance, the motivation for this was a commercial one, to guarantee availability of stock rather than to manage plant health risk but this interest in sustainability highlights the potential for co-benefits of practices in aligned areas of interest, as long as the routine monitoring of notifiable pests and diseases is implemented.

4.4.2.2 Assessment of the supply chains in green infrastructure

The plant supply chain for green infrastructure projects was discussed with each interviewee. The themes that emerged from this part of the interviews with both those responsible for the design of schemes (ie landscape architects) and those responsible for their implementation (ie landscape contractors) expressed a degree of frustration at the constraints on decision-making when it comes to responsibility for procuring plants. For example, the landscape architects reported that they were either involved too early or too late in a project to introduce the criteria they felt were important, whilst the contractors reported that the designs and specifications for planting were fixed before they could contribute to discussions about provenance or availability. However, the landscape architects reported a dual problem of being both not being engaged consistently throughout a project (and thus unable to maintain the necessary 'institutional memory') but also not being sufficiently trained in biosecurity risk management.

The contractors reported that as a result of plant procurement issues (eg the unavailability of a specified plant), they were often in situations where they had to source alternative plants; the subsequent challenge they reported was that it was difficult to identify appropriate individuals (either landscape architects or clients) who would take responsibility for reviewing variations critically or with the necessary expertise. As a consequence, the contractors reported that they would often make substitutions with the expectation that the developer / client would not look closely at the proposals in any case.

By contrast, the feedback from the developers illustrated a complex situation. On the one hand, they felt confident that the professionals engaged on the project were sufficiently trained and informed about the requirements of legislation relating to the planning system or the specification and planting of plants, the issue that both developers identified was that frequently it was the technical expertise in implementing the regulations or legislation that was lacking. Both developers gave examples of situations when they felt that the resulting planting was underwhelming (especially for houses for sale in the early phases of a development) and as a consequence, replacement planting specified by the contractor had been sourced at short notice.

In terms of understandings of the ways that the different sectors interact, the landscape architects reported that their principal interactions were with civil engineers, architects, and their client; the landscape manager and contractors reported that they engaged most with trades directly (who had responsibility for procuring plants), and that designs prepared by landscape architects were often treated as a guide to what should be implemented, rather than fixed instructions.

Representatives from plant nurseries were not interviewed in this research but they were frequently identified by landscape architects and contractors as being proactive and the parties most responsible for plant health management. When prompted, the landscape architects recognised the importance of Place of Origin status; to this end, they reported that they relied on tree nurseries' procurement and propagation practices when advising clients and creating specifications.

4.4.2.3 Biosecurity processes followed

The responses to questions about biosecurity processes varied significantly.

The landscape manager and the landscape contractors were best informed about best practice for managing plants, the policies that are relevant to procurement, and the status of pests and diseases in the area they managed; as a consequence, they were mindful of the need for plant passports and the relevance of the Plant Healthy scheme, and ensured that plants delivered to site had plant passports and were in good condition. They take care to discuss biosecurity measures with sub-contractors and nurseries, and are exploring opportunities to grow their own plants on site.

One of the landscape architects was aware of the need for biosecurity measures (for example plant passports) and the existence of the UK Plant Health Risk Register, but typically addresses the need for biosecurity measures in their projects by specifying that 'all plants must be procured in accordance with best practice and relevant legislation' and that 'plants should be procured from nurseries as close as possible to the planting site' rather than specific measures that should be taken. Both of the landscape architects reported that they felt they were not 'at the coal face' and that they relied on other sectors or parties in terms of decision making. An example of this was given, of a landscape architect recommending contract growing at an early stage of the project (RIBA Stage 2, RIBA 2020) and at Stage 4 (ie the point at which planting and construction contracts are awarded, immediately before construction), their client asking what contract growing was.

The developer affirmed that responsibility for compliance with biosecurity measures lay with the landscape architect to specify plants and processes, and the contractors to meet the specification (unless instructed otherwise). Neither of the developers (or their project managers or quantity surveyors) sought evidence of certification of standards from their consultants or contractors, or required inspection of plants at the point of planting.

4.4.2.4 Reflection on recent projects

The interviewees each identified a recent project that could be used as a case study for this exercise.

One landscape architect discussed a project where ash dieback is prevalent in the surrounding area. Although no ash trees were on the site before the project, they reported being mindful of the risks of planting *Fraxinus excelsior*, and although they had a brief to include native species in their designs, they did not include this species in the planting palette and used *Acer pseudoplatanus* instead. They were aware of recent projects by colleagues where *Fraxinus excelsior* was widely specified and planted, and considered this to be a significant failure; in other projects that they have direct experience of, they have frequently seen high tree mortality post planting but tend to not be closely involved in the later stages of a project and suspect that lack of watering is the key issue. In a similar vein, the other landscape architect reported that they had seen oaks being planted with lesions; the trees died in the following years and were not replaced.

The landscape manager reported knowledge of *Phytopthora kernoviae* being present on the site that they manage, and as a consequence they monitor plants that are known hosts for signs of ill health. Where they suspect a plant is diseased, they have a standing protocol to remove plants at the earliest stages, partly for visual amenity and to reduce future requirements for interventions, but also in the case of trees, to manage public safety.

Both the landscape architects and the landscape manager emphasised compliance with approved plans, responsibility for inspecting (and returning if needed) plants at the point of delivery and high quality information about plant selection as being critical weak points in the biosecurity continuum.

Neither developer could identify an instance where biosecurity had affected their projects, although it was later identified in a site walk-over with us that a number of larch trees had been planted as street trees, and that these presented biosecurity risks. They expressed surprise that this was an issue, and undertook to discuss with their consultants. The landscape architect that they appointed was tendered for at the master plan stage, and they identified commercial factors (eg price, availability at the point of planting, visible presence of greenery at the point of planting) as being key for their decision making.

4.5 Opportunities to improve biosecurity in GI through plant specification and procurement software

Throughout each stage of the consultation and surveys, stakeholders were asked to identify areas of risk and opportunity where new procurement conditions could be most effective. The answers are synthesised and grouped in five themes.

4.5.1 Plant selection and variations to contract

Landscape architects and contractors identified the processes of plant selection and specification as a key opportunity for improving critical weak points. Individuals from each sector raised examples where plants in the ground were significantly different from the approved plans and in this way, making processes of decision- making and liability 'opaque'. From their perspectives, having approved palettes of plants that were contractually recognised as being acceptable alternatives to those specified would be a pragmatic way of being able to resolve tensions between the approved plans and the plants that were available in the marketplace. The Landscape Consultant's Toolkit (Landscape Institute, 2019) was identified as being an appropriate guidance document that could be revised to accommodate this.

4.5.2 The planning process

Landscape architects and developers highlighted the role of the planning process in driving the requirements for pieces of work: it was recognised that without it being standard practice for planning conditions to require Five Year Landscape Management Plans and specifications for soft landscape works, it would be likely that landscape architects would often not be engaged to produce these pieces of work and that instead the work would become part of the contractor's responsibility. The implication from this feedback is by requiring evidence of compliance with Plant Health Management Standards as a Condition of Planning Permission (ie, satisfactory evidence provided to the Local Authority before works can commence on site) would not only raise awareness of the importance of managing biosecurity risk but provide a mechanism for enforcement if needed.

4.5.3 Plant health and biosecurity knowledge

In this theme it was felt (expressed in different ways) that the nursery, contracting and landscape management sectors were the best informed about plant health management and biosecurity risk. In the landscape architecture sector as a whole, it was felt that there was a dearth of technical knowledge and understanding of the existing legislative frameworks; amongst developers it was felt that their sector was more focused on 'sustainability' and that ensuring good practice here was enough of a challenge without the added layer of biosecurity.

However, it was felt that whilst developers might rarely have an understanding of what 'good' looks like in terms of plant health management, if they could be motivated to show greater care, then positive change would be more likely to follow.

4.5.4 The development marketplace

Recent changes to trends in building ownership (particularly in urban and commercial sectors) were identified, with greater involvement of tenants in making demands of landlords for improved facilities. For example, one landscape architect reported that in recent projects, prospective commercial tenants had scrutinised Ecology and Biodiversity Plans more closely than the landlord, and as a consequence greater investment in the green infrastructure had been made. Requiring evidence of compliance with biosecure procurement requirements and publishing associated documentation online in Planning Portals alongside all other documents submitted to discharge planning conditions would enable prospective tenants to interrogate landlords on these matters. However, this is likely to be seen as a tangential opportunity from a policy perspective.

4.5.5 Risk based approaches

The stakeholders across all sectors emphasised the importance of aligning new measures with the scale or risk. For example, professionals recognised the risks associated with planting large trees, and suggested that focus be given to these. However, this feedback illustrates the ways in which value and risk are evaluated: a counter-example might be given of hundreds of smaller herbaceous perennials and shrubs presenting a larger cumulative risk.

5 Development of GIBase 2.0

5.1 A pipeline for data to industry guidance

To date, industry focus in this field has concentrated on the supply-side of plant production, for example in the control of movement of plants, the conditions in which they are propagated or the selection of novel genetic materials. The research highlighted in this report shows that the demand-side requires equal and urgent attention, emphasising that simply providing more money to incentivise tree planting is not the (only) answer to these intersecting challenges. Addressing intersecting challenges will require a 'systems' approach that provides the essential information needed to facilitate improved decision making and manage the supply and demand challenges that frequently arise. To this end, we see GIBase as playing two roles: initially, acting as a database that harnesses and structures publicly-available green infrastructure data that can be interrogated for a range of applications, and in future stages, providing a download function that inputs biosecurity data into formats that can be used in plant specifications.

5.2 Database structure

The GIBase 2.0 database contains three sources of data, included in this report as Appendices 1-3:

- Appendix 1 acts as the database key, providing a full account of the plant taxa specified in Scottish green infrastructure projects (identified as 'Major Developments' by the planning system). The plant data are included with core information relating to planting location (decimal latitude and longitude to two decimal places), Life form, Genus, Species and Quantity.
- Appendix 2 presents core data from the Plant Health Risk Register, restructured so that it is organised by plant taxa, in terms of Family, Genus and Species. The method for calculating the Cumulative Mitigated Risk Rating is set out in 3.4 above.
- Appendix 3 builds on the previous two datasets and calculates a Relative Risk Rating based on the frequency of plant usage specified in Appendix 1 and the CMRR in Appendix 2.

5.3 Development of a revised Product Data Template for plants

The Product Data Templates (PDT)[1] used in modern digital design workflows, such as Building Information Modelling (BIM), present an opportunity to formalise plant information: PDTs are principally used in the construction industry in the design process as a repository of information about the materials used to construct buildings or procure engineering works and typically record performance, procurement and management data. These PDTs are spreadsheets that can be attached in a relational way to vectors in a digital drawing environment and as such, they can be associated with a designed object all the way through a project, ultimately being used by site managers or quantity surveyors to quickly engage with suppliers or certify materials delivered to site.

[1] https://www.landscapeinstitute.org/technical-resource/pdt-store/

However, three barriers prevent PDTs from being deployed effectively for plants: firstly, the types of information that are used in PDTs for plants are not fit for purpose, having been replicated from engineering products, and as such, fail to describe the complexity of a living organism as opposed to a brick, slate or window. Fields such as 'Tolerance' 'Embodied carbon' and Biodiversity' for example, are potentially useful but are functionally impossible for users at present, whilst similar fields such as 'Biosecurity risk' are absent altogether. Secondly, robust quantitative data about plant performance has yet to be created to describe plant functioning, and as such, the nuances of plant morphology, physiology and provenance are impossible to capture in the tools that the industry use. As a consequence, this lack of industry-agreed performance data means that there is likely to be significant variation between users in how these fields are populated.

Appendix 4 sets out a solution to these challenges, not only conceptually (by distinguishing fields that relate to whole-plant functioning from those that describe the format that the plant should be supplied in) but also practically, by providing a means for integrating the biosecurity information that should be central to decision making. Resolving these two barriers represents significant progress for users across the supply chain of horticultural plants not only in terms of improving the types of knowledge our industry relies upon but also the way that the information is accessed and used in decision-making. It is routine for supply-side issues to present a need for substitutions or variations to a contract: having a resource for hosting industry-agreed data would enable users to readily search and access alternatives, treating planting databases like thesauruses instead of encyclopedias.

6 Next steps

In addition to exploring the known challenges facing urban environments such as climate change and biosecurity risk, this report provides insights into previously under-investigated short-comings in the selection and supply chain processes. Identification and analysis of these blind spots allows us to refine the criteria for a solution to critical challenges, such as how and why the mortality rates for new plantings are so high, and why we see such narrow functional and taxonomic diversity in our urban forests. For example, the finding that plant selection does not appear to vary in relation to landscape character or location demonstrates that the lack of plant expertise in the specification process is only part of a chain that is connected to the widespread substitutions and variations to contract that are made at later stages in the supply chain.

In the following sections we identify six fields where progress could be made that would deliver the transformative national scale potential of biosecurity-led green infrastructure.

6.1 Development of data handling methods

The methods for developing GIBase and calculating the CMRR are conceptually straightforward but labour-intensive; each could be improved through more sophisticated digital tools and harnessing AI. For example, the construction of GIBase 2.0 required approximately 500 person hours to identify suitable projects and transcribe the data: a web-scraping algorithm that was able to search the distributed databases managed by Local Planning Authorities and carry out an OCR text transcription function would make it significantly less time intensive to update the database and remove human bias whilst also increasing granularity of the data.

6.2 From macro to micro: creating locally-sensitive data

The data recorded in GIBase 2.0 indicates that approximately 7 million plants were planted in Scotland's towns and cities during the period 2019-24, highlighting the significant role that that urban plants play not only in the Scotland's economy but also to ecosystem resilience.

This finding also illustrates the important point that biosecurity risks are not evenly distributed across the British Isles but are highly sensitive to habitat and location: the biosecurity risks posed by the widespread planting of non-native plants in urban habitats are qualitatively different to those posed by forestry or agricultural operations and require a nuanced response. The location data held in GIBase 2.0 allows us to map biodiversity values and biosecurity risk at a national-scale (notwithstanding the recommendations identified in 5.3) and enables policy makers and local authorities to understand the implications of individual projects at regional and local scales.

To enable GIBase to provide meaningful insights into locally-sensitive decision making, three further steps could be taken. Firstly, including data relating to plant physiology and performance (eg life history and functional traits) would allow decision makers to consider questions such as tolerance of stress, disturbance, or ecosystem service delivery such as carbon sequestration or water uptake. The field of plant strategies is an area of highly active research interest at present (eg Laughlin, 2023), and Figure 7 illustrates a conceptual pathway for mapping life histories of plants based on functional traits onto characterisations of urban habitats. As computational power increases and resolution of plant data develops to include intra-specific trait variation, such an approach has the potential to provide strong insights into plant performance in the context of specific micro climates and locations.

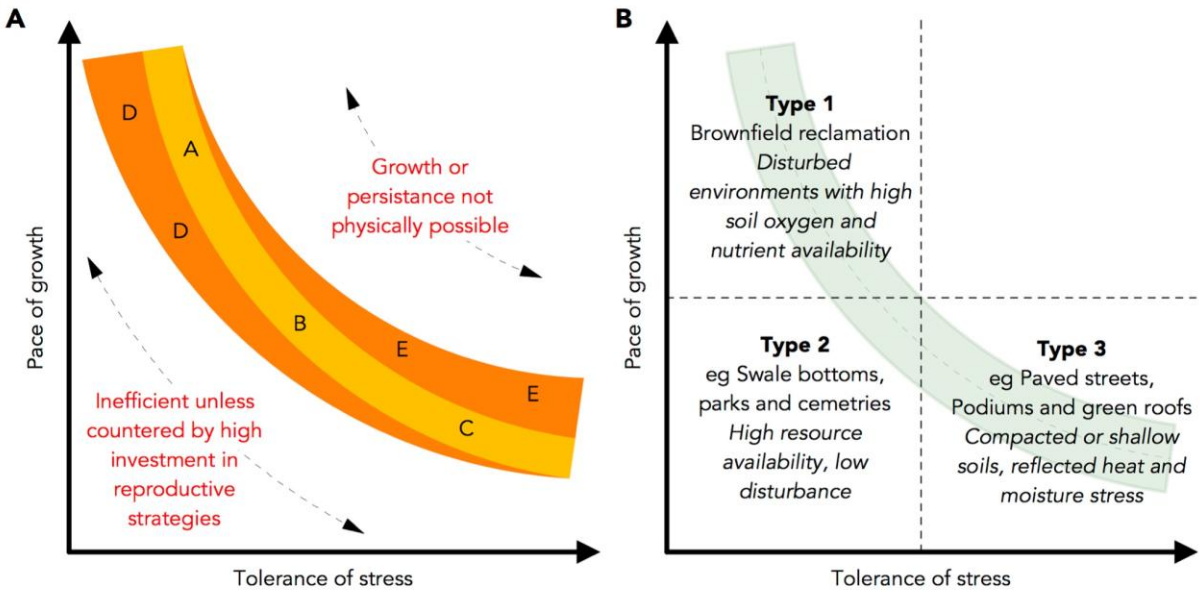

Figure 7. Mapping plant strategies onto characteristics of urban environments. Taken from Watkins et al (2021)

The second step to developing GIBase involves taking a probabilistic approach to invasive species management. Tools that forecast climate fitness based on biogeographical data are widely used in forestry, eg in the Ecological Site Classification (Forest Research, 2023) and Climate Matching Tool (Broadmeadow et al., 2005), and in botanic gardens, eg in the Climate Assessment Tool (BGCI, 2023). However, although these tools advance our capabilities, each is designed for specific applications and has its own inherent challenges in being applied for this kind of study.

To resolve this, we developed a machine learning approach that applies Bayesian statistics to species distribution modelling (Watkins, 2023). This process allowed us to identify the most meaningful climate variables to explain species distribution, and create nuanced, robust models of each species' climate niches. We then used these niche models to create probabilistic forecasts of species suitability in their existing ranges and novel environments.

Figure 8 illustrates an output of this approach using a case study of *Lonicera nitida,* a shrub that originates from Sichuan, China, and is widely grown in urban landscapes. Valued for its robust growth and wide range of planting uses, it is recognised as an important species in urban environments, albeit for different reasons, both horticulturally (the species was awarded an Award of Garden Merit by the Royal Horticultural Society) and by ecologists (as a potential Species of Concern). Taking this approach, we modelled locations across GB and Ireland where these climate variables under severe future climate pathways (RCP 8.5) would give rise to the plant becoming invasive: in Figure 8 the areas in green represent locations where there is a high probability of invasion risk, decreasing to orange.

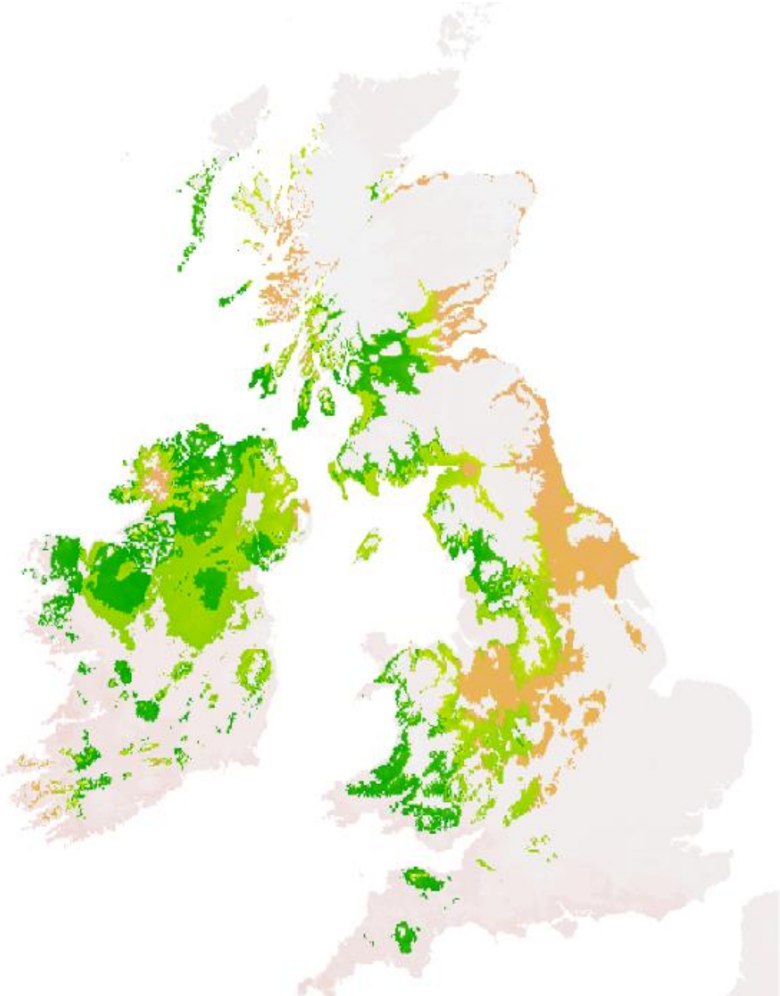

Figure 8. Invasion risk of Lonicera nitida in Britain and Ireland under a severe future climate scenario (RCP 8.5).

As can be seen, sites across northern and western Ireland, and western England, Wales and Scotland are likely to be particularly well-fitted to *Lonicera nitida*, describing a relatively tightly bounded range of distribution. Areas to the east are likely to be too droughted to sustain viable populations of this species. Repeating this approach for species of concern would be a tractable next step, yielding fine-grained guidance for plant growers and users.

In the third and final step, including robust data on biodiversity values would allow plant specifiers to meet emerging requirements such as Biodiversity Net Gain. At present, plant biodiversity data are based on high level characteristics such as nativeness, plant size or attractiveness to pollinators. Developing a metric that includes the richness of plant-animal and plant-microbe interactions, such traits as bark ruggedness, leaf domatia, or tissue chemistry would enable a simple quantitative measure to be included in the PDTs that are required in the BIM process.

6.3 Developments recommended in the Plant Health Risk Register

The CMRR and Relative Risk assessment both rely on the data in the Plant Health Risk Register Defra, 2023). As can be seen in the sections above, there are a number of issues with the Risk Register as it is currently formatted that preclude it from being harnessed by plant users, likely because the methods used to describe plant-microbe relations tend to be observational rather than experimental, resulting in uneven coverage of plant species in the Risk Register. Further, it should be noted that the assessments in the Register are a priori skewed as they reflect legislative use cases, hence inclusion of genera and broader host groups, and are prioritised by the UK Plant Health Service, often in response to emerging threats, assessments conducted by EPPO or the revision of EU legislation.

Undertaking an experimental approach to testing the relations between all the pests in the Risk Register and the plants that grow in Scotland would be a significant and highly risky undertaking. To this end, an inference approach to pest-host risk (potentially based on a combination of traits and phylogeny) that fills in the gaps in coverage would be a tractable and useful interim step that could be verified by future experimental studies.

6.4 Integration with Biosecure Procurement Requirement

In our consultation with industry stakeholders (4.4), we found a range of views in response to the question of how the introduction of a Biosecure Procurement Requirement (BPR) would influence the plant supply chain: from the perspective of the developers and landscape architects, the introduction of the BPR was seen as relatively straightforward to implement, as long as sufficient training and investment in awareness-raising could be provided. Using a format of plant data that could be used in specification documents (as in the PDTs provided by GIBase 2.0) was seen as essential so that variation in standards could be minimised and clarity provided to contractors.

From the perspective of those directly handling and working with the plants, it was felt that the introduction of the BPR would lead to a narrowing of the market, with contractors more likely to reduce the number of nurseries they would engage with. As a result, they anticipated a decrease in species diversity and availability and an increase in costs, partly as a result of a narrowing of the market but also due to the meeting the requirements of the Plant Health Management Standard both practically and in terms of administration. Within this feedback the process of substitutions was repeatedly raised, partly from the perspective of greater clarity over acceptable alternatives being welcomed but also in terms of contractors having fewer opportunities to seek commercial advantages of supplying plants that were variations to contract: they felt that having maximum latitude in procurement offers commercial opportunities and flexibility when budgets are under pressure. Having an independent framework for assessing when plant species are suitable alternatives, as offered by GIBase, in this way offers a tractable route to avoiding inappropriate variations that have the potential to increase biosecurity risk.

Stakeholders shared the perspective that the earliest points of a project were critical to the decision-making that follows, and that as a general principle, the earlier the requirement could be introduced the better. However, three critical stages emerged, where deployment of the data held in an extended version of GIBase could support biosecure procurement:

- Firstly, during the process of site investigations and assessment. For large scale developments, this is associated with the Environmental Impact Assessment and applications for planning permission. It was felt that if methods for assessing potential biosecurity risk (eg horizon-scanning, place-based interactions with the Plant Health Risk Register) could be developed and implemented in the PHMS, then this would justify contractual relationships and decision-making later in the project to be designed to address these risks.
- Secondly, when concept plans or site master plans are developed, typically as part of an application for Full or Outline Planning Permission. This stage was seen as the point at which specifications for trees could be agreed, and in turn, orders for contract growing could be placed with nurseries. From the developer's perspective, this introduced an additional budget risk at a point when finances were being leveraged, and options for bonds and securities were discussed in the event of variations to plans being required at a later stage.
- Thirdly, the Planning Conditions that are imposed when Planning Permission is awarded: contracts for designers are typically very closely aligned with the planning conditions that a local authority imposes on a project, and it was recognised that although this would bring additional consultancy fees, the introduction of a standardised plant health or biosecurity management condition would provide a simple but legally-binding mechanism for compliance with a standard, similar to those in the fields of ecology and arboriculture.

6.5 Leveraging cross-sector support

Throughout the consultation and desk-based audience research, the importance of early intervention in the process of specifying and planting plants emerged as a critical step that would ensure that any requirements can be planned for and budgeted for by the agent responsible for infrastructure delivery. However, within this there is a finding that is considered implicit by the industry but that should be highlighted in a policy context: that change should be integrated within existing frameworks for managing contracts and value systems or else being regarded as 'red tape' or unenforceable.

The table below sets out a process map for how cross sector support could be leveraged.

Existing frameworks	**Challenges**	**Opportunities**
Contractual relationships between parties	There is currently a disconnect between the parties responsible for specifying products and processes (designers), those responsible for their procurement (clients, developers), and those	High quality plant data that integrates with contemporary digital design workflows (eg Building Information Modelling, product data templates) could be created that provide opportunities for

	responsible for their enforcement (Local Authorities)	specifiers to detail the required level of biosecurity risk management for a given product. Ensuring that these data are available in software agnostic formats (eg Excel files) and are presented in a standardised, industry-accepted format would ensure that all parties have an easy to access, easy to read, and easy to certify means of assessing compliance.
The Planning System	There is currently no opportunity for Local Authorities to understand the cumulative biosecurity risk presented by large landscape projects, or set out a requirement for practices for managing these risks.	Developing a short form of words with Local Authorities (in coordination with Directorates for Housing and Local Government) that could become a clause in the standard Planning Conditions would be a light touch way of implementing the BPR.
RIBA Plan of Works	The Plan of Works sets out high level objectives for quality assurance within the design and construction process.	Introducing clauses for biosecurity alongside Health and Safety would ensure that Project Managers and Quantity Surveyors are aware of the need to require evidence of compliance from appropriate professions in the supply chain.

7 Conclusion

In this report, we carried out research in five areas that are central to the green infrastructure industry, and address the question of whether it is possible to harness existing datasets and digital design workflows to improve plant selection and reduce the biosecurity risks presented by green infrastructure practices.

In undertaking this research, we surveyed 126 green infrastructure projects across 24 local authorities in Scotland (approximately 10% of the major projects in the past five years), and created a revised database of the plants that are used in the designed habitats that make up our green infrastructure. The database reveals that Scotland's green infrastructure is not well prepared for the risks presented by climate change or increased levels of plant pests and diseases. This situation is reflected in the narrow range of plant species that are used in green infrastructure projects and in the significant gaps between policy expectations and industry delivery when it comes to compliance with planning commitments.

To address this issue, we highlight a number of recommendations that would result in a step change in Scotland's responsiveness to pest outbreaks and readiness for a changing climate, including:

- Improvements to the evidence base that is used for decision making:
    - Plant Health Risk Register maintained by Defra should be accessible in two formats, organised from the perspectives of pests and the plants that they are associated with, and then revised to fill in gaps in coverage.
    - Plant performance data that integrates plant physiology, biosecurity risk, invasiveness traits, ecosystem service delivery, climate fitness and aesthetic criteria should be standardised across the Green Infrastructure sectors.
- Within the design and procurement process, a suite of software-agnostic digital resources that organise these data should be agreed and maintained by an industry body.
- At a national level, the introduction of a planning condition that requires the submission of a Biosecurity Management Plan (e.g. for five years) before construction can start would be a relatively light touch means for embedding a cross-sector approach to managing plant health at landscape scales. The submitted plan should include:
    - The maintenance phase where any plant health or invasive species issues can be flagged and reported as they arise.
    - A responsible person checking plants as they arrive to make sure that they are the specified species and that they are healthy.
    - Maintaining the integrity of planting designs to prevent specified plants being swapped out at the time of planting due to supply chain issues. If plans are able to include a ranked list of suitable replacement species, this can also help limit the chance of an INNS species being used.
    - Standard definitions of provenance should be included to take into account local adaptation and the possibility of maladaptation of introduced provenances.

    - A template assessment to help developers evidence that their plan will deliver positive effects for biodiversity.
    - Consideration needs to be given to enforceability due to the differing legislation in England and Scotland.
- The above will require significant biosecurity and invasive species awareness raising and training for professionals so that plants aren't misidentified and plant health issues can be spotted and reported as soon as they develop. This could be along the lines of existing guidance such as "be plant wise", but tailored to a professional audience.

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