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Leverage points for improving urban biodiversity conservation in the Anthropocene: A novel ecosystem lens for social-ecological transformation

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ABSTRACT

Environmental governance faces persistent challenges worldwide, with traditional conservation and restoration policies often proving ineffective against ongoing environmental degradation and biodiversity loss. This is driven largely by complex regulatory procedures and an outdated understanding of ecosystem dynamics and change which often fail to effectively engage stakeholders or acknowledge the emergence and value of disturbed or novel ecosystems. This paper advocates for a paradigm shift in conventional environmental policy in the Global North to embrace ecological novelty and reevaluate conservation strategies, particularly within urban contexts. Drawing on case studies from Ireland, Australia, and the United States, it examines existing environmental legislation and identifies critical leverage points for transformative change utilizing a systems thinking and multispecies justice perspective. The findings highlight cross-cutting themes, similarities and differences across regions. We conclude with recommendations for alternative approaches to biodiversity conservation that account for the global redistribution of species and the prevalence of novel ecosystems. This may enable policymakers, practitioners and other stakeholders to envision more flexible, nimble, and adaptive policy frameworks that strive toward mutual flourishing and address the evolving challenges of the Anthropocene.

1. Introduction

Environmental degradation, biodiversity loss, and ecosystem collapse present an established and ongoing challenge for environmental governance worldwide. The most common and widely adopted conservation and biodiversity-focused policies are enabled through a system of institutions, decision-making processes, and legislative actions driven by regulatory procedures that are often complex or ineffective (Bennett and Satterfield, 2018). Such regulations and guidelines are key mechanisms for environmental protection and are commonly implemented by organisations, practitioners, or communities on the ground that may be excluded from the planning or legislative process. Additionally, implementation gaps, lack of incentives, and conflicting objectives between environmental protection and unfettered economic growth create further challenges for policy outcomes (Howes et al., 2017). This becomes particularly evident in urban areas where urban governance of biodiversity faces challenges such as weak political will and public perception, gaps in institutional capacity, lack of knowledge of ecosystem structure and function, and scale mismatches (temporal, spatial, and functional) between ecosystems and their managing institutions (Wilkinson et al., 2013).

A significant limitation of modern environmental policy, particularly in the Global North, is the outdated view that ecosystems and species compositions are static, balanced, and rooted in a specific place and time period (Clement and Standish, 2018, Bridgewater and Yung, 2013). Within conservation and restoration practice, this entrenched paradigm has fostered reductive approaches and binary classifications such as 'native vs non-native', which often positions invasive, introduced, or

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alien species as 'bad' enemies to be eradicated (Bartel, 2020, Gould, 1998, Marris, 2013, Lidström et al., 2016). The resulting policies require alarming levels of financial input and carbon-intensive practices, for example, A$24.5bn in Australia (Bradshaw and Hoskins, 2021), and $47bn since the 1960s on invasive species management in the US (Fantle-Lepczyk et al., 2022). Despite significant investment, these efforts have shown limited long-term effectiveness in managing invasive species (Pearce, 2015, Dana et al., 2019). While this may be similar to many biodiversity management interventions or approaches, which require ongoing influx of resources and continuity, invasive species management is particularly problematic from an ethical perspective and because it disproportionately focuses on economic outcomes often at the expense of addressing environmental impacts (Inglis, 2020, Pearce, 2015). Countries like Australia for example continue to face the highest extinction rates of any country worldwide, due to a myriad of issues such as uncoordinated efforts across governance and management structures, landscape types, and scales, gaps in knowledge, and lack of stakeholder engagement, whilst relying on one of the strictest biocontrol and invasive species management approaches in the world (Graham and Bartel, 2020).

While it is commonly regarded that invasive species are assumed to be one of the many drivers of biodiversity loss (Ipbes, 2019), this 'war on invasives' has expanded to influence perceptions of all non-native species and the pursuit of 'pristine' native habitats obscuring the root causes and drivers of the biodiversity crises (Lidström et al., 2016, Mastnak et al., 2014, Lidström and West, 2017, Slobodkin, 2001, Larson, 2007, Davis, 2012). Whilst biological invasions are cited as one of the greatest drivers of biodiversity loss (Bacher et al., 2023), research has shown that root causes such as trade and transport, socio-economic development, and climate change are the primary drivers of biological invasions (Essl et al., 2020, UNEP, 2023).

Despite this, current environmental policies focus largely on conserving and protecting 'pristine' ecosystems and remnant vegetation, creating restoration objectives aimed at returning damaged ecosystems to historical baselines. These efforts, however, in many cases have regrettably failed to improve ecological outcomes (Thomas, 2013). This conventional approach to conservation stems from a reductive understanding of ecosystem change and overlooks nature's agency, resilience, and inherent dynamic characteristics (Graham and Bartel, 2020, Orion and Holmgren, 2015, Marris, 2013, Pearce, 2015, Bartel, 2020). Furthermore, it seems disengaged from the global challenges as well as the realities and ecological uncertainties of the Anthropocene (Clement, 2020) – an era characterised by human impact on Earth's global ecosystems, climate, and geology (Crutzen, 2006). A driving force of these impacts is urbanisation, a process of significant landscape transformation which can exponentially accelerate negative impacts on social, ecological and technological systems, and environmental health (Schell et al., 2020). A more nuanced understanding of ecosystem services, functions and systems more generally could offer opportunities to explore broader, sustained, and positive social-ecological objectives for cities (Schwarz et al., 2017, Ziter, 2015).

As global trade and urbanization accelerate, the world's biomes are increasingly composed of novel ecosystems - new assemblages of biotic communities that emerge in sites of disturbance with little or no human management (Morse et al., 2014). Despite their emergence worldwide, policy decisions, conservation, land use, and restoration goals continue to adhere strictly to subjective historical ecological baselines and other biological indicators that do not reflect recent and significant changes to the Earth's system (Clement and Standish, 2018, Perring et al., 2013, Bridgewater and Yung, 2013, Pearce, 2015). In most parts of the world, ecological shifts driven largely by human activities and climate change have altered the ecological regime, diversity, abundance, and distribution of species, rendering historical baselines ineffectual and requiring an impractical investment of resources to achieve conventional management goals. Nonetheless, biodiversity conservation is often framed as the protection of rare or culturally valued assets from threats which researchers increasingly point out focus heavily on outputs (e.g., number of trees planted) and neglect outcomes (e.g., ecosystem processes) especially as ecosystems transform (Gould, 1998, Higgs, 2012). Thus, current legal and policy frameworks are often inadequate to address the proliferation of novel ecosystems. However, there is an increasing trend toward some reform of existing laws in places like the EU and the United States, with some legal experts finding ways to realize alternative governance approaches that work within the constraints of existing laws (Garmestani et al., 2019b, Harvey et al., 2024). Despite these promising trends, many recognize the need for new approaches that attend to the nuanced ways in which natural and social systems have and will continue to change over the coming decades and require us to question conservation assumptions and entrenched paradigms of 'pristine' and native nature (Miller and Bestelmeyer, 2016, Evers et al., 2018, Collier and Devitt, 2016).

In this paper, we add to the developing arguments for the urgent need to 'embrace ecological novelty' (Bridgewater and Hemming, 2020, Bridgewater and Yung, 2013), with a focus on urban areas. To do so, our objective is twofold: first, we reflect on biodiversity conservation and protection - in particular how biodiversity, land management, and regulation of invasive species are valued and framed in the environmental legislation in three case study locations: Ireland, Australia and the United States. We accomplish this by reviewing key environmental policies that address biodiversity loss, invasive species management, and conservation through the 5W1H method and analyse the data through a systems-thinking perspective, specifically the four system characteristics. Policies included are at different levels with an emphasis on urban policies, but also national, federal and regional policies, as they drive the development of legislation at local-urban levels. Secondly, to explore the cross-cutting themes that emerged across national, regional and local legislation, we identify critical leverage points from a systems thinking perspective again to envision a more expansive framing of urban biodiversity. Here we argue how a novel ecological lens can inspire a shift in how biodiversity is conceptualized and implemented for biodiversity conservation taking into consideration the global redistribution of flora and fauna, and the emerging predominance of novel ecosystems, especially in urban areas.

Within this second aim, this paper specifically examines emerging and alternative ways of assigning value and how it can transform larger policy frameworks by focusing on key leverage points. Although this leverage points exploration focuses on urban areas of the Global North, considering the shared global nature of the biodiversity crisis and current inadequate solutions, we propose that a greater understanding of novel ecosystem policy dynamics and reimagining policies can also offer transformative insights for other regions and landscape types. Additionally, we suggest an urgent need for reconceptualizing regional and global conservation targets and strategies considering emerging efforts, plans, and proposed legislation that may impact the field over the coming decades. We conclude by discussing key recommendations for land managers, land stewards, and people who have the autonomy to change their landscape to care for and enhance biodiversity in the Anthropocene.

2. Conceptual framework: leverage points in systems thinking

In systems thinking, leverage points are places within a complex system where a small shift can lead to significant changes (Meadows, 2009). In the context of urban biodiversity, identifying and targeting these leverage points may be instrumental in reimagining an effective, equitable, robust, and responsive environmental governance system (Bennett and Satterfield, 2018). In her seminal work, Donella Meadows (2009) presented 12 leverage points that range from the least effective to the most effective. Abson et al. (2017), have categorised these as ranging from shallow to deep interventions for systems change. See Fig. 1 to understand these leverage points in the realm of system characteristics and the ways in which each leverage point represents a different level of

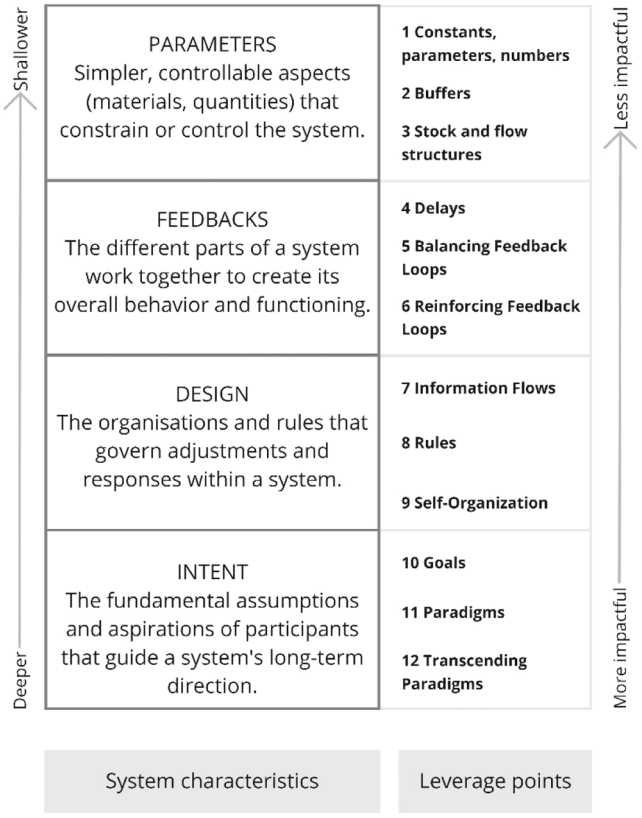

Fig. 1. Leverage points and system characteristics (Abson et al., 2017, Meadows, 1999).

intervention that can be used to bring about systemic change or influence behaviour within complex systems.

Fundamentally, a system is defined by its intent, and executed through its parameters. Among the shallower leverage points, *Constants, Parameters & Numbers*, refer to the numerical values or parameters within which a system operates. Targeting these values typically has the least impact on the overall system. *Buffers* or *Stocks* are reserves that help to stabilize a system. Adjusting the size of buffers can influence the system's resilience, however, this is limited by the capacity of the *flow structures* along which the buffer stocks travel. *Delays* in feedback loops within a system can lead to slow responses and inaccurate information. Altering the structure of delays relative to the stock characteristics, by either reducing or in some cases, increasing delays, can impact the effectiveness of system behaviour. *Feedback Loops* can be adjusted to balance and reinforce a system's response. Short feedback loops allow for a quicker response. *Balancing Feedback Loops* are self-correcting mechanisms which maintain stability in a system by counteracting deviations from the desired state. *Reinforcing Feedback Loops* tend to amplify the outcomes of a system, often leading to exponential growth or collapse. Reducing the gain around a reinforcing loop is usually a better stabilizer than strengthening a balancing loop. By reducing the growth loop, the balancing loop has time to function.

The *Structure of Information Flows* shape the way decisions are made within a system. Sharing certain information with certain stakeholders can heighten understanding and in turn influence operations within a system. The *Rules of the System*, govern its scope and its freedom. Rules drive how a system behaves, therefore reimagining rules can have a powerful impact on outcomes. *Self-organisation,* in the context of the leverage points framework, is the capacity of a system to change, evolve, and facilitate self-adjustment within itself to ensure it is nimble, adaptable, and resilient. It's important to note that self-organization within the scope of urban ecology refers to the ability of ecosystems to develop and maintain self-sustaining processes and functions, without human intervention. The last three points represent the deepest places to intervene in a system and can drive profound system transformation. The *Goals of the System* or its purpose inform its behaviour. Redefining the goals can guide the system in a different direction. *Paradigms* are the fundamental beliefs and assumptions that shape the mindset and worldview of individuals and societies. Changing paradigms can lead to profound shifts in understanding and behaviour. The final leverage point, with the greatest impact is *Transcending Paradigms.* This involves a fundamental shift in consciousness and worldview. This represents the deepest and most transformative leverage point.

These leverage points provide a framework for understanding how interventions at different levels can influence the behaviour of complex systems. It is important to note that the effectiveness of a leverage point may vary depending on the context and the specific characteristics of the system in question. Within this study, our foci of analysis through the case studies located in the Global North seeks to identify factors which fundamentally influence how the environmental policy system is structured and how solutions are framed.

3. Methodology and methods

3.1. Extraction approach

This study takes a two-stage approach to policy analysis. The first stage uses the *5W1H* (what, why, who, when, where, how) framework as the extraction approach to obtain the main elements of the key policy and regulatory legislation for three case studies: Ireland, Australia, and the US (see Table 1, ESM). These regions were selected based on the authors' expertise, access to information, and common language, offering a diverse cultural, institutional, and legal backdrop for analysis. This multi-case approach allows for identifying similarities, differences, and transformative changes that can be adapted to other regions.

The 5W1H method, traditionally used in journalism works to map research on a topic (Jia et al., 2016). It asks six basic questions (why, why, what, where, when and how); providing a structured way to tell a story with essential information (actor, motivation, content, location, time, causality) (Hart, 1996, Pan and Kosicki, 1993). We adapted these questions to reflect environmental policies and legislation to extract baseline data (see Table 1). Policies were obtained from online sources and policies were examined by looking for the answers to the 5WH1 questions.

Given the extensive number of environmental policies in each location, we developed criteria for selecting relevant policies. They needed to directly impact biodiversity conservation, landscape management, invasive species management, and novel ecosystems. Policies that have an impact on species and ecological communities were also included. Although our interest lies in the context of urban areas, nature-based solutions, and novel ecosystems, we included policies at various governance levels (national, state, local) to understand the influence across different scales and how higher-level policies influence urban biodiversity (e.g. policies for Australia are included at the federal level,

Table 1
5WH1 approach used to examine Environmental policy and legislation-focused questions.

5WH1	Policy and legislation-focused questions
(1) *Who*	the ones designing, implementing, enforcing, complying, influencing or experiencing the outcomes of the legislation
(2) *Why*	the motivations and objectives behind the legislation
(3) *What*	the legislations contents - ideas and issues it addresses
(4) *Where*	the locations/context in which the legislation is enforced
(5) *When*	time in which the legislation is enforced or triggered
(6) How	the mechanisms and processes through which the legislation is enforced and/or complied

state level using Victoria, and local level using a western local governmentarea located in the Greater Melbourne metropolitan area). A complete list of selected policies is available in Table SM1, Supplementary Information, and a summary is presented in Tables 2 and 3 in the results.

3.2. Analytical approach

After extracting relevant information using the 5W1H approach, we applied the leverage points framework from systems thinking (Meadows, 2009) and the system characteristics (Abson et al., 2017) to structure and describe the findings. Reviewing the policies through the 5W1H approach helped us obtain key ideas from the environmental legislation and the leverage points framework provided a deeper examination into 'what the system is doing, why it is doing it, who is responsible, and how the system creates its own behaviour' (Meadows, 2009). The leverage points framework thus adds an additional lens to understand not only what the policies say, but delve deeper and try to understand what drives the system. We present the results as a description of environmental governance, particularly in the Global North, focusing on factors of intent, design, feedback, and parameters. We draw examples from the case study locations to illustrate how the various policies and regulations function. In our discussion, we revisit the leverage points and system characteristics to identify 'promising leverage points for reform' to enhance our understanding of novel ecosystems, and their management (Clement and Standish, 2018). The discussion focuses on urban biodiversity conservation and management.

4. Results

Based on the review of selected policies for the three regions, this section describes the environmental policy system by examining 'what the system is doing, why it is doing it, who is responsible, and how the system creates its own behaviour' (Meadows, 2009). A leverage points and system characteristics (intent, design, feedbacks, parameters) framework allows us to explore how these systems operate, their underlying rationale, and assists in identifying regional differences and similarities.

4.1. Intent: a discourse of invasion biology, conflicting values and goals

The intent of each system is influenced by several ideologies of conservation and environmental management including the discourse of invasion biology; a field focused on the study of invasive species and their ecological, environmental, and evolutionary impacts on ecosystems. This among other factors informs a species-centric perspective within policy and planning, highlighting the negative impacts of specific non-native species on local biodiversity, and orienting policies toward protecting unique and endangered species (Davis, 2006). This is often accomplished by listing particular species under a framework of endangered species legislation and implementing dedicated conservation programs for threatened habitats (see Table 2 for a summary of intent key environmental legislation).

In Ireland, biodiversity protection is guided by European and national legislation. The EU Birds Directive (1979) (EC, 1979) and Habitats Directive (1992) (EC, 1992) established the Natura 2000 Network, to safeguard 'endangered' habitats and species. Ireland reports on the status of these sites every six years (NPWS, 2024b). Nationally, the Wildlife Act 1976, and the Wildlife (Amendment) Act, 2000, provide a legal framework for conservation through species protection (Dohlgh, 1976, 2000), and the designation of Natural Heritage Areas (NHAs) (NPWS, 2024a). In Australia, the diverse and unique ecology, including many endemic species is protected by Strategy Frameworks like The Threatened Species Strategy, as well as Intergovernmental Agreements such as The Australian Intergovernmental Agreement on Biosecurity. These frameworks address species decline and target recovery. They are enforced through the main environmental legislation, the Environment Protection and Biodiversity Conservation Act (EPBC Act, 1999). Similarly, the US employs a primarily species-centric approach to policy, protecting endangered species through legislation like the Endangered Species Act (1973), and addressing invasive species through the National Invasive Species Act (1966) and Executive Orders (13112). The intent of the Endangered Species Act (ESA) is to identify and protect critical habitats essential for species recovery and to prevent further habitat loss, providing guidance and funding to develop recovery plans to restore a species to a stable population level, and prevent harm to listed species. On a global level, the US stands out as the only UN member state (aside from the Vatican City), not party to the United Nations Convention on Biological Diversity, which Australia and Ireland joined in 1993 and 1996, respectively (CBD SECRETARIAT, 2024).

In urban contexts, various conservation and restoration approaches often have similar overarching framings but prioritize efforts differently. For example, invasive species management within cities is a shared priority across the study regions but with different intents and strategies. In the US, there are a variety of federal, state and local policies and laws that help guide conservation, restoration and invasive species monitoring and related activities. At the city scale, numerous US cities have enacted "weed control ordinances" to address unkempt "weedy" areas for public health, safety, and aesthetic purposes. This is guided by a

Table 2
'Intent' of key environmental legislation by regions.

Feature	Ireland	United States	Australia
Primary Legislation	Wildlife Act 1976 EU Birds Directive 1979 EU Habitats Directive 1992 EU Water Framework Directive 2000 Environmental Impact Assessment Directive, 2011/2014	The Lacey Act 1900 Migratory Bird Treaty Act (1918) Pittman-Robertson Act, 1937 Endangered Species Act (1973) The Wilderness Act of 1964	Environment Protection and Biodiversity Conservation Act 1999
Intent	Protection of 'endangered' habitats and species and restoration to 'favourable' status. 'good' status for waterbodies. Mitigating impacts of plans and projects.	Economic and trade, species and wildlife preservation, and parks conservation.	Landscape management to protect and restore unique species and ecological communities.
Invasive Species Legislation	European Communities (Birds and Natural Habitats) Regulations 2011 (Third Schedule) EU Regulation no. 1143/2014 on invasive alien species EU (IAS) (Freshwater Crayfish) Regulations 2018	Federal Noxious Weed Act of 1974, National Invasive Species Act of 1996 The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 Native Plant Materials Policy (2008) Executive Order 13112 (1999)	Australian Intergovernmental Agreement on Biosecurity (IGAB); State of Victoria Catchment and Land Protection Act 1994 (National guiding frameworks: Australian Weed Strategy and Australian Pest Animal Strategy)
Intent	Biosecurity awareness, surveillance, prevention, control (limited biocontrol).	Prevention, control, eradication, some biocontrol.	Prevention, control, eradication, with a strong emphasis on biocontrol.

range of legislation such as Executive Orders 13112 (White House, 1999), 13751 and 11987 which mandates the regulation of "alien species" that are not native to local ecosystems, as well as the Nonindigenous Aquatic Nuisance Prevention and Control Act (1990), Lacey Act (1900), Federal Noxious Weed Act of 1974, The Plant Protection Act of 2000 and Native Plant Materials Policy (2008) at the federal level, as well as similar configurations at the state and local levels (See Supplementary Information for a full list of laws and policies analysed). In Ireland, the European Council regulation on the 'prevention and management of the introduction and spread of invasive alien species' (2014) guides several parallel policies like Ireland's National Biodiversity Action Plan which continue to impact urban ecosystem management. Similarly, management of weeds, as well as other 'pests' in Australian cities has a strong emphasis on biocontrol, but like Ireland, a distinction is made between alien species that do not represent a threat and those which are labelled as invasive. Local governments oversee weed management on public and private lands, following state regulations under federal strategies like the Australian Weed Strategy (Commonwealth OF AUSTRALIA, 2017b) and Australian Pest Animal Strategy (Commonwealth OF AUSTRALIA, 2017a).

4.2. Design and feedbacks: siloed and top-down approaches

The environmental policy landscape in the three regions is shaped by a complex interplay of social structures and institutions which drive reinforcing and balancing feedbacks and interactions. These systems generally adopt a distributed, multi-level governance approach involving environmental policies and programs at the local, state, federal/national and transnational levels. In Australia, for example, this approach is leading to more equitable changes. The 2021 State of the Environment report included Indigenous knowledge alongside scientific data to achieve a holistic understanding of ecosystems. However, is not the case overall. Overlapping regulations, siloed institutions, and divided responsibilities often result in confusion, inefficiency, and weak policy integration, leading to poor biodiversity outcomes (Perrings, 2012, Frederiksen et al., 2017, Ross and Dovers, 2008). A self-correcting (balancing) feedback loop identified in this study across all regions is the dominance of top-down environmental policy and governance structures, which enforce policies and facilitate feedbacks between social structures and institutions. While this can alienate or preclude certain communities and exclude diverse knowledge sources from policy planning, highlighting critical issues of distributional and procedural justice, it also helps to 'balance out' the different levels of governance and their policies, such as local biodiversity plans, with the same conservation narratives.

In Ireland, various local agencies oversee environmental protection and water quality including the National Parks and Wildlife Service (NPWS), the Department of Housing, Local Government and Heritage, and the Environmental Protection Agency (EPA). However, the NPWS plays a greater role in implementing biodiversity and conservation policies, managing protected areas like the Natura 2000 network in line with EU directives. At the local level, Heritage Councils support and promote heritage conservation, appointing heritage and biodiversity officers to local authorities to oversee matters related to cultural and natural heritage.

Similarly, in Australia, several institutions and organisations oversee and enforce environmental legislation. The central federal agency, currently the Department of Climate Change, Energy, the Environment and Water (DCCEEW), is responsible for environmental policy development and implementation at a national level. Parks Australia is another significant entity responsible for managing the nation's parks and marine reserves, playing a key role in biodiversity conservation efforts. Additionally, the Indigenous Land and Sea Corporation has been instrumental in supporting Indigenous Australians in land management, particularly through Indigenous Protected Areas aimed at conservation. These agencies collaborate with state and territory environment departments to enforce national policies and establish region-specific regulations tailored to local needs. State-level efforts are further supported by threatened and invasive species scientific committees, which evaluate the conservation status of flora, fauna, and ecosystems. Moreover, organizations like the Australian Conservation Foundation, as well as Landcare and Natural Resource Management Groups, offer local ecological knowledge to inform conservation decision-making. This legislative structure can result in some variations in environmental regulations, monitoring mechanisms, and environmental outcomes across different parts of the country.

In the United States, several governance bodies oversee environmental policy and governance. At the federal level, agencies like the Environmental Protection Agency (EPA), the Department of Energy (DOE), and the Department of the Interior (DOI) are central to shaping and enforcing national environmental policies. These agencies create regulations based on federal laws such as the Clean Air Act, Clean Water Act, and Endangered Species Act, which set the framework for national environmental standards. The U.S. Fish and Wildlife Service, National Park Service, National Oceanic and Atmospheric Administration and Bureau of Land Management assist in enforcing these federal laws and develop specific programs to promote the conservation and recovery of endangered and threatened species. State governments, through their Departments of Environmental Protection or equivalent bodies, have the authority to tailor these federal regulations to their specific regional contexts. States are responsible for implementing and enforcing federal environmental laws, while also addressing state-specific issues, such as localized pollution control and resource management. They may also introduce additional regulations that go beyond federal requirements to address unique environmental challenges within their borders. At the local level, cities, counties, and municipalities play a crucial role in designing environmental policies that address conservation and environmental challenges, as well as urban-specific issues like green space management. In addition, the Invasive Species Council coordinates efforts to address invasive species across different levels of government. These agencies often have differing policy objectives and targets, which causes difficulty in assessing the impact of specific legislative actions.

A significant difference between the EU, Australia and the US lies in how biodiversity generally is framed and codified within policy and legislative mechanisms. In the US, biodiversity measures are rarely included in binding legislation, rather they are encouraged as voluntary endeavours determined by each state. In contrast, Australia emphasises biodiversity protection through a lens of biosecurity, utilizing language around the protection of unique, endemic species and ecological communities. In the state of Victoria, the Catchment and Land Protection Act 1994 (Calp, 1994) categorises weeds as 'state prohibited', 'regionally prohibited', 'regionally controlled', and 'restricted'. Descriptive language for such species includes noxious, invasive threats, and invaders, and actions towards them include prevention, eradication, and control. Historically Ireland focussed almost exclusively on protecting 'endangered' habitats and species. However, longstanding voluntary guidelines were strengthened in recent policy. The 4th National Biodiversity Action Plan now has a statutory footing, making general biodiversity measures binding in national legislation.

While balancing loops self-correct and stabilise the system, reinforcing feedback loops amplify change and produce instability (see Fig. 2). This can be beneficial if the changes result in positive environmental outcomes, but detrimental if they cause unclear outcomes, weak compliance or enforcement, and ineffective environmental monitoring and evaluation (Samuel AC, 2020). This then generates mistrust which ultimately undermines the system. An example from the US context is a misalignment of both the intent and design between local, state, and federal policy. Furthermore, the enforcement of these policies then creates incongruent targets which disregard bioregional trends or dynamics at the ecosystem level (Adler, 2005). Additionally, many federal policies are created by legislators who lack relevant expertise, and thus the outputs generate voluntary or best-practice guidance, creating

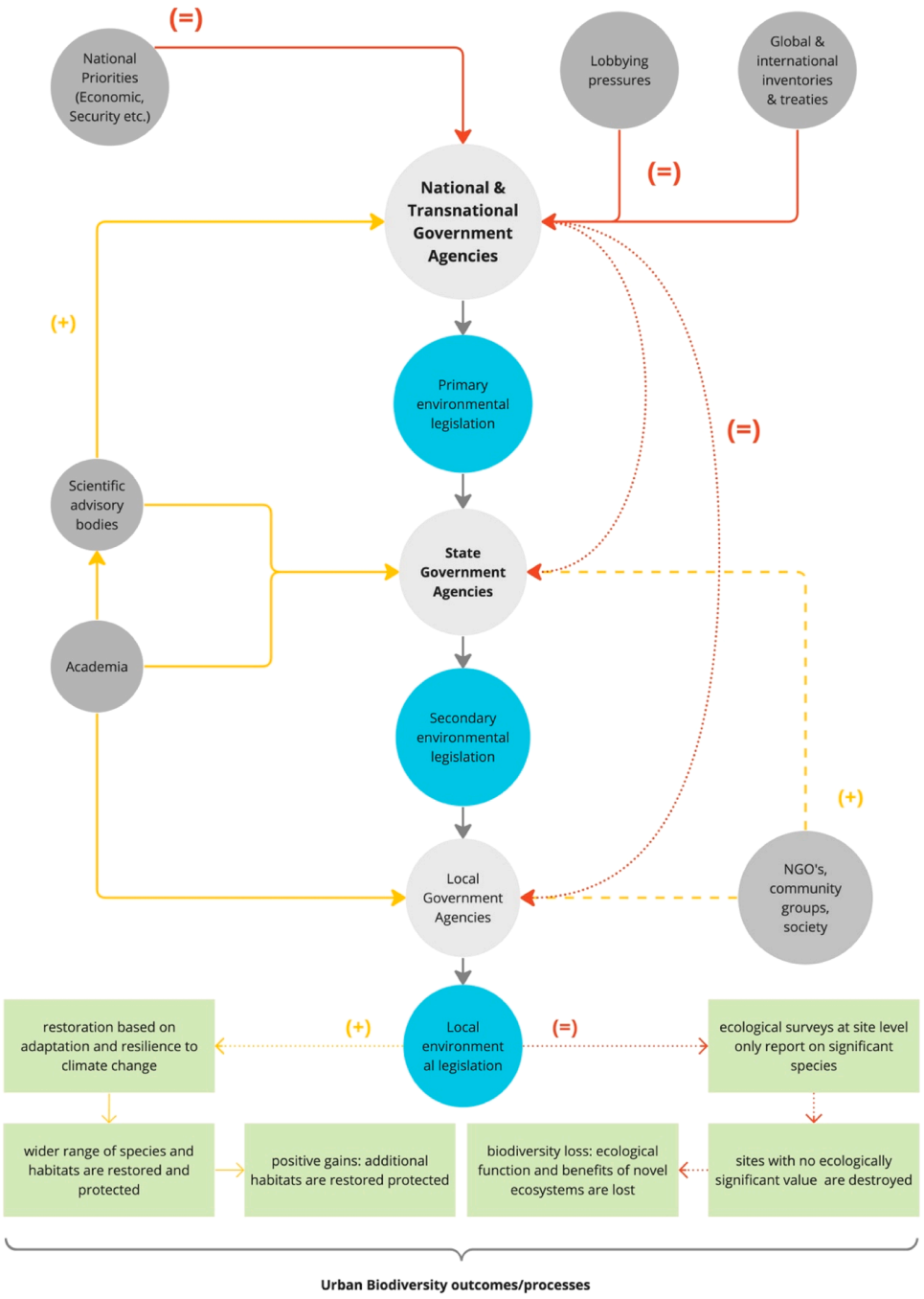

Fig. 2. Diagram synthesising the policy reviews by mapping similar patterns across the three case studies in terms of structures, dynamics, and interactions. While it does not capture the complexity of each case study region, it suggests that the intent, design, feedbacks and parameters in the three regions are alike. Yellow arrows represent balancing loops. Red arrows represent reinforcing feedback loops. They highlight key feedbacks and dynamics that act as enablers or disablers of positive environmental outcomes. The green boxes are suggested outcomes based on balancing or reinforcing feedbacks.

further confusion and inconsistency. In Australia, the inclusion of First Nations knowledge in environmental decision-making is an example of a reinforcing feedback loop. While it has created some instability, it is expected to amplify its effect positively within the policy landscape.

4.3. Parameters: measuring, monitoring and assessing biodiversity and land management

All three case study regions have diverse conservation frameworks and biodiversity targets, with environmental policy primarily focused on protecting "native" flora and fauna. These frameworks include metrics and strategies for habitat restoration, species protection, and establishing protected areas. Ireland and Australia have legislation to address biodiversity loss and protect ecosystems, while the US focuses more on monitoring invasive species and regulating trade and agriculture. These legislative measures include parameters around endangered species protection, land use planning, and environmental impact assessments. Table 3 summarises key parameters and metrics for major policies in each region.

In summary, higher-level policy parameters across all study cases provide frameworks for developing measurements and targets, rather than prescribing specific metrics. Measurement approaches typically

Table 3
Selected Environmental Policy Metrics in Australia, Ireland, and the United States. These policies have a key place in the governance ecosystem – as key influencers of other policies, institutions, and system dynamics and decision-making processes. We bring policies at national level, state and local levels to understand their relationships.

Name of the policy	Parameters/Metrics
Australian Legislation	
EPBC Act (National/federal)	Threatened Species List Categories and expert advice.
Planning and Environment Act 1987 (state, Victoria)	Population restoration and habitat protection.
Catchment and Land Protection Act 1994 (state, Victoria)	Four prescribed measures for the control of noxious weeds: application of herbicide cultivation of the soil, physical removal, and mulching.
Victoria Environment Protection Act 2017 (state, Victoria)	Preventative and risk-based regulations; environmental performance and environmental health reporting.
Hobsons Bay Community Law 2015 (local; urban. Greater Melbourne)	Land (private) kept free of weeds, pests and grass or undergrowth on the premises does not exceed 150 mm in height.
Ireland Legislation	
Birds Directive; Habitats Directive; Water Framework Directive; EIA Directive (European Union)	6-year monitoring cycle of protected habitats, species and water bodies. Targets 'favourable' and 'good' status. Mitigates development impacts on protected sites through AA/ EIA.
Wildlife Act 1976. Wildlife Amendment Act 2000 (National)	Designates Natural Heritage Areas. Restricts activities such as hunting, baiting, and hedgerow cutting. Protects certain species. Mandates licences and derogations for certain activities.
Planning and Development Act 2000 (National)	Implements the AA and EIA process for plans and projects. Mandates that Local Authorities include objectives for nature and the environment in their development frameworks.
Ireland's 4th National Biodiversity Action Plan 2023–2030 (National)	Increased resourcing for biodiversity action, conservation and restoration, human-nature connection, research, and collaboration. Mandatory reporting for public bodies.
Green Space Factor (South Dublin County Council) (local; urban)	For green infrastructure, new developments must meet a target ratio of green to grey space. Green features are given various ratings. Preserved trees score highly, while short lawns have a low score.
USA Legislation	
Endangered Species Act (1973) (National)	Permits and Exemptions; Population Surveys and Trends; Habitat Condition and Coverage.
National Invasive Species Act (1996) (national)	Control invasive aquatic species from entering U.S. waters, including the Great Lakes; management of ballast water discharged by ships.
The Wilderness Act of 1964 (National)	Wilderness designation criteria: area must be at least 5000 acres of land or of sufficient size; must have special ecological, geological, or historical value; land must be federally owned.
New York Ocean and Great Lakes Ecosystem Conservation Act (NYOGLECA) (state, New York)	Monitoring populations of fish, marine mammals, seabirds, and aquatic plants, wetlands, and other critical habitats. Monitoring water quality parameters; tracking vessel traffic, maritime commerce, and the condition of port facilities.
City of Austin Local Ordinance 10–5–21 (local; urban, City of Austin, Texas)	Weeds or grasses more than 12 in. tall. Class C misdemeanour by a fine upon conviction not to exceed $500; abatement of the property.

focus on the status of species and habitats based on their significance and appearance in global inventories, (International Union for Conservation of Nature Red List of Threatened Species), treaties (Ramsar Convention on Wetlands of International Importance), or local lists of unique, threatened or significant species and habitats. This logic also applies to legislation concerning alien and invasive species legislation. These overarching parameters are then translated into state, regional and local legislation and strategies to drive biodiversity conservation. At the intent level, national policies are driven by narratives of pristine, unique and threatened species-based protection. In the US and Australia, the narratives also influence local strategies, but additionally, they conflate weeds and pests with rubbish, uncleanliness and disorder, justifying their control and eradication through penalties and local ordinances.

5. Discussion: Leverage points for systems transformation through a novel ecologies approach

Environmental policies for nature, wildlife, and biodiversity in the three studied locations share a common ancestry. They stem from overarching frameworks like the European Directives (Ireland), the EPBC Act 1999 (Australia), and the Endangered Species Act 1973 (USA). As is typical in environmental legislation, these policies prioritize conservation principles focused on protecting and restoring pristine ecosystems and historical assemblages of species (Bridgewater and Hemming, 2020). However, as the research suggests, dominant conservation paradigms in developed nations often emphasize the inherent value of rare or threatened species, regardless of their ecological role. Particularly in countries with a recent colonial past (US and Australia), a sense of nostalgia for pre-urbanization species assemblages might influence an implicit bias towards protecting native and charismatic species (Barua, 2011).

We argue here that these frameworks may appear to have roots in ecocentric worldviews that are underpinned by intrinsic valuations of nature. However, in large part, the systems examined within this study tend to evolve and are transformed by visions which prioritize a sustainability paradigm (Coffey and Marston, 2013). Unfortunately, actions over the last decades framed under the sustainability umbrella, have failed to address biodiversity loss (Rupprecht et al., 2020). This is evident in urban biodiversity conservation, in which competing interests, such as land development, clash with environmental outcomes. This creates tension within environmental governance frameworks between the goals of biodiversity conservation and socio-economic development, growth, and extraction. This discrepancy arises from regional variations in species composition and abundance, historical legacies of colonization and oppression of Indigenous people, and national priorities driven by economics, trade or agriculture. We argue that legislation, particularly in urban areas, that focuses on the protection of certain species because of their unique value and conservation for human health, fails to recognise how human health is inextricably linked and interdependent with the health of other organisms while ignoring the autonomy of ecosystems and urgent need for mutual flourishing. As per all study cases, when the tendency is to selectively eradicate, preserve or restore certain species or ecosystems that are deemed valuable or beneficial to humans, opportunities to restore and protect less charismatic, ecologically significant or prevalent species often found in novel ecosystems and urban environments declines (Egerer and Buchholz, 2021, Soanes et al., 2019). This is a feedback loop that reduces the impact of change by reinforcing narratives of nativeness, uniqueness and spatial-temporal belonging.

This view stands in opposition to an understanding of biodiversity as all the variety of life on Earth. In each case study area, this human-centric worldview continues to drive policy and governance mechanisms related to ecological systems management. Meadows (Meadows, 1999) argued that the transformational capacity of a particular intervention is dependent upon the properties of a system. As such, some

interventions would cause changes at a shallower level, whilst others have the capacity to cause transformational change (Meadows, 1999). Although there are untapped capacities within existing laws to enhance social-ecological resilience and improve environmental outcomes (Garmestani et al., 2019a), we argue similar to other studies that target deeper interventions (Davelaar, 2021, Abson et al., 2017), for the need to change the deep leverage points – those that seek to transcend paradigms by shifting the 'intent' of 'actors that shape the emergent direction to which a system is oriented' (Meadows, 1999, Abson et al., 2017). We think this to be critical because in order to design and implement changes at shallower leverage points, these need to be informed by a different set of values, goals and worldviews. We do this through a novel ecosystem lens, a thought exercise that starts by recognising change and nonlinearity of ecosystems and accepts the reality that we now inhabit mostly altered ecosystems that cannot be reversed to ideal pristine states. Here we advocate for an approach that broadens its systems of values and recognises that we inhabit disturbed landscapes and that we need to work with novel ecosystems, non-native, alien and 'invasive' species, rather than against them and the ideas they represent in deep-rooted imaginaries. This is underpinned by the idea of biodiversity conservation as an inclusive, caring, and compassionate worldview and practice. This by no means is a call to stop traditional conservation and restoration efforts and actions, but rather a call to rethink and reimagine what and how we value and if this can be more inclusive of the variety of life on Earth we protect. In the following section, we offer an alternative system using novel ecosystems as guides, but also as the universal ecosystem types that land managers, stewards, policy-makers and the community will have to work with if we want to address biodiversity conservation. As a preamble, Fig. 3 below outlines the deconstruction of the system.

5.1. *Reimagining the systems paradigm through a novel ecosystem lens: our deconstruction of the existing system*

Novel ecosystems, with their unique blend of species, offer a promising lens for developing new conservation paradigms. While there are many trade-offs to consider, novel ecologies and the multiple organisms they support tend to exhibit a range of traits and functions that researchers describe as particularly resilient and adaptive to disturbance regimes and ecological challenges found commonly in urban areas (Sax et al., 2022, Thomas, 2013, Tredici, 2010, Mcphearson et al., 2013, Mcdonnell and Hahs, 2015). For instance, many of the plant species

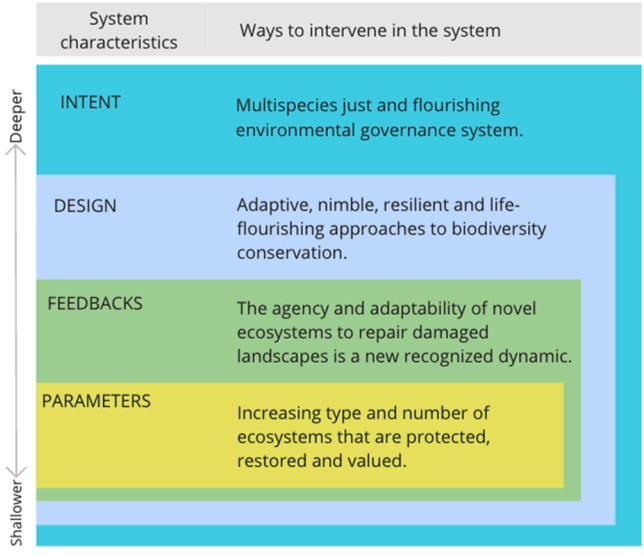

Fig. 3. Conceptual diagram explaining our 'deconstruction' of the system through the systems thinking farmwork.

found within novel ecosystems tend to be disturbance-tolerating, can reproduce and respond rapidly and flexibly to change, and have exhibited some ability to remediate damaged soils while also providing a range of ecosystem services and contribute to urban biodiversity, which benefits both humans and nonhumans (Robinson and Lundholm, 2012, Knapp et al., 2022).

Novel ecosystems in this sense, are nimble and flexible systems that are highly adaptable and in many ways a response to our current climate crisis and something the majority of the world's urban areas will need to coexist and contend with (Sax et al., 2022, Collier and Devitt, 2016). This does not preclude the importance of continued management and consideration of the impacts of certain species, but rather novel ecologies offer an invitation to consider alternative policy formations which are more holistic and adaptive (Knapp et al., 2022, Kowarik, 2011) and move beyond human exceptionalism (Pacini-Ketchabaw et al., 2016). This is particularly salient in light of new assessments, reports and policies emerging globally such as the Kunming-Montreal Global Biodiversity Framework developed at COP15, which aims to protect 30 % of the world's land, ocean and inland waters. Will novel ecologies and urban environments more generally be included in this protection, and how will such policies guide local and regional approaches to conservation? In this context, we offer a set of recommendations to inform policy and governance systems based on the four system characteristics and 12 leverage points framework. We present these ways to intervene in the system as practices foregrounded in inclusion and mutual flourishing.

5.2. *Intent*

12. *Transcending Paradigms*: Envision and enact flexible environmental governance systems that are underlined by principles of multispecies justice (eg. Just futures) (Houston et al., 2017). A multispecies just paradigm places value on all living beings and systems, their relations, and interactions, and finding ways of co-flourishing (Celermajer et al., 2020, Celermajer et al., 2021). Within this relational approach, climate change, social, spatial and other forms of justice are considered as part of legislative systems. This entails a reconceptualization of conventional biodiversity targets and reframing biodiversity as a measure of planetary flourishing and health (Sachs Olsen, 2022). Interesting to note is that transcending paradigms and shifting worldviews to reshape the structures and behaviour of a system does not have to be enacted from a top-down model (i.e. targeting primary bodies of legislation and national government institutions), but rather from bottom-up interventions. For example, a study in Colombia showed that bottom-up interventions in the areas called *resguardos* (socio-political entities and collective properties made up by Indigenous communities) '*were solely driven by the indigenous peoples' knowledge and cosmovisions*' (Burgos-Ayala et al., 2020). This enabled the creation of Life Plans designed and developed by the autonomy of Indigenous communities to sustain their traditional knowledges and worldviews and create behaviour and structure changes in traditional management paradigms (Burgos-Ayala et al., 2020).

11. *Paradigms*: A shift towards new models of conservation and promotion of biodiversity that are adaptive, nimble, and reflect emerging trends in ecology and urban systems science. These new trends are starting to expand their scope to consider the multiple benefits of non-native species to humans, cultural services, and social services (Threlfall and Kendal, 2018, Sax et al., 2022). A scientific process with long-standing biases for non-native species has focused on quantifying the threat and harm they inflict on humans and biodiversity while hampering opportunities to understand the benefits they offer.

10. *Goals*: Focus conservation on the function of species and ecosystems rather than their origin (Davis et al., 2011). Environmental protection for species and habitats should be premised on the multiple services and functions provided to ecosystems, particularly in the case of cities and disturbed landscapes. To this point, we bring on decade-long

calls for conservation to embrace novel ecosystems as being a reality of managing landscapes in the Anthropocene.

5.3. Design

9. *Self-Organisation*: Incentives to survey, restore and protect novel and hybrid ecosystems that are established and/or are providing ecosystem functions to human and nonhuman species and working to restore damaged landscapes. This should include training for effective stewardship and awareness of how to manage and care for disturbed habitats, which in turn can help build empathy for more-than-human communities. Understanding the social-ecological processes unfolding in novel ecosystems offers insights into how these spaces self-organise and can help us find ways to increase and protect biodiversity in cities, especially in areas that can no longer support native species due to the stressors of urbanization, climate change or other factors. (Kennedy, 2022).

8. *Rules*: Enact and utilize policies, provisions and procedures that are flexible and adaptable. They have the capacity to adapt when new knowledge is available and recognise that ecosystems are not in a steady state of equilibrium, but rather constantly changing, with climate change acting as an amplifier and magnifier of this change (Craig et al., 2017). Having the capacity to adapt requires developing 'feedback policies' or a policy system that is designed to learn and allow for management processes to evolve when new information is available (Meadows, 2009). This adaptive capacity however, must be based on the recognition of change, uncertainty and the entanglement of human-nonhuman relations, rather than on replicating the nature-culture binary that leads to reinforcing what Gelves-Gomez et al., (Gelves-Gomez et al., 2023) call 'Postcard Nature' which continues to control and represent Nature through a static protectionism lens. Incentives to survey, restore and protect novel ecosystems that are established and/or are providing ecosystem functions to human and nonhuman species and working to restore damaged landscapes.

7. *Information Flows*: Design environmental governance systems that are designed for intrinsic responsibility (Meadows, 2009) – which stems from a moral duty, but also extrinsic responsibility, which 'is driven by an assumed positive relationship between activities and performance. This will require imprinting an ethical code of multispecies justice that encourages the production of ecological knowledge on different ecosystem types, a larger range of species and better ways of translating this information to diverse groups of stakeholders. Increasing our ecological knowledge, for example, of the biodiversity potential in urban novel ecosystems (Bonthoux et al., 2014) and developing mechanisms to translate this can influence decision-making and affect behaviour change. These knowledge components and flows of the system can be encouraged through co-design programs and projects that bring together and enable diverse knowledges and groups to participate, experience, understand and contribute to the system.

5.4. Feedbacks

6. *Reinforcing Feedback Loops*: Strengthen and streamline the structures, institutions, procedures and processes that improve learning and decision-making between human agents and their behaviour in responding to ecosystems (Mastrangelo and Cumming, 2024). Supporting, amplifying and boosting citizen or community science programs and environmental activism can be ways to increase awareness and behaviour changes. These types of programs improve social-ecological interactions and can lead to a system that is more stable, resilient and on a path toward ecological recovery (Mastrangelo and Cumming, 2024). This produces trust in the system, as well as fairer and equitable outcomes, thus increasing the legitimacy and strength of those parts of the system.

5. *Balancing Feedback Loops*: Implement a multi-scalar and multi-temporal approach to assessments and monitoring that considers bioregional dynamics and changes. A 'silent' ecological destruction occurs when small to medium developments slowly destroy ecosystems at a local scale which results in large-scale destruction of ecosystems and biodiversity loss when accumulated through time and space (Whitehead et al., 2016). This 'death by a thousand cuts' occurs and is enabled by outdated environmental policy systems and it has been argued can be corrected through several mechanisms, such as cumulative impact assessments. Implementing a cumulative effects landscape approach to environmental assessment and management (Dales, 2011). These mechanisms can be fed into the higher–level policy frameworks to affect the relationships between higher-level policy frameworks with considerations of what happens locally or regionally.

4. *Delays*: Reducing the delay ('giving time') in these ecosystems to repair the landscape and increase biodiversity can impact the effectiveness of system behaviour. In other words, allowing novel ecosystems time to change through ecological succession, but also assisting through restoration efforts, can reduce the time it takes for people to be aware, recognise and protect the social-ecological value of novel ecosystems. Achieving behavioural shifts also requires reducing delays in the system. This can be done by encouraging and facilitating, through different actions and interventions, the agency, capacities and adaptability of novel ecosystems to repair damaged landscapes and ensure their capabilities to exert their beings and doings are enhanced and protected.

5.5. Parameters

3. *Stock and Flow Structures*: Re-examine classification systems as well as narratives of invasiveness, weeds, or exotics. This relates to an understanding of what biodiversity is and that an approach to biodiversity conversation and protection should be inclusive of all species (Schlaepfer, 2018).

2. *Buffers*: Change the type and number of ecosystems that are protected, restored and valued. This intervention has the capacity to increase the area of land designated for protection and conservation. This will open an entire range of possibilities for social-ecological actors to intervene, experiment, activate and enhance spaces that are currently not deemed worthy of conservation.

1. *Parameters*: Establish benchmarks and targets based on mutual flourishing for both humans and more-than-human beings. Increase the number of species that are protected based not only on their nativeness but on other variables, such as their contributions to the ecosystem, to climate change adaptation and mitigation.

While many of these recommendations may be difficult to implement, there are encouraging examples of alternative approaches and policy formations emerging globally. In the US the natural landscape movement has pushed many local governments and municipalities to rethink ordinances focused on removing vegetation or application of herbicide. Instead, climate-resilient plantings, which consist of both native and nonnative plants, are increasingly allowed and encouraged (City Of Oberlin, 2017). Another example is the Cleveland Pocket Prairie program organized by researchers at Ohio State University's Gardner Lab to explore how allowing vacant lots to evolve into prairie ecosystems rather than mowing them down or applying herbicide can increase pollinator populations and conserve biodiversity (Parker et al., 2020, Turo et al., 2021). These trends are also emerging in Australia, and European countries, including Ireland, In the latter for example, the All-Ireland Pollinator Plan seeks to reverse the decline in pollinators by using an all-island approach, including all scales of planning and interventions, and incorporating an all-citizens approach (community, individuals, businesses, etc) (Aipp, 2021). Through these they are having far more impact in rewilding by targeting all types and scales of landscapes, including those highly disturbed novel ecosystems. Ireland and Australia are also undergoing reforms with the new EU Nature Restoration Law and partial reforms to the EPC Act, respectively. Although they could signal a change in the current trajectory of poor environmental outcomes, neoliberal regimes and business-as-usual

strategies continue to inform their development.

Based on the work presented in this study, we would like to conclude this section with two points. The first is a call to increase our knowledge of novel ecosystems, including species composition, ecosystem functions, and social-ecological dynamics. There are significant opportunities to do this through ground-up approaches, for example using citizen science to assist in building up a good evidence base. The second is to draw inspiration from novel ecosystems in an urban context to inform alternative approaches to governance and legislation, but also in multiple landscape types and scales. The novel ecosystem concept is less debated in urban contexts and offers opportunities to explore and gain knowledge (Teixeira and Fernandes, 2019), thus accelerating a shift in environmental policy framing and implementation.

6. Conclusion

In this paper, we reviewed key environmental policies in three regions: Ireland, Australia, and the USA to explore how biodiversity and landscape and invasive species management are framed and valued and their implications for biodiversity conservation in the Anthropocene. Using the leverage points in systems thinking as an analytical framework we identified similar but also differing themes and patterns across the three policy systems, namely that the intent is eco and humancentric, the design and feedbacks are often misaligned, incongruous, or not flexible, and the parameters are focused on only a narrow set of metrics that privilege protection of unique, charismatic species. Based on the review of key environmental policies we then reimagine the existing policy system through deep leverage points for how systems can be transformed through a novel ecosystems lens. With this we frame new ways for valuing biodiversity – as all life on Earth – and suggest new environmental governance strategies inspired by novel ecosystem characteristics, such as adaptability, flexibility, transformation, nonlinearity, and unpredictability. We argue these principles can help us care for and manage the landscapes we now inhabit, which are highly disturbed ecosystems. We expect this work to help decision-makers and land managers develop more holistic management approaches that align better with the coupled crises of climate change and biodiversity loss.

We recognise change at the intent level is a difficult task and encourage change to occur at shallower levels. It is important as well to recognise that although the reviewed policy systems in those case studies do have the power to influence other regions worldwide, it is important to investigate what other places, particularly in the Global South, are doing. This will be particularly relevant for informing environmental governance systems that have entrenched worldviews and policies that are inflexible and unable to adapt to the uncertainties of the Anthropocene.

CRediT authorship contribution statement

Marcus Collier: Writing – review & editing, Writing – original draft, Validation, Supervision, Funding acquisition, Conceptualization. **Fiona Nulty:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization. **Christopher Kennedy:** Writing – review & editing, Writing – original draft, Validation, Formal analysis, Data curation, Conceptualization. **Melissa Pineda Pinto:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2024.103926.

Data Availability

I have shared the link to my data/code at the Attach file step'

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