Advanced Research + Invention Agency ARIA

Programme Thesis

Accelerated adaptation

v1

Yannick Wurm, Programme Director

CONTEXT

This document presents the core thesis that underpins the Accelerated Adaptation programme, which sits in the Engineering Ecosystem Resilience opportunity space.

Sign up to receive updates about the opportunity space and learn more about the programme.

An ARIA programme seeks to unlock a scientific or technical capability that

+ changes the perception of what's possible or valuable;
+ has the potential to catalyse massive social and economic returns; and
+ is unlikely to be achieved without ARIA's intervention.

PROGRAMME THESIS, SIMPLY STATED

An overview of the programme thesis, accessible & simply stated

Over 25% of assessed animals and plants risk extinction within a century [1]. This potential loss is shaped by the intensification of human-driven changes in land use, movement of species and their pathogens, pollution, and climate change. Indeed, our activities create **environmental pressures that now exceed the abilities of many species and ecosystems to adapt** sufficiently to persist [2], and we have surpassed seven of nine proposed biophysical limits linked to stable life on Earth [3]. Biodiversity losses affect both the extent of ecosystem service provision [4], and the ability of those ecosystems to respond to disturbance [5]. Hence, these environmental changes put under existential threat the irreplaceable benefits every nation needs from nature [6], including pest control, carbon sequestration, clean water, and the production of food and materials [7].

Nature protection encompasses a broad range of approaches, from conserving, recreating, and rewilding habitats, to captive breeding and species translocation. Such efforts, and those to reverse environmental pressures toward pre-industrial levels, are essential. However, even the most ambitious efforts may struggle to match the scale and pace of environmental change, risking ecosystems destabilisation and irreversible loss. Furthermore, well-established approaches are typically unable to address the mechanistic foundations of resilience – from interacting genetic, epigenetic, and physiological processes within organisms, to the behavioural, symbiotic, and community-level dynamics that determine how species and ecosystems fare under novel conditions.

New technologies could unlock new pathways for complementing and enhancing well-established nature stewardship approaches [4,5]. Genomics, assisted selection, and biotechnology have transformed agriculture, how we perform research on human disease, and how we diagnose individual patients. Robotics and AI-enabled automation have transformed supply chains. These same technologies are revolutionising our ability to measure and model nature; they are also creating mechanisms towards market recognition of biodiversity and ecosystem services. Such improvements can drive needed policy and behavioural changes. Yet if species are on track towards extinction, or ecosystems at risk of collapse, our intervention options remain extremely limited.

We thus now also need to be able to help vulnerable species acquire beneficial traits: preparing them for known environmental pressures, or building resilience to less predictable environments. Applying this new capability judiciously could directly help the focal species survive so they continue to deliver critical ecological traits or ecosystem services. These outcomes in turn can help the many other species that depend on them. Ultimately, maintaining and improving redundancy in the provision of ecological traits and ecosystem services increases overall ecosystem resilience.

This ARIA programme aims to create the tools for accelerated adaptation in wild species and ecosystems and to deliver detailed case studies in contained settings. To achieve this, we will unite cross-disciplinary teams of experts in ecology, evolution, ethics, biological engineering, conservation, robotics, and AI. Projects could focus on strategically chosen vulnerable species, such as trees [6], which can support hundreds of other species [6], and/or critical functional groups such as pollinators or soil nutrient cycles that underpin ecosystem services [7].

Alongside technical research, we will incorporate ethical and governance dimensions from the outset. While this programme will not deploy novel interventions in the wild, the research conducted under the framework we propose has the power to transform conservation and ecological engineering approaches, expanding well-established stewardship approaches with complementary tools. It is critical that any tools are created with robust ethical consideration from the outset, to support a transformation that enables a future where both humanity and biodiversity can persist and flourish.

This programme thesis is derived from ARIA's [Engineering Ecosystem Resilience] opportunity space. The programme thesis was shaped by hundreds of one-on-one conversations, feedback from dozens of stakeholders on earlier drafts, twenty-two discovery projects, and over 15 workshops, presentations, and webinars encompassing over 250 attendees. Engagement spanned conservation practitioners and NGOs, regulators, startup founders, ethicists, investors, insurers, philanthropists, academics, governmental scientists, and intergovernmental policy-makers.

PROGRAMME THESIS, EXPLAINED

A detailed description of the programme thesis, presented for constructive feedback

Why this programme

Nature's services and resources are essential to our existence. Our relationship with natural living systems has historically been extractive. Until now, the intrinsic resilience of species and ecosystems has enabled them to respond and continue to provide for our needs.

However, the environmental challenges we see today are substantially more acute and diverse than in the past, now outpacing nature's ability to buffer, adapt, or evolve. Indeed, seven of nine biophysical thresholds associated with stable life on Earth during the Holocene have now been crossed—four in just the past 15 years [3]. Over 25% of assessed animals and plants are at risk of extinction over the next 10—100 years [8], creating widespread dangers that span biomes and raising the risk of cascading collapses, where small-scale losses can lead to large-scale unravelling of ecosystems as we know them [9].

The accelerating pace and scale of biodiversity loss threaten our way of life. Over half of global GDP depends on ecosystem services and the natural systems that generate many of these services are under severe threat [10,11]. UK GDP is already expected to shrink by up to 3% by 2030 due to chronic nature degradation [12]. For example, pollinator decline alone puts ~£630 million of annual UK crop production at risk [13]; predator insects annually contribute at least £145 million pounds to producers of three key UK crops annually by consuming pests [14]. Global extensions of such **threats to agricultural ecosystem services undermine food sovereignty** worldwide [7]. Furthermore, most medicines originate from plant compounds [15], meaning that preserving biodiversity keeps future bioactive drugs discoverable [16]. Wild spaces and the plants, animals, and fungi they contain are also vital for mental health and wellbeing and cultural identity, and have intrinsic value [17,18]. Both moral imperatives and practical necessity compel us to preserve Earth's living heritage and maintain ecosystem function [18].

Humanity's most urgent challenge is thus to halt and reverse human-controlled drivers of detrimental environmental change. Large-scale interventions such as restoring natural landscapes, transitioning from agricultural monocultures, curtailing use of pesticides and fertilisers, eliminating plastic and chemical pollution, reducing the international movement of plants, animals, and their pathogens, and restoring atmospheric greenhouse gas concentrations to pre-industrial levels are all crucial to alleviate the pressures facing our ecosystems. The realisation by World Economic Forum leaders that over the next 10 years, four of the top five global risks are environmental [11] supports our perspective that we now need radical and proactive programmes to support nature.

Nature does know best. But when the pace of environmental change far exceeds nature's ability to adapt, populations will decline, can be pushed into maladaptive trajectories, and ultimately species can be extirpated or go extinct, and functions lost. Alongside reducing the pressures we have created, should we not also develop the means to help species withstand them? Doing so carries risks. But so does choosing not to, when the alternative is losing species and the ecosystem functions they underpin.

We pragmatically recognise that the large-scale transformations required to reverse environmental pressures are unlikely to materialise fast enough to halt ongoing losses. Species losses and degradation of ecosystem functions will thus continue, increasing risks of cascading disruption, unless we undertake targeted interventions. Substantial innovations in high-resolution nature sensing technologies are under way, as are new data integration and modelling approaches. The improved ability to measure and model nature puts us on a pathway towards driving policy, market, and behavioural changes. At the same time, if we conclude that species are on track towards extinction, or ecosystems at risk of collapse, our intervention options are extremely limited.

Recent technological breakthroughs offer a pathway that complements direct conservation and policy efforts and which could significantly reduce the risk of ecosystem collapse even as environmental conditions continue to shift. Indeed, the 2025 IUCN World Conservation Congress endorsed case-by-case assessment of synthetic biology as a conservation tool [19] and recognised the potential of AI for conservation [20]. In alignment with ARIA's mandate to advance science and technology "at the edge of the possible", the Accelerated Adaptation programme seeks to harness new and emerging technologies to launch this compelling parallel approach. Research on new interventions will occur exclusively in controlled laboratory settings and contained environments.

Responsibly applying the proposed accelerated adaptation capabilities under robust governance, ethical oversight, and appropriate social licence, could help forge a more mutualistic relationship with nature.

Accelerated adaptation is now within reach

Recent scientific and technological progress across multiple disciplines has converged to enable accelerated adaptation to become a reality:

+ **Commoditisation of robotics + hardware + electronic engineering**
  Custom incubators and growth chambers, and robots to automate handling, can now be created at scale, enabling high-throughput experiments to screen, prime, or select for adaptations in individual species or communities.

+ **High-throughput genomics**
  Genome-wide study is now possible in almost any species, revealing vulnerabilities and guiding breeding and assisted gene flow efforts. Fundamental genomics research has clarified the constraints and trade-offs that shape adaptation and evolutionary innovation [21,22].

+ **Precision molecular + cellular biology**
  Peptides, hormones, RNAs, vaccines, probiotics, and transient viral vectors enable targeted yet reversible and non-heritable interventions. Molecular and cell-culture approaches enable enhanced micropropagation, grafting, and breeding to support populations at scale. Targeted heritable alterations (e.g., gene editing) offer new research pathways for candidate traits.

+ **Artificial intelligence + machine learning**
  New AI/ML techniques enable rapid analysis and synthesis of existing literature and novel datasets, which previously would have been infeasible or required substantial labour by human experts. The ability to detect previously hidden patterns can enable new decision-making approaches.

+ **Ecosystem sensing + modelling**
  New sensor technologies provide high-resolution near-real-time data on biodiversity and ecosystem dynamics. These data enable direct measurement or inference of traits and functions, facilitate new modelling paradigms, and ultimately create the ability to better predict ecosystem responses to potential interventions and identify high-leverage points for maximising benefits.

Key assumptions and framing

+ Many critical ecosystem functions are delivered by assemblages, not individual species (examples include pollination, carbon sequestration, and soil health).
+ Ecosystems are composite networks of interdependent species and abiotic conditions, with uneven levels of connectedness and redundancy. Disruption to highly connected species or to critical functions can trigger cascading losses.
+ Assemblages of species that have long co-existed provide more resilient foundations than those involving species that are new to an ecosystem.
+ Every species loss constitutes a reduction in overall resilience and a loss of deep evolutionary history.
+ For most species, we still lack basic knowledge of needs, interactions, and adaptive capacity within and across generations. This creates substantial challenges to predicting responses to environmental changes.
+ All models have blind spots: satellite-data models are species-blind, ecosystem-level models are blind to evolution and genetics, evolutionary models are blind to ecological complexity and often disconnected from empirical data.
+ Not all species can move to more suitable environments fast enough (e.g., trees); some may struggle even if moved (due to difficulty in local adaptation, competition for niches/nesting sites), or have multiple requirements (e.g., breeding vs overwintering locations).
+ Techno-optimists argue that 50 to 200 years from now, limitless renewable energy will have resolved challenges related to greenhouse gases, that dense vertical farming will have freed most of our land for rewilding, and that the other major environmental pressures will similarly have been reversed. If one accepts these utopian views, the remaining challenge is to keep as many species alive and ecosystems functional as possible until then. If these utopian predictions fail to materialise, this programme is even more essential.

What we hope to accomplish: Accelerating adaptation for resilience

This ARIA programme seeks to enable wild species to rapidly overcome current and future threats, ensuring their survival, ecological function, and the resilience of the valuable natural infrastructure they provide**.** The resulting transformative paradigm for conservation and ecological engineering will complement well-established environmental protection and stewardship strategies. By accelerating adaptation of key ecosystem members or functions, we aim to preserve ecological interactions and maintain or recover important functions and services despite environmental changes.

Application contexts for this programme include:

+ **Preservation of species that many other species rely on** for food, habitat, or both, such as trees or reef-building corals, which have long generation times and cannot disperse or otherwise handle dramatic changes in seasonal environmental extremes. For example, some tree species support over 1,000 other species [6], but are vulnerable to climatic changes [23]. Pre-adapting such species to known threats could help preserve local species assemblages and thus help maintain ecological resilience.

- **Preservation of priority functional groups** such as pollinators, soil nutrient cyclers, or predators facing diverse challenges such as habitat fragmentation and exposure to pollutants. Accelerated adaptation of the species contributing to a functional group could ensure critical ecosystem functions persist under stress, providing cascading benefits across the communities of species they interact with.

- **Post-disturbance recovery.** Acute disturbances including deforestation, pollution, storms, heat waves, wildfires, and disease outbreaks can significantly destabilise local ecosystems. Accelerating the ability of key pioneer functional groups, such as bioremediating fungi or soil-binding plants, to rapidly establish and function under post-disturbance stress could significantly boost natural regeneration and the recovery of ecosystem functions and resilience.

- **Supporting strategically selected at-risk species** (e.g., those with cultural significance). Enhancing population viability by facilitating appropriate adaptation of characteristics such as fertility, genetic diversity, movements and their plasticity, or the ability to survive through specific environmental challenges can substantially reduce extinction risk to species deemed important for their own sake.

Two major directions of technical innovation can enable accelerated adaptation. The relevance and feasibility of the two directions, and whether both are needed, will vary across study systems:

1) **Supercharged natural adaptation.** This can include assisted migration, breeding, fertilisation, or hybridisation. It can include physiological priming through controlled exposure to environmental challenges (e.g., chemicals, future climatic conditions, inactivated pests/pathogens) which may lead to epigenetic or microbiome-level changes. It can include directed evolution under exposure to environmental challenges, and may use tricks such as shortened days, altered seasons, grafting, hormonal treatment, or *in vitro* gametogenesis to reduce generation times.

2) **Engineered molecular adaptation.** This can involve temporary changes to an organism, for example through injections or topical applications of RNA or peptides, the use of cell lines, or manipulating symbionts to achieve a particular goal (e.g., enhancing near-term survival, reproduction, or growth). Heritable genome modification can also be considered.

By responsibly applying accelerated adaptation under robust governance, ethical oversight, and appropriate social licence, we could reverse our extractive approach and forge a mutualistic relationship with nature, while simultaneously working to slow, and ultimately reverse, the underlying drivers of biodiversity decline.

Specific programme objectives

To deliver on the aim of enabling wild species to rapidly adapt to current and future threats the programme will:

1. **Demonstrate accelerated adaptation in wild species**
   Achieve clear, measurable improvements in targeted traits (e.g., survival, fecundity, functional performance) in wild systems under simulated stress, substantially beyond what unaided natural processes would deliver over the same time.

2. **Develop scalable platforms for accelerated adaptation**
   Generalise adaptation tools into replicable, scalable platforms, in particular using laboratory and computational automation so we can accelerate adaptation of various species to varying stressors.

3. **Create the tools to prioritise, predict, and de-risk interventions**
   Use modelling, data, and analytics to identify the most impactful targets (species, traits, systems), considering potential cascading benefits, and also risks, to support regulatory and investment decisions.

4. **Lay foundations for responsible deployment and future markets**
   Produce a credible translation strategy for responsible deployment. This includes contributing to the governance, regulatory, and data foundations needed, and addressing key gaps for appropriate measures of value.

Notes on metrics: default metric expectations include trait uplift (primary metrics: survival, growth, fecundity, or functional performance under stress) with targets framed to exceed the 99th percentile (i.e., median adapted performance at or above the top 1% of unadapted performance) where that baseline can be measured, persistence over ecologically meaningful timescales (e.g., ≥3–5 generations for short-lived taxa), and evidence of scalability / reproducibility.

What we expect to fund

To develop the capability of accelerating adaptation of wild species at scale, we will fund several types of teams:

+ **System-focused teams** will aim to increase resilience of their study system or the ecosystems it contributes to.
+ **Scaling Partners** will be brought on by System-focused teams to build capabilities essential for scaling the newly developed approaches.
+ **Modelling teams** will aim to develop new models and resilience metrics that incorporate trophic interactions, genetic diversity and environmental change in a manner that could ultimately support the deployment of the System teams' methods into the real world.
+ **Data and Analytics teams** will lead on standardising data and analysis approaches including through training other teams, and verifying outputs of System-focused teams.
+ **Ethics and Social Responsibility** teams will pursue research to support responsible future impact of new capabilities developed by System-focused teams.

System-focused teams are the core of our programme. A **study system** may be a group of species that are related or associated functionally (e.g., pollinators, soil nutrient cyclers, insect predators), taxonomically (e.g., trees), or ecologically (e.g., grassland, lichen). Study systems must be strategically chosen, with global importance and/or clear UK relevance. A study system may also have cultural value. Creators (i.e., people funded by ARIA) will initially focus on a single species and stressor in which they anticipate being able to show tractable progress within 18 months; they will subsequently generalise to at least one additional species or stressor. We encourage situations where focal species are highly connected, making cascading functional benefits more likely.

At a programme level, we anticipate funding teams working on complementary systems. We anticipate funding more work on terrestrial and freshwater systems than on marine systems, reflecting differences in tractability and the priorities of other funders. **Annex 1** provides a speculative list of ideas we would consider to be within scope. These are not requests; the examples aim to stimulate creativity by illustrating a breadth of possible approaches. The following are explicitly **out of scope** for this programme:

- Established conservation approaches – vital for ecosystem resilience, but not ARIA's focus.
- Direct work on invasive or pest species – although new technologies in this area hold promise.
- De-extinction efforts [24].
- Agricultural species (e.g., heat-resistant crop varieties).
- Species re-introduction programmes (e.g., re-introducing wolves).

System-focused teams should:

- Use existing evidence to explain why their chosen system should be prioritised, with a focus on its functional importance and ecological/community context.
- Embed social, ethical, and governance considerations from day one, including stakeholder engagement and social-license assessment.
- Select a first focal species and stressor, and which to subsequently pursue. Some teams may initially work on a more tractable "proof of concept" species-stressor pair before applying learnings to more ecologically impactful species-stressor pairs.

System-focused teams may:

- Need to identify the genetic basis of vulnerability, and/or determine whether the target function needs directional support in the face of specific environmental challenges (e.g., specific climatic condition, pollutant, pathogen, or parasite), or more generic support to become more resilient to perturbations in general (e.g., through increased fertility, genetic diversity, recombination rates, broader immune defences, or plasticity).
- Focus on accelerated natural processes or engineered molecular adaptation, or combine both.
- Propose multi-species designs when functions depend on multiple species.

We expect **System-focused teams** to achieve specific targets:

- **Meeting metrics for increased resilience**
  Teams must aim to achieve demonstrable increases in resilience using one of the three metrics below, or a justifiable alternative. Measurement capabilities may in some cases need to be developed. By default, teams should target outcomes that exceed nature's best-case, i.e., ≥99th percentile of unaided natural processes under matched stress scenarios.
    - **Improved function**. Examples: increased survival, growth, or fecundity, or faster recovery under or after stress.
    - **Increase in indicators of adaptability**. Examples: increased effective population size or related genetic metrics.
    - **Improved robustness of ecological function**. Rescue or maintenance of ecosystem service provision under conditions of environmental stress. Examples: pollination, predation ability, carbon sequestration, pest control.
- **Demonstrating sufficient persistence**: System-focused impacts should remain useful without excessive fitness costs over ecologically relevant timescales. While benefits should be long-term, the mechanisms to obtain them may be temporary.

- **Exhibiting scalability:** Newly developed protocols should be applicable across species and stressors.
- **Identifying milestones and risks**: Teams will provide clear metrics and quarterly milestones for tracking project progress. Plans will list early warning signs of failure and identify potential risks, including those that should trigger project cessation.

Scaling Partners will be brought on by System-focused teams, to develop and provide specialist expertise to improve the efficiency and scalability.

They may be new or existing entities including individuals, core facilities, contract research organisations, design studios, research labs, frontier research contractors [25], or collaborations among diverse entities. Scaling Partners may provide expertise on scalable delivery of one or more of the following:

- Genomic vulnerability mapping and molecular engineering (including cell culture, in-vitro phenotyping, design and synthesis of RNA, vectors, peptides or proteins, performing gene edits, creating transgenic lines).
- Automatic rearing + phenotyping. This includes:
    - Robotics for automated rearing in climate-controlled conditions (e.g., incubators, ecotrons, climate-temperature chambers/vivaria/terraria).
    - Sensors and algorithms for automated phenotyping of plants and animals.

Theory or modelling-focused teams. Given limited resources, we will need to improve our ability to identify priority functions, species, and communities where support can be the most impactful, to understand how to trade off different manners of supporting them, and to understand which levels of support are sufficient. For example, what combined level of genetic diversity and gene flow is needed and when? What are the impacts and risks of different interventions on resilience? We anticipate that integration of existing new datasets (e.g., from natural/incidental experiments, generated by System-focused teams) or small amounts of new data generation could underpin impactful novel theoretical, simulation or modelling efforts. New models may focus on one level (e.g., genetic diversity), or span levels (genes-species-ecosystems).

Data and Analytics team. In order to ensure that System-focused teams accurately show progress against the agreed milestones, we will have a centralised data team with the following responsibilities:

- Lead on standardising data, leading to the creation of a unified, comparable, FAIR Data set
- Measure and validate the outputs of all System-focused teams, including their benchmarking
- Deliver training for best practices in code and data handling to all System-focused teams
- Assist System-focused teams ad-hoc with specialist analysis or visualisation needs

This centralised Data and Analytics team could be an academic core facility, a data-science focused academic research team, or a contract research organisation. Most importantly, the team must have strong expertise in data and statistics, experimental design, and likely genomic analysis. If they are more technically focused, they may want to subcontract components of training delivery (e.g., to the software/data carpentries organisation).

Ethics and Social Responsibility-focused teams. We recognise there is a diverse set of ethical considerations in the funded areas that warrants specific ESR focused research and activities. As such, we do not want to be prescriptive here and welcome proposals that set out a belief on how the funded work will support the aim of the programme and, more generally, support an approach that is ethically and socially responsible to the communities it seeks to serve.

We would be interested to see proposals include the following types of activity, but remain fully open to other ideas:

+ Co-develop, with project teams and/or wider stakeholders, ESR tools, frameworks and guidance, based on ESR considerations of the programme and projects and building on existing frameworks where relevant.

+ Conduct programme-level ESR training and project-level support to ensure responsible delivery of goals and/or decision-making.

+ Produce evidence, insight, and practical guidance that can inform future governance models and/or regulatory pathways.

+ Applications focused on running public dialogues will not be considered for funding, as ARIA intends to contract with a specialist provider to manage a comprehensive public dialogue separately. Other forms of public and community engagement will be considered.

Structure and Budgets

The four-year programme is structured around two phases. Phase 1 (two years) establishes the methods, metrics, and proof points on diverse study systems. Phase 2 (two years) includes a continuation of work from Phase 1, while emphasising improvements in cost effectiveness and throughput based on Phase 1 results. Phase 1 may fund approximately 10-12 teams, while Phase 2 may fund a smaller number of teams.

Table 1) Sample funding structure showing approximate team numbers and phasing. Project costs are averages, and team counts per stage are illustrative rather than targets.

Ethics and Social Responsibility (ESR)

Interventions in wild populations raise profound ethical questions that cannot be resolved through technical excellence alone. This programme recognises multiple, sometimes conflicting, value systems: the intrinsic worth of species, their cultural significance, ecosystem integrity, and human, both current and future, dependencies on nature's services. We will embed an ESR and governance framework that enables consideration of key questions and provides oversight across the programme.

This framework includes four key components:

+ Guardrails,
+ Principles,
+ Programme-level governance and support,
+ Project-level requirements.

Guardrails:

This programme has established guardrails to limit risk from the outset:

+ All work within this programme's timeframe will be performed in contained settings appropriate to the study systems, with physical and procedural safeguards designed to prevent unintended environmental exposure. This containment allows us to develop and test interventions while limiting risks to real-world environments.
+ No releases to the wild will occur during the programme funding period. Nonetheless, teams must still design work with the potential for real-world application in mind.
+ Compliance with applicable UK and international frameworks is essential (including but not limited to:, Nagoya Access and Benefit Sharing protocol, Cartagena protocol, CMS convention, GMO regulations 2014, Wildlife and Countryside Act 1981, CBD precautionary approach, Ramsar convention, IUCN guidelines, appropriate UK regimes for chemicals/products (PPP, BPR, VMR, UK REACH)).

Principles:

We acknowledge that ethics are not static—what is acceptable may shift as evidence accumulates and public discourse evolves. Nevertheless, all projects must adhere to the following principles, both for the research they do in contained facilities during the programme and in planning for potential future real-world deployment:

+ **Precaution**: Teams must have evidence that use of alternative approaches could carry greater risk than intervention through accelerated adaptation, particularly where irreversibility is inherent to an approach. Risk assessments must consider both the immediate ecosystem and effects on longer temporal scales (e.g., 50+ years / 10+ generations). Teams must identify potential early warning indicators (unexpected population dynamics, range expansion beyond target areas, non-target species declines) that would trigger suspension or reversal of a future potential intervention (where this is feasible).

+ **Ecosystem integrity**: Potential interventions must assess and mitigate risks of harm to non-target species and ecosystem function, including:
    - Possibility of loss of genetic diversity or locally adapted alleles within target species, which could make the species more vulnerable to other environmental challenges.
    - Risk that enhanced resilience enables a target species to outcompete other native species, converting a vulnerable species into a pest.
    - Possibility that changes in the abundance or chemical composition of one species may affect others in the trophic cascade.
    - Risk that increased population size or range could increase the likelihood of disease transmission to other species.
+ **Transparency, consent, and social license**: Research that may eventually affect specific ecosystems requires meaningful engagement with local communities, indigenous peoples where relevant, and other stakeholders from the outset—even for contained/conceptual work that may only eventually affect those ecosystems years later. Teams will ultimately need to secure social license beyond regulatory compliance, acknowledging that some interventions may be technically feasible yet ethically or socially unacceptable.
+ **Equitable access**: Every team should be able to explain how their work could influence society, and what an equitable benefit distribution for their project would look like in practice.
+ **Responsible development**: Teams must utilise a framework for responsible research and innovation, such as UK Research and Innovation's Anticipate, Reflect, Engage, and Act (AREA). Techniques developed here could be misapplied to disrupt ecosystems or enhance pest species; teams must conduct dual-use assessments and propose safeguards.
+ **Non-maleficence**: No project may aim to increase extinction risk, reduce genetic diversity without compelling justification, or knowingly harm non-target species. Teams must explicitly consider worst-case scenarios.

Programme-level governance and support:

+ **ESR Advisory Committee ("Committee")** – we will establish a Committee, made up of international experts in the field, with a remit to provide advice and guidance to the Programme Director, to support oversight of matters related to the ethical and social considerations of the programme and funded projects. This may include advising on, and reviewing, the outputs and significant milestones from project teams. The role and remit of this committee will evolve to meet emerging ESR-related considerations of the programme.
+ **Proactive engagement** with the wider community – the programme team will proactively engage with:
    + UK regulators, government agencies, public bodies and stakeholder representatives (including JNCC, SEPA, DEFRA, Environment Agencies, ACRE and other devolved administrations and public bodies) to explore pathways for contained trials and eventual deployment.
    + International bodies and conventions relevant to the intervention and ecosystem context (e.g., IUCN; CBD/Cartagena/Nagoya; and where relevant CITES, CMS, and Ramsar), to align with, and build upon, existing and emerging guidance on interventions in conservation.

+ **Training and guidance** – programme-level training and guidance on ESR will be provided early in the programme lifecycle. We will identify opportunities to co-design and develop this suite of support with our Advisory Committee, funded ESR teams, as well as other teams, and external stakeholders in the ESR and research community.

+ We will establish clear escalation pathways for ethical concerns.

Project-level requirements:

+ **ESR considerations from the outset** – each project team must demonstrate, from the outset, their understanding of the ESR considerations for their proposed work, and include a plan for engaging with and/or addressing these throughout the project. This may include ensuring access to ESR expertise and/or additional support. It is intended that the Advisory Committee will play a role in supporting such assessments of what may be required, e.g., community engagement activities.

+ **Bespoke training and support** may be provided based on project need. This will be identified and agreed with the project team, with support from the Advisory Committee.

Intellectual property and access

ARIA's standard IP terms will apply to research we fund. To improve access to findings, protocols, code, and data assets, we do ask recipients to share what they can in an open manner in accordance with their organisational structure and where sharing does not conflict with security, ethical, or commercial considerations.

Pathways to impact beyond the programme

This programme is designed not only to deliver scientific proof-of-concept but to lay the groundwork for real-world translation. If successful, the tools and adapted systems it produces will be taken forward by others, through government procurement, commercial spinouts, philanthropic backing, or a combination of these.

The programme will generate four categories of valuable outputs:

+ adapted varieties of wild species with demonstrated resilience to specific environmental challenges;

+ reproducible accelerated adaptation protocols transferable across systems;

+ scalable platforms that reduce cost and time for new applications;

+ and prioritisation and risk models for intervention decisions.

Several developments make post-programme translation increasingly plausible. Biodiversity-related risks are increasingly on the agenda of business leaders, insurers, investors, and governments. The UK's Environment Act 2021 has already created a £280m and growing market for biodiversity credits in England, and comparable statutory markets are emerging internationally. Large-scale philanthropies focused on biodiversity have recently appeared, and a growing number of venture and institutional investors now focus specifically on nature and natural capital. Nature-based solutions (NbS) are already deployed for applications from coastal and flood defences to ensuring the presence of pollinators and natural pest control. But these solutions depend on the species involved being resilient enough to persist under changing conditions. The tools and platforms we build also have direct applicability to adjacent sectors including agriculture, forestry, aquaculture, and the management of vector-borne diseases.

Carbon, biodiversity, and nature-based solution markets all share a fundamental requirement: the interventions they pay for must persist. Credits and contracts typically assume 30+ year time horizons, yet the environmental pressures facing ecosystems are intensifying over exactly those timescales. Assets that die or degrade deliver no returns to investors, to credit buyers, or to the ecosystems themselves. Ensuring resilience of the species that underpin these markets is a precondition for market credibility and long-term viability. This programme builds the tools for that resilience.

Crucially, advances in environmental sensing and monitoring are making it increasingly possible to draw direct, auditable links between specific ecosystem interventions and the services they deliver. As this capacity for measurement, reporting, and verification matures, it strengthens the case for payment-for-ecosystem-services models, and with it, the commercial rationale for investing in the resilience of the species that underpin those services.

We anticipate that post-programme funding will realistically combine philanthropic bridge funding for field trials and regulatory development, venture and growth capital for spinouts with clear commercial applications, and procurement for adapted stock in publicly-funded restoration or privately-funded nature-based solution projects. We will also consider establishing a vehicle such as a public benefit corporation to steward intellectual property where commercial incentives alone are insufficient to ensure equitable access or long-term ecosystem benefit. None of these pathways is guaranteed, but the trajectory — biodiversity disclosure requirements, statutory restoration targets, growing institutional capital in natural assets — suggests the funding environment will be more favourable by the time the programme concludes. Our intention is to actively engage follow-on funders during the programme, and to support programme-funded teams in identifying relevant pathways.

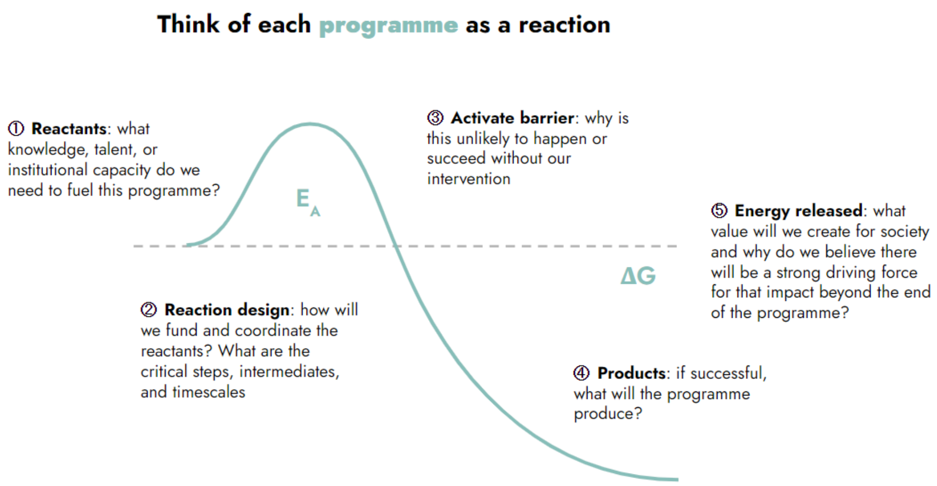
Engage

Click here to stay updated on programme updates and funding calls. You can also provide feedback that can help improve this programme thesis, by clicking here.

Success in the programme requires multidisciplinary teams. For groups or individuals needing assistance in building these teams, you can register your capabilities and missing expertise to our teaming tool, allowing us to support matching with other registered teams.

PROGRAMME THESIS, REACTION DIAGRAM SUMMARY

We can metaphorically think of an ARIA programme as a chemical reaction and use a simple reaction diagram to summarise the key elements of the imagined programme.



① **Reactants:** Technological solutions and expertise exist across robotics, ecology, evolution, biological engineering, and AI that are not yet fully exploited for nature protection. Yet the UK has world-class capability and research in these areas, and boasts among the highest density of conservation organisations and efforts in the world. Emerging advancements are poised to transform conservation if united under a shared mission. The UK has already cemented its leadership through legally binding Environment Act 2021 targets for 2042, and measures such as England's new Biodiversity Net Gain market projected to reach £3b.

② **Reaction design:** This programme will leverage the deep expertise and societal passion for conservation that characterise the UK by funding development of systems, platforms, and models that innovate, translate, and scale tools for inducing rapid adaptation and resilience in natural systems. Our work will overcome current limitations that prevent exploration and adoption by integrating scientific, technical, and societal expertise. All work will be rooted in community consultation and ethical frameworks to ensure that solutions address ecological integrity and community priorities.

③ **Activation barriers:** Existing barriers are technical, economic, regulatory, and societal. Current research and funding mechanisms remain siloed by discipline and risk appetite, leaving cross-sector technologies underdeveloped for conservation. ARIA's intervention is essential to de-risk high-potential approaches, overcome fragmentation, and integrate technical, ethical, and governance considerations that conventional programmes cannot.

④ **Products:** Successful projects will deliver products (adapted plants and animals) that provide ecological resilience and ecosystem services more cost-effectively than approaches being currently used. Further, our scalable platforms to accelerate adaptation could enable rapid expansion to other conservation and ecosystem service-relevant systems. Finally, the platforms we build will have high relevance beyond nature-protection, with key markets including agriculture, fisheries, and human health.

⑤ **Energy released:** This programme will catalyse a new innovation economy around ecological resilience, expanding the UK's leadership in bioengineering and AI to new sectors while directly protecting the natural capital that underpins economic and societal stability. Key outputs should include novel tools for conservation, and changing the conversation about what approaches are feasible for maintaining ecosystem services, and which are ethically acceptable.

Annex 1

The following examples illustrate potential interventions that span two broad modes of innovation. **"Supercharged Natural Adaptation"** approaches harness and intensify processes such as inducing phenotypes through environmental exposure, or selection across generations. In contrast, **"Engineered Molecular Adaptation"** approaches involve direct molecular or genetic modification of the target organism or its biological partners.

These examples are **not proposed projects**, but **thought experiments** designed to provoke discussion about the kinds of interventions that could yield transformative outcomes.

Target System	Approach Type	Intervention	Expected Outcome
Trees, starting with English Oak (*Quercus robur*)	Supercharged Natural Adaptation	Place saplings in climate-controlled chambers to projected 2100 conditions (heat, drought, late frosts); select 2% survivors for planting.	Oak trees physiologically primed to future UK climate extremes, and with genetic variants that likely help their ability to cope. These saplings should directly have greater survival chances, and increase the prevalence of alleles useful for survival in the oak genepool.
Dragonflies/ damselflies (*Odonata*)	Supercharged Natural Adaptation	Multi-generation selection in gradient of pesticide concentrations using shortened photoperiods + seasons to accelerate generations.	Increased pesticide-resistance of species that are important predators of agricultural pests [14]
Dung beetles (*Geotrupidae*, *Scarabaeidae*)	Supercharged Natural Adaptation	Multi-generation selection for greater aeration of livestock faeces, fecundity, and persistence in excrement from medically treated livestock (e.g., ivermectin used to treat parasites is toxic to beetle larvae).	Maintain >£360m annual benefit to cattle industry through reduced pests & parasites, and increased soil nutrients [26]. Can decrease methane emissions 10-20% [27] from faeces.
Diverse target plants	Supercharged Natural Adaptation	Vaccinate plants ahead of an advancing wave of pest fungus or insect. Take key proteins from pest fungus or beetle, or specific plant hormone like salicylic acid, and use drones to automatically inoculate plant's phloem or xylem ahead of the pest arrival. This should prime the plants through triggering the systemic acquired resistance response and protect against pest damage.	Precision protection of key plant species, e.g., oak, ash, heather, bog mosses that have an oversized role in supporting other species. Reducing damage by pests, will retain services to native species that depend on them.
Successionary pioneer species	Supercharged Natural Adaptation	Selection experiments to accelerate the ability of early colonising species to stabilise environments after disturbance, e.g., waste contamination, physical disturbance, salt-water intrusion.	The equivalent of biological early response teams could be deployed to the site of disturbances to allow rapid recolonisation by stabilising species.
Spp. at risk from habitat fragmentation or loss of migration corridors	Supercharged Natural Adaptation	Deployment of autonomous drones capable of capturing seeds and transferring to areas with more optimal climates, i.e., facilitating expansion beyond the natural rate.	Increased maintenance of genetic diversity, ability of adaptive alleles or haplotypes to spread.

At-risk amphibians, e.g., great crested newts (*Triturus cristatus*)	Engineered Molecular Adaptation	Develop species-specific adenovirus vector which exposes newts to harmless ranavirus proteins, thereby vaccinating the newts against actual ranavirus.	Survival in the face of a widespread and highly detrimental ranavirus.
Bumblebees (*Bombus* spp.)	Engineered Molecular Adaptation	Develop species-specific adenovirus vector delivering RNA interference against parasite (e.g., *Crithidia*, *Nosema*, or *Syntretus*).	Immunity to otherwise impactful parasites that suppress survival or reproduction. These parasites are cosmopolitan and can be spread among bumblebee species.
Bog mosses (*Sphagnum* spp.)	Engineered Molecular Adaptation	Application of receptor-matched peptides that induce physiological changes that lead to greater heat wave/drought resistance.	Greater heatwave survival, and thus bog persistence / peatland foundation.
Vulnerable solitary bees (e.g., *Adrena, Megachile* spp.)	Engineered Molecular Adaptation	Provide engineered probiotics so the gut microbiome has neonicotinoid degradation capacity.	Pesticide tolerance without genetic modification of the host.
Beneficial or culturally important micromammals (e.g., Red squirrel (*Sciurus vulgaris*))	Engineered Molecular Adaptation	CRISPR-mediated introduction of squirrelpox resistance genes from grey squirrels.	Eliminate a key threat faced by the susceptible red squirrels when they encounter the asymptomatic carrier grey squirrels. Generalised capability that can be applied across other micromammals & pathogens.
Vulnerable vertebrate spp.	Engineered Molecular Adaptation	Develop cell culture, or reproductive methods (e.g., pluripotent stem cells, superovulation) to increase generation capacity.	Increase census population size/supercharge adaptive potential, allowing particularly at-risk spp. with small pop. sizes space to overcome extinction due to stochastic effects.

Lexicon

This draft lexicon provides a set of working definitions for concepts used in our programme thesis. The goal is to establish a shared, operational vocabulary to ensure clarity in this interdisciplinary work.

The definitions presented here are starting points. Please challenge, critique, and propose improvements to these definitions.

Adaptive alleles: Variants that are beneficial under the conditions of interest due to the fitness advantage they confer, typically by altering protein structure, enzymatic efficiency, or *cis*-regulatory elements in response to a specific environmental pressure. An allele's adaptive value is typically contingent on specific environmental pressures; some alleles beneficial in certain environments may become fixed, others may remain polymorphic (for diverse reasons).

Bioactive compounds: Substances including molecules, peptides, or proteins that have a biological effect on other living organisms; these can form the basis for medicines.

Biodiversity: In public discourse, biodiversity is often equated with species richness. Scientifically, the term spans genetic, species, functional, and phylogenetic dimensions across scales.

Biodiversity measurements: This is a concept that spans multiple organisational levels and spatial scales. At the species level, alpha diversity quantifies richness within habitats, beta diversity measures compositional turnover between habitats, and gamma diversity captures landscape-scale richness. Additional metrics characterise evenness (abundance distributions), functional diversity (trait variation), phylogenetic diversity (evolutionary distinctiveness), and genetic diversity within populations. These measurements can target compositional, structural, or functional aspects of biological systems depending on conservation or management objectives.

Conservation biology: An applied, interdisciplinary science that aims to diagnose and mitigate anthropogenic threats to biodiversity and ecosystem integrity.

Ecological tipping point: A critical threshold in a system parameter at which a small perturbation can induce a nonlinear state shift to an alternative stable state due to positive feedback mechanisms. Reversions post tipping are likely hard, if not impossible. Post-tipping-point states are typically considered less desirable than prior states.

Ecosystem: A spatially and temporally bounded system comprising interacting organisms and their physical-chemical environment (substrate, hydrology, climate), characterised by flows of energy and materials, biogeochemical cycling, and emergent properties arising from biotic-abiotic feedbacks. Explicitly includes abiotic context as determinants of interactions and processes.

Ecosystem engineering for conservation: Encompasses deliberate interventions in ecological systems to achieve conservation, restoration, resilience, or climate adaptation objectives.

Ecosystem services: The suite of benefits derived from natural capital, categorised as provisioning, regulating, supporting, and cultural services.

Extirpation: Elimination or local extinction of a species from a particular region, even if the species survives elsewhere.

Functional group: A set of species that collectively deliver a focal ecosystem process (e.g., pollination), often interchangeable to some extent, conferring functional redundancy and resilience.

Functional redundancy: The capacity for multiple, taxonomically distinct species within the same ecosystem to perform equivalent ecosystem processes. Greater redundancy increases resilience.

Genetic diversity: The total genetic variation within (and among) populations of a species, commonly quantified by molecular metrics (nucleotide diversity, allelic richness, heterozygosity). Adaptive potential for a specific trait is instead quantified by its additive genetic variance (variance in the heritable component of the phenotype that responds to selection).

Genetic erosion: The stochastic or directional loss of alleles from a gene pool, leading to a reduction in genetic diversity and a subsequent decrease in the population's adaptive potential to future environmental change.

Genetic resilience: A population's capacity to persist through environmental perturbations without a state shift. Fundamentally dependent on standing genetic variation and resulting phenotypic plasticity.

Holocene: The Holocene is the current geological epoch, beginning after the last major Ice Age, a marked period of relative climatic stability when human civilizations, agriculture, and most modern ecosystems developed.

Natural world: The Earth's biosphere and its integrated abiotic systems, considered exclusive of anthropogenic constructs and modifications.

Populations: A group of individuals forming a reproductive community that is characterised by a shared gene pool and a specific demographic trajectory.

Pre-adaptation: The process of adapting an organism to an anticipated environmental challenge.

Species: Another common biological term with a fuzzy meaning. An evolutionary lineage or group of individuals, typically defined through the "biological species concept" of being reproductively isolated from others.

Symbiont engineering: Transplantation of existing or novel microbes to a host in order to modify the phenotype of the host.

Synthetic biology: An engineering-driven discipline focused on the *de novo* design and construction of synthetic genetic circuits, metabolic pathways, and orthogonal biological systems based on principles of modularity and standardisation.

System: The explicitly bounded operational unit of study, ranging in scale from a species to a global biome, defined to encompass the interacting components and processes relevant to a specific scientific question.

Vulnerable species: A formal IUCN Red List category for a species determined to have a high probability of extinction in the medium term, based on quantitative analysis of population size, geographic range, or rates of decline.

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