#ALL4CLIMATE ITALY 2021

EMBL

Harnessing molecular biology to accelerate the Green Recovery

Solutions for urgent global challenges

Acknowledgements

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1. White paper: context and goals

1.1 Background

G7 Climate and Environment: Ministers' Communiqué, London, 21 May 2021

As we continue to address the ongoing pandemic, we acknowledge with grave concern that the unprecedented and interdependent crises of climate change and biodiversity loss pose an existential threat to nature, people, prosperity and security..[1]

Climate science is clear – global carbon emissions need to be net zero by 2050 if we are to avoid the worst impacts of global warming. As we begin to make strides towards a post-COVID world, there is now an opportunity for economies to lead a Green Recovery on a global scale, and thus fulfil one of the objectives of the UN Climate Change Conference of the Parties (COP26).

The 2021 G7 summit culminated in rich nations reaffirming their goal to limit global warming to 1.5°C and agreeing to protect and restore 30 % of the natural world by the end of this decade. The next opportunity for 196 countries to agree what action will be taken and what funding will be made available to tackle global warming takes place in November 2021 at COP26. Progress is being made towards the G7 goals; global spending on renewable power, electric vehicles, and other technologies reached a record level in 2020. However, despite the G7 communiqué on Climate and Environment recognising the important role of research and systematic observation to support and guide action, we believe there is a lack of awareness of the many tools and solutions that scientific research can deliver. In this white paper, we present several avenues for how life sciences research and research-based innovation can be harnessed in the fight against environmental damage and climate change.

Along with the US$100 billion[2] needed to support climate change adaptation and mitigation, a further global investment in research is necessary to protect our natural world. From seagrasses in oceans to bacteria in the animal gut, every living thing in nature is part of a complex and dynamic ecosystem[3], living in community with other life in physical and chemical environments. Healthy ecosystems, both in terms of high biodiversity[4] and balanced relationships among organisms, are fundamental to life on our planet and to human well-being. A study carried out by environmental scientists and public policymakers estimated the notional

[1] https://www.gov.uk/government/publications/g7-climate-and-environment-ministers-meeting-may-2021-communique/g7-climate-and-environment-ministers-communique-london-21-may-2021

[2] Independent Expert Group on Climate Finance. (2020). Delivering on the $100 Billion Climate Finance Commitment and Transforming Climate Finance. United Nations, New York, USA

[3] An ecosystem is a biological community of interacting organisms and their physical environment.

[4] Biodiversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.

economic value of ecosystem products and services[5] to be US$125 trillion per year.[6] This includes the provision of food, water, fuel, and other raw materials; the pollination of crops; and the prevention of floods or soil erosion. This value – and, conversely, the cost to society of losing these products and services if they are not protected – is around two-thirds higher than global GDP. The real cost is much higher when considering that most ecosystem services will be irreplaceable in the face of climate change and that damage is likely to be permanent.

There is still much uncertainty about how we can realise the goals of net zero carbon economies and restored planetary health. Tangible solutions need to be based on sound science and driven by research and innovation. Although such solutions have undoubtedly been discussed in the context of COP26, there has been no dedicated strategy involving molecular life sciences in the international response to climate change. Failing to appreciate the power of molecular biology to accelerate the green recovery has resulted in a number of key opportunities being missed. This paper seeks to bridge some of these gaps in awareness and proposes that molecular biologists have a key role in tackling environmentally induced degradation. Timely investments in research to understand the molecular basis of deleterious changes in ecosystems as a result of environmental challenges will be crucial to mitigate the risks of climate change and concurrently to accelerate a green recovery.

1.2 Scope of the EMBL workshop

As Europe's only intergovernmental organisation for life sciences research, the European Molecular Biology Laboratory (EMBL)[7] is well placed to contribute and coordinate knowledge on molecular biology's role in the Green Recovery from scientific and policy perspectives. On 13 July 2021, EMBL hosted a multidisciplinary workshop to determine how the life sciences can be better leveraged to develop climate change solutions. The workshop, which was part of the All4Climate – Italy 2021 programme, sought to identify new areas and existing synergies and opportunities in the life sciences – particularly in the field of molecular biology – that could be better harnessed to enable a green recovery.

This white paper summarises the EMBL-led workshop discussions, which focused on the relationship between the molecular world and the environmental issues facing humanity and proposed research ideas, solutions, and recommendations of how to translate them into actions to enable and accelerate a green recovery. The paper has been produced by EMBL in collaboration with the experts listed as the workshop participants.

[5] Ecosystem products and services include genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity.
[6] Costanza R *et al*. (2014). Changes in the global value of ecosystem services. *Global Environmental Change* 26:152–158
[7] https://www.embl.org

2. Identifying opportunities

2.1 Overview

During the past year, pioneering developments in molecular biology have been implemented in the global fight against COVID-19 and have delivered solutions that have proven to be vital for human health. As innovative vaccine production continues and our understanding of the biology of the novel coronavirus improves, the latest report from the Intergovernmental Panel on Climate Change (IPCC)[8] made it abundantly clear that similar advances in planetary health are needed to ensure a safe and thriving world. As was the case in tackling COVID-19, the molecular life sciences are essential in developing new knowledge and innovations for mitigating the impact of human action on the natural world. Similarly, it will require international collaboration to realise the best outcomes.

2.2 Issues, opportunities, and solutions

The workshop identified potential solutions offered by molecular biology and other life sciences that spanned a range of environmental topics. The issues and proposed solutions that were raised underline how critical molecular biology is to understand, mitigate, and adapt to rapid environmental changes. Some of these issues have only recently come to the attention of molecular biology research communities at large and therefore require further in-depth study by the scientific community. For other issues, however, molecular biology can provide immediate solutions that are supported by decades of detailed fundamental research, and can now stimulate innovation or be scaled up to provide impactful solutions.

The key areas of opportunity between the life sciences and environmental topics have been categorised based on the planetary boundary concept[9], proposed in 2009 and revisited in 2015, which aims to define the environmental limits within which humanity can safely operate and ensure human well-being. Based on the workshop discussions, each category was then allocated an impact rating of high (where molecular biology could make a significant or novel impact), medium (where molecular biology could make a moderate impact), or low (where molecular biology could make a less pronounced impact). It was agreed that this paper would focus on four high-impact issues only. The following sections detail the contribution that molecular biology can make in the four high-impact planetary boundaries: global warming, ecosystems and the loss of biodiversity, biogeochemical flows and manufactured pollutants.

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[8] IPCC (2021). Summary for policymakers. In: Masson-Delmotte V *et al*. (eds.) *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK (in press)

[9] Rockström J *et al*. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society* 14(2):32; Steffen W *et al*. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science* 347:1259855. DOI: 10.1126/science.1259855

The innovative ideas outlined here are deemed to be realistic considerations likely to provide meaningful solutions for the prevention and mitigation of the effects of environmental change, in both the short and long term.

2.2.1 Global warming

From a physical sciences perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, and making strong reductions in other greenhouse gas emissions.[10]

Limiting cumulative CO_2 emissions requires major changes in the way that society and global economies operate. However, there are many ways in which the molecular life sciences can provide insights and solutions to help society achieve the ambition of reducing emission rates.

Modern meat production has a huge impact on climate change. Credits: Adobe Stock

A large source of carbon emissions comes from modern farming practices, and specifically the farming methods used to satisfy the growing demand for meat and fish. Here, molecular biology and other life sciences can offer solutions that either lead to fewer emissions from current farming practices or provide low-carbon alternatives to meat. Cattle are responsible for releasing into the atmosphere a very large amount of methane, which is a by-product of the processes that break down food in their gut. Developing new cattle feed that results in less methane being produced, while still providing the protein and nutrients cattle need, could lead

[10] IPCC (2021). Summary for policymakers. In: Masson-Delmotte V *et al*. (eds.) *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK (in press)

to a significant reduction in the amount of methane that cattle farms produce. Genetic research into cattle traits, the cow microbiome (essential for digestion), and cattle feed can help to develop these new products. Going further, there is a developing market for alternative foods, either as a replacement for meats or as new mass-market food groups, such as those being grown through aquaculture systems. To support the development of alternatives to meat – such as synthetic meat that is 'grown' in factories and plant-based alternatives – a molecular understanding of the sensory characteristics of plant-based meat and nascent cellular agriculture methodologies can be used to improve the yield and palatability of plant-based protein crops.

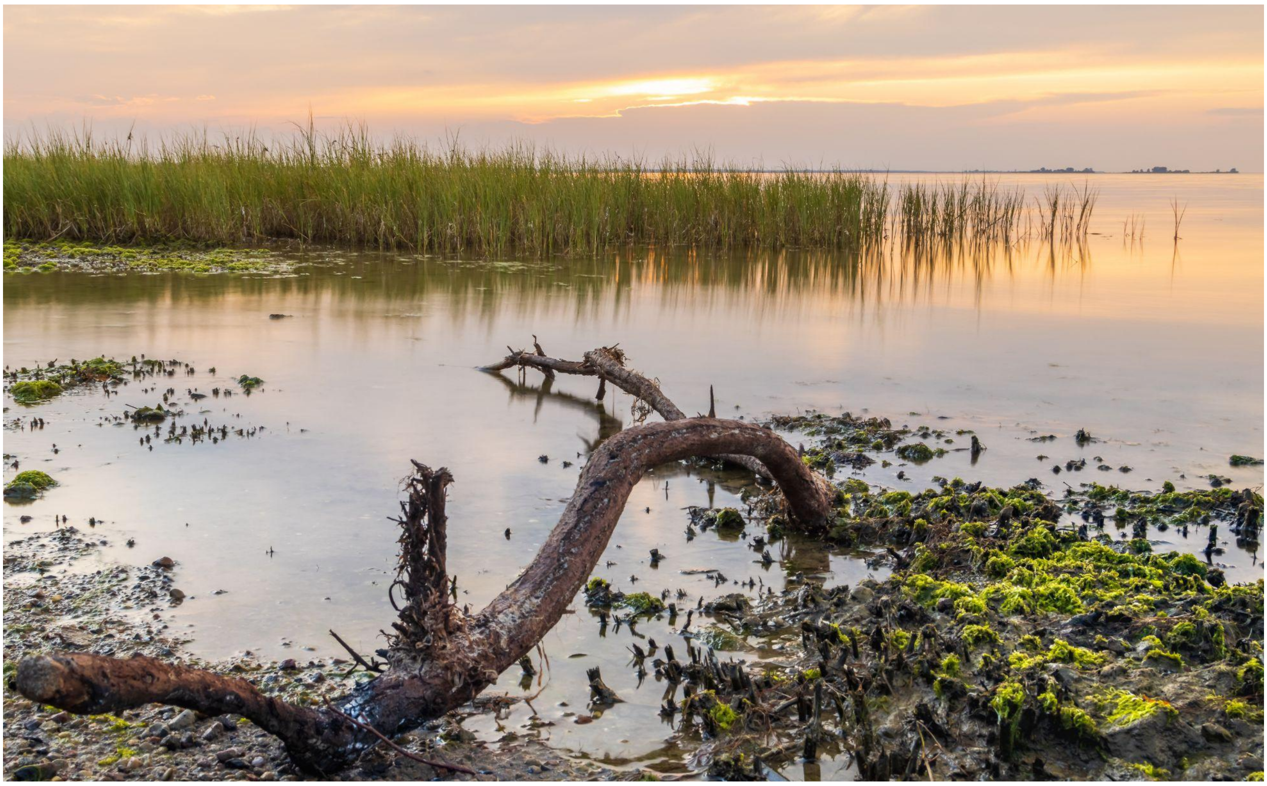
Another large source of anthropogenic emissions comes from the burning of fossil fuels. Finding new types of sustainable fuel sources is an area of significant interest for research and industry. Recent developments in synthetic and systems biology are paving the way for fourth-generation biofuels, where specially engineered microorganisms or crops could serve as the primary sources of biofuel. Molecular biology can continue to contribute to realising this aspiration through improving the yield, habitat range, and usability of biofuels.

A further large source of carbon emissions globally is the consumption of goods. Many common materials are energy intensive to produce, yet could be replaced by alternative materials generated by biotechnology. An example is building materials, which could be replaced with biomaterials made from fungal mycelium or bio-based plastics. This approach would enable a bio-based economy that exploits renewable biomass for the generation of products used in our daily lives. The production of new materials should be with consideration for appropriate industrial composting or recycling facilities.

As well as reducing the cumulative emissions from human activity, society needs to actively remove carbon from the atmosphere in the pursuit of a net zero or a carbon-negative economy. Here, molecular biology and other life sciences can play a big role. The ability of specialised organisms to capture CO_2 is a process on which all life depends. One of the key contributions of the molecular life sciences is to study the processes involved, such as photosynthesis, a key mechanism involving carbon fixation that captures 400 Gt of CO_2 annually. There are species of algae and prokaryotes that are incredibly effective in sequestering carbon from the atmosphere and the oceans, indeed better than trees and plants. A deeper understanding of their function and molecular mechanisms could allow these organisms to be incorporated into large-scale processes that remove carbon from the atmosphere. Cutting-edge molecular biology research is currently being used to develop synthetic technologies to capture CO_2 far more efficiently than naturally evolved systems can. These biology-based solutions could become phenomenal tools for large-scale removal of greenhouse gases in the future and form a key part of a net zero or a carbon-negative economy.

2.2.2 Ecosystems and the loss of biodiversity

Human alteration of the global environment has triggered the sixth major extinction event in the history of life on Earth. Humans have already caused widespread changes in the global distribution of organisms. These changes in biodiversity[11] alter ecosystem homeostasis[12] and change the resilience of ecosystems to environmental change. This has profound consequences for the biological resources[13] that humans derive from ecosystems. The large ecological and societal consequences of changing biodiversity must therefore be minimised, to preserve options for future solutions to global environmental problems.[14]



Wetland and coastlines are an example of a dynamic and complex ecosystem. Credits: Adobe Stock

Organisms live in complex and dynamic ecosystems where biological communities – composed of microbes, animals, and plants – interact with each other, and with physical and chemical factors. As set out in the latest IPCC Report, human activity has already altered Earth's climate in ways that are irreversible over hundreds to thousands of years .[15] To decipher how life adapts, prospers, or declines in changing environments, the environmental factors that influence organisms must be identified and understood, as must the molecular and organismal

[11] Biodiversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.
[12] Homeostasis is the ability or tendency of a living organism, cell, or group to keep the conditions inside it the same despite any changes in the conditions around it.
[13] Biological resources include genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity.
[14] Chapin FS III, *et al*. (2000). Consequences of changing biodiversity. *Nature* 405:234–242. DOI: 10.1038/35012241
[15] IPCC (2021). Climate change widespread, rapid, and intensifying – IPCC. 9 August 2021. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

changes. Untangling the complex relationships between organisms and their environments remains a longstanding scientific challenge.

Stable ecosystem function, the physicochemical and biological processes that occur within an ecosystem to maintain life, is crucial for human survival (for example, for the production of food, medicine, consumer goods, and materials). However, as biodiversity declines at alarming rates due to habitat destruction, deforestation, urbanisation, pollution, climate change, and other anthropogenic effects, natural ecosystems are changing on a massive scale. Some consequences of human action on ecosystems include the emergence of new infectious diseases; the increasing spread of antimicrobial resistance, which is predicted to cause 10 million deaths each year by 2050; climate change and soil erosion, which are causing aridification and increased agriculture risks around the world; and the loss of forest and ocean life, which affects natural resources. To stop and reverse these effects, an understanding of the factors that destabilise ecosystems and the impacts of these factors is essential.

To gain a better understanding of Earth's ecosystems and how they function, life sciences research needs to study the ways various life forms react in the context of a changing environment. Molecular surveys of ecosystems – including the identification of plant, animal and microbial communities and the metabolic pathways they deploy in different contexts, together with measurements of relevant environmental factors – are key to reveal organisms and functional traits of biotechnological relevance, such as those that can increase carbon fixation or remove pollutants. These studies should include a broader range of environmentally relevant model organisms. For example, in-depth knowledge of species that are resilient to specific environmental stressors or the study of sentinel species that signal environmental fluxes and the molecular mechanisms that underpin their responses can then be applied to help more sensitive species to survive changes to their environments. Molecular biomarkers identified using field experiments, and validated and further investigated in controlled laboratory settings, can then be used in diagnostics or targeted solutions.

These practical approaches would help scientists to understand the effects of environmental changes on an ecosystem and provide early warning systems for potentially irreversible ecological changes in specific at-risk ecosystems. In turn, this could inform policy initiatives across Europe and around the world.

2.2.3 Biogeochemical flows

Human-induced degradation of ecosystem states (such as overfishing and land degradation) and the increase in nitrogen and phosphorus flow on both regional and global scales are causing undesirable nonlinear changes in terrestrial, aquatic, and marine systems. Vast quantities of these nutrients are added to the land around the world in the form of fertilisers. However, they are commonly washed out of soils and accumulate in aquatic settings, where their build-up leads to water-quality degradation. Impacts can include noxious and toxic algal blooms, loss of aquatic vegetation, oxygen deficiency, disruption of ecosystem functioning, loss of habitat, loss of biodiversity, shifts in food webs, and loss of harvestable fisheries.[16] Simultaneously, these impacts serve as a slow driver of anthropogenic climate change at the planetary level.[17]

Algal blooms can be caused by the runoff from agricultural fertilisers ending up in bodies of water such as rivers, lakes and oceans. They can cause a degradation of water quality and the destruction of the habitat. Credits: Peter Griffin

Managing biogeochemical flows is a complex problem open to many potential interventions from molecular biology. Ammonia is the most common form by which nitrogen is introduced into the environment, and most ammonia arrives as soil fertiliser generated by the fossil fuel industry. The molecular life sciences can help reduce the world's dependence on manufactured fertilisers by improving the ability of soils to naturally support agricultural plant growth. This could be achieved, for instance, by engineering bacteria that are efficient at nitrogen fixation and using these as novel 'fertilisers' to assist plants in obtaining the nitrogen required for growth. However, the ecological impact of introducing an engineered bacteria to soils needs further research and societal acceptance. Similarly, excess nitrogen in the soil can be removed by nurturing and boosting microbiological denitrification. Promoting healthy topsoils ensures more nitrogen can be stored and reduces the amount that is leached out into the water system, where it often has devastating effects on marine biodiversity.

Another pathway through which the molecular life sciences can reduce the nitrogen load on the environment is by modifying the food we eat or feed to livestock. The incorporation of

[16] Rabalais NN (2002). Nitrogen in aquatic ecosystems. *Ambio* 31(2):102–112. DOI: 10.1579/0044-7447-31.2.102
[17] Rockström J *et al*. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society* 14(2): 32

nitrogen can be made more sustainable by manipulating a wider range of crop plant species to fix nitrogen in symbiotic association with nitrogen-fixing bacteria. This requires a better understanding of the signalling and developmental processes underpinning these symbioses.

The other large-scale source of nitrogen is the combustion of fossil fuels and biomass; solutions for finding sustainable fuel sources are presented in the Section 2.2.1.

Phosphorus is another important fertiliser that is added to the land in vast quantities. There are two problems associated with its current use: it causes eutrophication of waterways, similarly to nitrogen; and it is a non-renewable resource that is mined. A better understanding of the natural recycling of bioavailable phosphorus would reduce the need to use a non-renewable resource and reduce the amount that ends up in the world's rivers, lakes, and seas.

2.2.4 Manufactured pollutants

New substances, new forms of existing substances, and newly introduced life forms have the potential for unwanted geophysical and/or biological effects.[18] Manufactured pollutants include chemicals, plastics, and other engineered materials or organisms. Pollution can accumulate in ecosystems and climb up food chains, with adverse effects on human and planetary health.

The scientific schooner Tara spent six months in 2019 dedicated to the study of plastic particles from 9 of the main rivers in Europe. Credits: Massimo del Prete/EMBL

[18] Steffen W *et al*. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science* 347:1259855. DOI: 10.1126/science.1259855

A vast array of manufactured pollutants is being added to the environment at an increasing rate. For example, the total number of pollutant molecules in human-consumed food has been estimated to be greater than 20,000.[19] Their variety and the range of biological processes they disrupt makes this an important area of research. A pressing issue is measuring how these pollutants interact with various life forms at the molecular, organismal, and ecosystem levels.

Molecular biology can also provide solutions to help 'clean up' our environments. There is a wealth of research investigating areas such as the microbial biodegradation of plastic polymers; the metabolism of pharmaceuticals in the environment; flame-retardants and other micropollutants; and the management of lignocellulosic waste.[20] Novel enzymes from the mining of genomic data could lead to the discovery of naturally occurring processes to break down the environmental pollutants (to reduce environmental toxicity) or to replace chemical synthesis with naturally occurring enzymes and/or microbial communities. New chemical screening campaigns could also enable scientists to characterise chemical libraries of pesticides, antibiotics, natural compounds, and steroids, as well as primary and secondary metabolites in the context of the health of environmental and microbial systems.

Furthermore, the development of safer alternative chemicals and materials through molecular biology-based metabolic engineering would reduce the need to use more dangerous pollutants. The growing list of such alternative compounds encompasses a plethora of molecules, from biofuels and drugs to polymers and speciality chemicals[21], that are currently manufactured through environmentally damaging chemical processes.

3. Recommendations

3.1 Strengthening research components to increase impact

The research-based solutions outlined in this paper will be essential to the Green Recovery of our planet. The degree to which fundamental molecular biology research has been applied to the issues outlined in Section 2.2 in the past and how these areas of research are supported in the future will determine the timescale within which effective solutions can be found and

[19] Based on a review of databases provided by, among others, the Environmental Protection Agency (US), Food and Drug Administration (US), Food Standards Agency (UK) and European Food Safety Authority (EU), provided by Anna Lindell and Kiran Patil, MRC Toxicology Unit, University of Cambridge, UK

[20] De Lorenzo V (2017). Seven microbial bio-processes to help the planet. *Microbial Biotechnology* 10(5):995–998. DOI: 10.1111/1751-7915.12816

[21] Ko Y-S *et al*. (2020). Tools and strategies of systems metabolic engineering for the development of microbial cell factories for chemical production. *Chemical Society Reviews* 49:4615–4636. DOI: 10.1039/d0cs00155d

implemented. Based on previous research, molecular solutions can have a significant impact as long as they can be tested efficiently and scaled up in time, as demonstrated by the accelerated development of the COVID-19 vaccines.

The application of molecular biology in the fight against environmental damage and climate change not only has the potential to generate novel, bio-based solutions to tackle environmental challenges but also lends itself to a systematic and structured approach in developing new solutions. We have identified elements in the route from fundamental research to industrialisation that need to be adapted and supported to maximise the impact of molecular biology for any potential green recovery.

Identification. Due to remarkable advances in technology and quantitative data generation – particularly in genomics, cellular and molecular imaging, and metabolomics – molecular biologists now have the capacity to follow the dynamics of living matter in real time and at multiple biological scales: from exploring the molecular components inside a cell, to measuring single cells and multicellular tissues, to studying whole organisms, populations and ecosystems. Gaining molecular and mechanistic insights to understand how organisms respond to changing environments, and how they influence their environment, is now feasible; for example, stable and radioactive isotope tracing allows for the tracking of individual atoms within biological systems.

In oceans, waterways, coastlines, and soils, there is a yet uncharted panoply of lifeforms that are integrated in and fully dependent upon the surrounding environment. To gain a full understanding of environmental impacts and potential solutions, research needs to be carried out in the natural environment as well as in laboratories, with a broader range of samples and increased sampling scope, working across geographies and over extended periods of time.

Tools normally used in the lab can be adapted for use in natural settings, but new equipment for use in sometimes extreme environmental conditions will need to be developed. Coupled with advances in computational power and artificial intelligence, molecular information collected alongside chemical and physical parameters in the environment will enable rigorous analyses of ecosystem states across different timescales, to identify their evolution and help to define critical events such as tipping points.

Investment is also needed to develop and maintain international collections such as seed banks, botanic gardens, herbaria, and microbial culture collections. An overview of organisms and their ecosystems, defined molecularly, will provide the foundation for understanding life in context and how it depends upon and alters its environment. This is essential if we are to mitigate the effects of or adapt to negatively changing environments.

Study and improvement. High-throughput molecular data, structural biology studies, and high-resolution imaging on a range of spatial and temporal scales will lead to many hypotheses of potential solutions, which will need to be tested either in laboratories or in controlled experiments in the field. For example, understanding the molecular components underlying an organism’s response to different stressors requires the controlled manipulation of the organism (such as its genome, RNA, or protein) using a variety of molecular tools, followed by the visualisation and measurement of the effects of this manipulation under different conditions. Research based on these types of data-driven predictions can then begin to optimise the effectiveness of a target biological system and mechanism that has been identified and studied to tackle the environmental issue in question.

Development and scale-up of new solutions. Molecular solutions for the issues described in Section 2.2 can range from optimising biological processes and systems (such as photosynthesis) to creating entirely new biological innovations (such as mycelium-based building materials). To have maximal impact, and in recognition of the short timescales left to tackle the environmental issues facing society, newly discovered solutions need to be taken out of the laboratory, scaled up, and delivered at pace.

New synergies between life sciences researchers, industry partners, policymakers, and the public need to be created and harnessed now so that there exist networks of trusted key players to deliver solutions. Forums like the UN Climate Change Conference, the IPCC, and the UN Biodiversity Conference are current frameworks where these synergies could be identified.

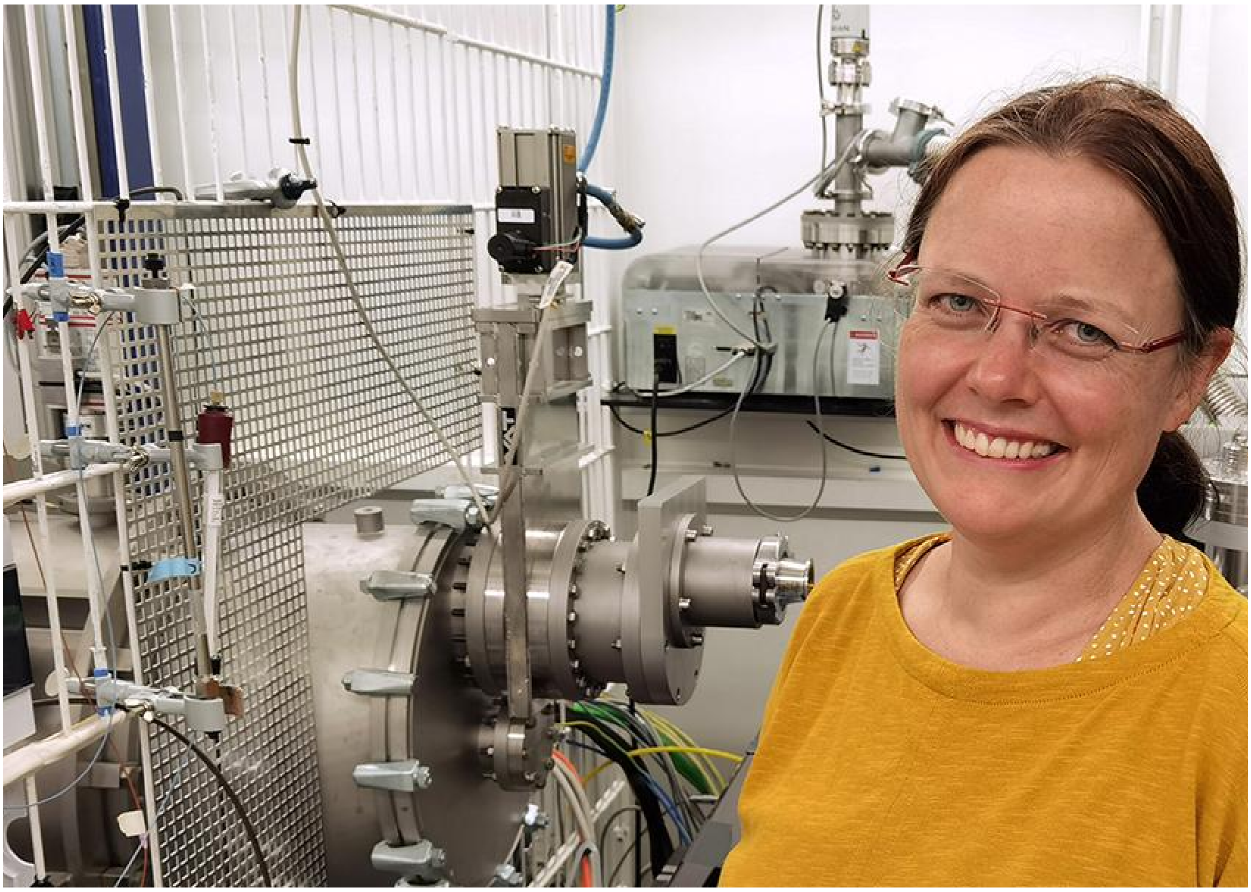
For researchers, engagement with these partners is needed to ensure that research focuses on outcomes that will be accepted by industry, policymakers, and society. Engagement should also be used as an opportunity to flag the most promising solutions, so that industry and policymakers can pick winners early in the development cycle and provide the funding and support needed to drive their delivery. Industry partners can assist researchers in developing solutions by exploring practical considerations such as whether a potential solution can be scaled effectively and how best to do it economically. For example, the automation benefits of biofoundries have become integral for industrial translation and tackling the challenges of standardisation. Researchers would also require support to grow an idea into a product in the form of incubator spaces and legal services such as patent advice. For policy makers, as well as providing ongoing financial support for researchers, engaging early with researchers, industry, and the public will allow them to create the legal frameworks needed for new solutions and to carry out the necessary public engagement to ensure that solutions have public support.

Once these social, political, and industrial synergies are established, one benefit of many biotech solutions is that they can be relatively easily scaled, especially if biological materials are to be used as the product. This is well illustrated by the rapid scale-up of mRNA vaccine production during the COVID response. Because biological materials self-propagate, only small amounts are needed to disperse as products – for example, in the soil for nitrogen fixation or CO_2 fixation – and they will then expand naturally.

However, it should be recognised that innovation in the scale-up of bioprocesses is still needed, as traditional bioprocesses can be capital intensive and expensive to scale. Along with the investment in new tools and biobanks suggested in the identification phase, there will also be a need for investment to increase the capacity of manufacturing and production plants for biotech solutions that are flexible and that can be deployed at the sites of use.

3.2 Cross-disciplinary research infrastructure

The infrastructure within which scientific research takes place affects the speed at which the environmental issues presented in this paper can be studied and solutions implemented. A fit-for-purpose, interactive research infrastructure (research ecosystem) designed to support cross-disciplinary science through appropriate funding mechanisms and training schemes will not only accelerate the impact of the solutions exemplified in this paper but also enable ideas to take shape that can currently not be envisioned. Only when feasible and practical synergies within all disciplines of science are emboldened can solutions be delivered at pace.



EMBL is taking a structural biologist's approach to better understand nanoplastic particles, combining advanced X-ray technology and biophysical techniques. Credit: Tobias Graewert/EMBL

Cross-disciplinary collaboration

Given the scale and pioneering nature of the scientific research needed to tackle such challenges, success is only feasible as a collaborative, global effort. Scientific endeavours must integrate many disciplines in an international, innovative, and interdisciplinary way, bringing together molecular biology and other disciplines such as epidemiology, ecology, toxicology, zoology, engineering, and mathematical theory. For example, to best understand how photosynthetic microbes can be harnessed as a biological carbon fixation approach, oceanographers can inform molecular biologists about the most strategic locations to sample these organisms. Collaborations with engineers can create the sampling technology needed, and data scientists can help to analyse and interpret the vast amounts of heterogeneous data collected. These collaborations will facilitate new ways of developing technologies and researching life with the practical goal of creating solutions to mitigate the effects of environmental damage. Harmonised efforts will ensure informed and impactful national and international policy and guidelines, especially concerning ecological issues.

Funding mechanisms

A paradigm shift in how science is currently conducted is needed to incentivise and drive interdisciplinary collaboration in a more diverse and widespread way if these global challenges are to be tackled. This means inventing new modes of funding that can better serve the needs of researchers addressing large-scale and applied research questions. Funders and research institutions must protect the basic, discovery-driven research that is at the core of scientific progress. Yet a new scientific structure should facilitate the interaction of multiple scientists from different fields, fostering multidisciplinary cross-fertilisation. This structure must ensure open access to data and research outputs, reward collaboration over competition, and provide forums and platforms that enable scientists and representatives from industry, government, non-profits, and the wider society to meet. In this way, complex problems can be identified and solutions appropriately elaborated and implemented efficiently. To represent scientific perspectives accurately, this structure must be inclusive and enable open innovation. Intellectual property must be protected in a process that is rapid and inexpensive, whenever there is a potential path for new product development, while also ensuring access and benefits sharing.

Training future leaders

A new generation of scientists must be trained to carry on this multidisciplinary approach to environmental challenges. Informing early-career scientists of the need to integrate environmental concepts into their research will ensure that solutions flourish and gain further momentum in the future. Postdoctoral training schemes that enable collaborations between academic and industry partners will provide trainee scientists with a wider range of training, increasing collaborations among multiple sectors and across borders. New conferences and courses that incorporate molecular biology with topics of global importance – such as species dynamics, biodiversity, and ecosystem preservation and restoration – will be essential in ensuring early-career scientists are equipped with the knowledge needed to explore these areas.

3.3 Ethical and legal considerations

Molecular biology has an ethical duty to apply its tools and knowledge to address society's most pressing needs, including the current environmental crisis. Research in these areas should be solution oriented, given the urgency of the current situation and the importance of reversing the damage that has been and continues to be done to nature. Molecular biology cannot solve all the issues facing society, but it has a major part to play. Clear legal and ethical guidelines will need to be developed to ensure the role of molecular life sciences is efficiently pursued with respect to climate change and its impacts, adhering to agreements such as the Nagoya Protocol on Access and Benefit-sharing and to the 'do no harm' principle. Molecular biologists must listen to all of society's actors to help develop solutions that can be implemented and that have a realistic chance of being accepted. Communication with the public is key when applying solutions that stem from molecular biology to the natural world, and we must present innovation in a way that breaks down barriers rather than reinforcing the current resistance to engineered or synthetic biology.

3.4 Public engagement and citizen science

The public's awareness of climate change and other environmental issues rises as we approach any large climate change conference such as the upcoming COP26. However, molecular biology and the role it can play in the Green Recovery are generally not discussed in the context of climate change or the other planetary boundaries covered in this paper. Furthermore, the scientific facts and solutions that are discussed, both in terms of environmental issues and the life sciences, are not always efficiently communicated to the public, which in turn results in a lack of awareness and mistrust. With applications of molecular biology now entering mainstream use – such as DNA testing, genomic medicine, crop production and biofuels, and gut-friendly foods – it is more important than ever that policymakers, politicians, the research community, and the public are provided with accurate information to ensure fully informed debate and decision-making. In the case of life sciences, this should be considered a priority when, as part of the solutions proposed in this paper, certain activities directly affect the public.

It is therefore necessary to include public awareness as a strong pillar in the communication strategy of all the parties involved in delivering the Green Recovery. The aims should be to ensure the support of the public, the understanding of the measures taken, and the acceptance of any possible environmental changes occurring as a consequence.

One way of engaging with the public in these important issues is through citizen science[22] projects. By promoting collaboration between the public and scientists, citizen science can lead to the co-design and co-creation of solutions, making their acceptance more likely. Engagement can occur at any point in the development cycle presented in this paper, including identification[23], study and improvement[24], and development and scale-up of new solutions.

[22] Citizen science is the involvement of the public in scientific research
[23] An example of engagement at the identification stage is the Nature Metrics eDNA Discovery Lab (www.edna-discovery.life)
[24] For example, see Lee J *et al*. (2014). RNA design rules from a massive open laboratory. *Proc Natl Acad Sci U S A* 111(6):2122-2127.DOI: 10.1073/pnas.1313039111

4. Conclusion

The role that the molecular life sciences can play in tackling climate change and environmental degradation has so far been underappreciated. The study of the complexities of life, however, has significant potential to develop novel and bio-based solutions for climate change, biodiversity loss, biochemical flows, and manufactured pollution that cover prevention, adaptation, and mitigation.

To achieve greater awareness of these untapped opportunities, we have outlined some areas in this paper that could form potential solutions for urgent global challenges. In some areas, several decades of foundational research can be leveraged to create near-term solutions that can be scaled up. Other research areas that are relatively new will require more research and the development of new technologies and may provide solutions in the long-term. We have also outlined the key research components that need to be adapted and supported to drive forward this area, which include creating the optimal research ecosystem and funding mechanisms to support interdisciplinary collaboration, appropriate ethical and legal frameworks, and training for future scientists. Creating the right kinds of partnerships as well as engagement with the public will be pivotal in bringing about effective research and innovations to harness the molecular life sciences for the green recovery.