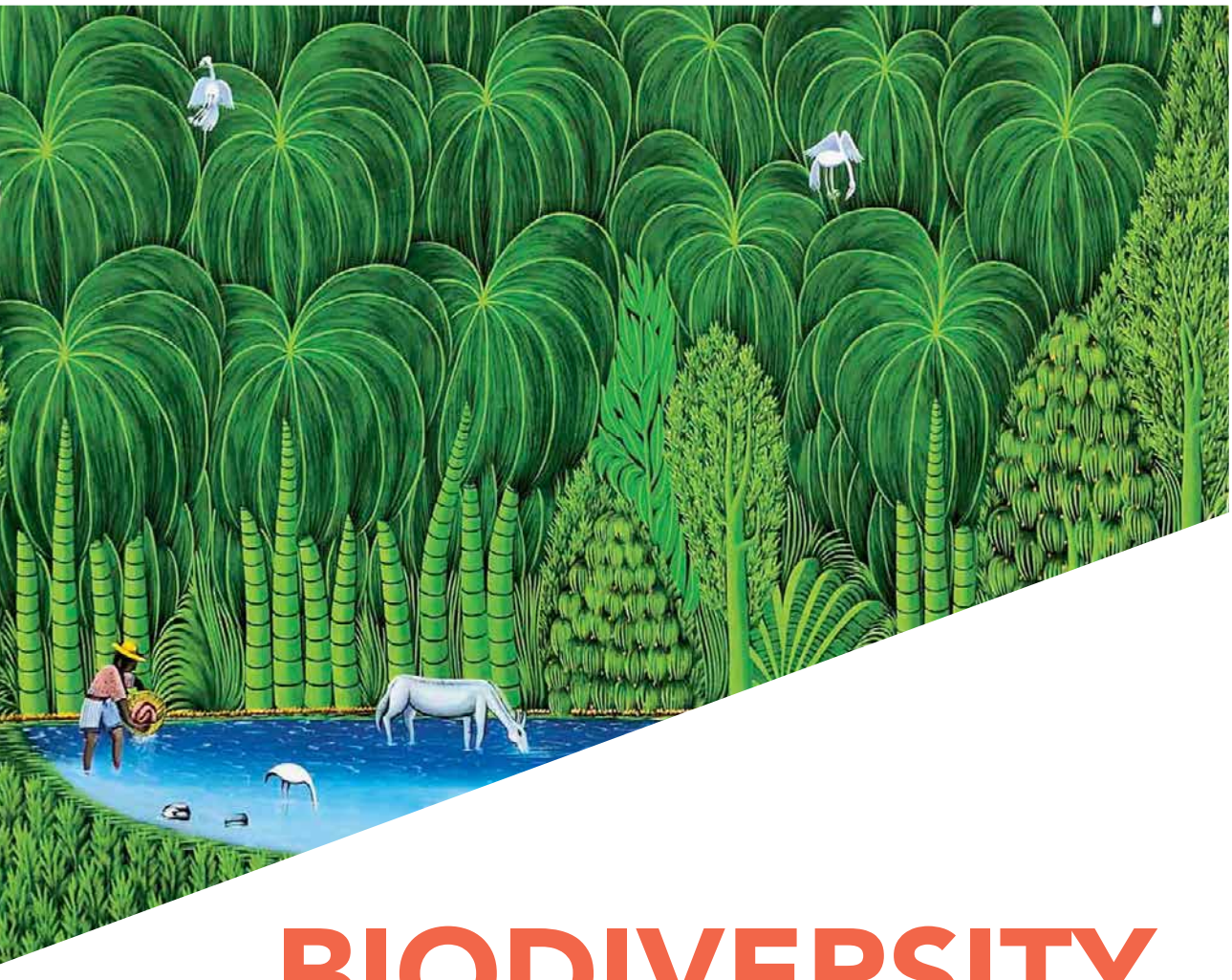

BIODIVERSITY
IN THE GLOBAL SOUTH

Research
for a sustainable world

IRD Éditions

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IRD Éditions
INSTITUT DE RECHERCHE POUR LE DÉVELOPPEMENT
FRENCH RESEARCH INSTITUTE FOR SUSTAINABLE DEVELOPMENT

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Every text in this publication is accompanied by logos evocative of the 17 sustainable development goals promoted by the UN in 2015 (www.un.org/sustainabledevelopment/fr/), with a view to ensuring IRD's research – including old research – is consistent with the most current trends in terms of research for development.

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Preface

VALÉRIE VERDIER

CEO of the French National Research Institute for Sustainable Development
(*Institut de Recherche pour le Développement*)

It gives me great pleasure to provide the preface to this work, which shines a spotlight on some of the research projects and outcomes which best illustrate IRD's commitment to biodiversity and sustainable development. At this crucial time, caught between the disappointing results of the Aichi Targets and the hope for a new post-2020 agenda for biodiversity, it seems more urgent than ever to demonstrate how research can help us rise to the global challenge of protecting biodiversity.

As we know, sustainable development and the science of sustainability are relatively recent inventions: the former was formally defined in the early 1990s in the wake of the Rio Conference, while the second has risen to prominence only over the past decade. IRD is certainly a more long-standing scientific institution, but the structure of our research operations has long promoted original science and nurtured the emergence of projects focusing on the priorities of understanding and protecting biodiversity and ensuring sustainability in our current ways of life.

This unique position can be largely explained by IRD's long-standing engagement with our partners in the Global South. For over seventy-five years, the research conducted at IRD has prioritised a long-term approach in the field, conducive to close collaboration with our partners. This commitment has become even stronger in recent years, with the systematic pursuit of fair, sustainable partnerships which have a real, positive impact on societal sustainability and environmental efforts in the Global South, as well as catalysing the development of research capacities in these parts of the world.

The second major factor is the multidisciplinary nature of the research conducted at IRD. Rising to the challenges of "development" has inspired the Institute to develop and adopt a scientific approach whereby different disciplines combine and interact in order to better respond to the human, social and ecological issues affecting countries in the Global South. Of course, IRD, like the majority of the world's research organisations, was long influenced by an approach to development which we now know could occasionally yield negative consequences for natural milieus and environmental

dynamics. And yet, the resolutely multidisciplinary philosophy of IRD also fosters the emergence of more integrated approaches which are better attuned to the interactions between humans and non-humans.

Of all the great contemporary environmental challenges, protecting biodiversity is probably one of the most complex issues we face, due to the combination of global trends and specific, local contexts. This complexity is amplified further when we consider that the biodiversity which we seek to protect cannot be understood independently of its interactions with the human societies who live with it, use it, manage it, promote it, protect it and, occasionally, destroy it. Precisely because of this complexity, we urgently need to adopt research processes which are user-focused and co-constructed, drawing upon knowledge taken from a broad variety of scientific, societal and traditional systems of learning.

IRD is committed to working alongside organisation which, like the UICN, have been fighting to protect biodiversity for more than seventy years, as well as younger institutions such as the IPBES and the FRB, whose contribution to promoting biodiversity and establishing the issue as a pressing societal priority is undeniable, as well as the great array of stakeholders – researchers, practitioners, decision-makers and local people – who contribute to the extraordinary vitality of the research being done in the Global South. IRD remains fully committed to a vision of scientific endeavour which yields tangible, utilisable knowledge for the Global South, sustainability science in the strongest sense of the term, protecting our planet and its biodiversity, so that they can thrive in the long term for humanity.

This volume represents a significant milestone in our pursuit of this shared goal of sustainability, offering a condensed summary of some of the most impactful research conducted by researchers at IRD and our partners, all in the name of better understanding and protecting biodiversity. This is not a matter to be consigned to the realm of international affairs: it is our responsibility to co-construct a new approach to biodiversity, taking into consideration the potential for conflict and synergy with other sustainable development goals, and the limits imposed by the viability of Earth's natural systems.

Introduction

ESTIENNE RODARY
Research Director in Environmental Geography
Director of the Societies and Globalization Department
French National Research Institute for Sustainable Development

Since first coming to prominence at the turn of the 1990s, the twin concepts of biodiversity and sustainable development have had a profound impact on our understanding of the relationship between humans and the environment. Despite their points of convergence, effectively combining these two concepts has not always been simple, for reasons both historical and political. We now face the two-fold challenge of cementing the connection between social and ecological action, while also ensuring that these efforts meet high standards of ethics and social justice.

Preserving nature: the long game

Although the term biodiversity was only coined in the late 1980s, conservation policies have a much longer history, in which the UICN played a prominent role. The first measures aimed at protecting nature were introduced in the late 19th century, emerging as a global preoccupation in the latter half of the 20th century and becoming increasingly substantial ever since, both quantitatively and qualitatively. Protected nature reserves have been the principal tool deployed in support of conservation policies for most of this period. Virtually non-existent at the end of the 19th century, such reserved now cover approximately 17% of the earth's land mass. The growing urgency of marine issues has also led to the development of conservation policies focusing on the world's oceans, where protected reserves are now more numerous and more expansive than those on land. But there is more to conversation than such spatial tools, and the past thirty years have witnessed a proliferation of instruments designed to protect biodiversity, not least those focused on ecosystem services, payment for environmental

services, biodiversity compensation etc. These different instruments aim to simultaneously reinforce the incentivising dimension of conservation by adopting mercantile mechanisms, while also diversifying the range of tools available to support conservation policies.

Biodiversity: from a sectoral approach to an integrated understanding

At the same time, biodiversity policies have sought to expand the range of stakeholders interested and involved in conservation efforts. To begin with, this meant placing the emphasis on what were clumsily defined as "local populations," which is to say those stakeholders whose lives and livelihoods are most directly affected by conservation measures. A second wave of diversification came about as the globalisation of conservation saw the formation of professional networks with increasingly diverse geographical backgrounds, in parallel with the development of new scientific instruments and communication tools, which are now structured on a global scale.

Since the emergence of biodiversity as a concept, conservation policies have sought to engage with it at different levels. Firstly, in terms of ecological dynamics, no longer evaluated purely in terms of the disturbance caused by human activities, but instead taking into account the specific histories of different ecosystems and the diversity that these divergent trajectories can create. Moreover, biodiversity requires us to better appreciate human diversity and the incredible multiplicity of practices and knowledge that result from it, fuelling the diversification of the instruments and tools designed to regulate these complex interactions.

It seems clear that the restructuring of science and policy around the concept of biodiversity has driven a radical shift from an isolationist position, focused on protecting specific species or spaces, towards an approach whereby biodiversity is incorporated into every area of public policy (*mainstreaming* the issue, to use the modern parlance).

Sustainable development: a holistic approach

Emerging around the same time as biodiversity, the concept of sustainable development has had a similarly transformative effect on our relationship to the environment. What sets the two apart is the decidedly holistic bent of sustainable development. Like biodiversity, it is a concept explicitly designed to help us appreciate the central importance of environmental challenges to the functioning of our societies. But sustainable development adopts a more overarching approach, proposing an analytical framework which aims to inform all societal choices and political actions.

Whereas biodiversity policies are based on a specific objective — the protection of living organisms — and seek to incorporate this goal into all social dynamics, sustainability provides a theoretical context in relation to which all actions are to be positioned and understood. The most eloquent visual representation of sustainable development — where the sphere representing "ecology" overlaps the "social" and "economic" spheres – neatly sums up the ambition of this concept: to encompass the entire spectrum of political objectives in a single reference framework, overlaid with a constant preoccupation with the environment.

The objectives of sustainable development: bringing ethics back into the fold

The formal definition of global sustainable development goals (SDGs) in 2015 might at first sight appear to be simply another step towards integrating environmental issues into decision-making processes at the global level. In fact, the SDGs appear to represent a partial but significant shift back towards social issues. Objectives such as gender equality, access to decent education, health and the reduction of inequality, to name

but a few, reflect the extent to which questions of ethics and justice have returned to the fore in the normative frameworks being developed and promulgated by international institutions. This is not so much a matter of incorporating environmental issues into existing human affairs, but rather of imbuing policies designed to protect nature with an ethical dimension.

But what are the concrete results of these new political standards and benchmarks, be they national or international? The history of development policies, such as the controversy which has attended the institutionalisation of sustainable development, is testament to the stubborn disconnect between political declarations and their practical application, due to genuine difficulties encountered in the implementation process, or else to publicly-espoused positions used to cover up for strategies which are in fact diametrically-opposed. The structural transformation being driven by climate change is a perfect illustration of the gulf which sometimes exists between declarations in the media and the reality of political agendas. When it comes to biodiversity, this gulf may be widened further still by the structural, ecological and social specificities of each milieu and territory, meaning that global governance on biodiversity cannot be synonymous with a one-size-fits-all solution.

Sustainability, diversity and ethics at the heart of scientific preoccupations

The threefold challenge of incorporating biodiversity into contemporary society, adopting a holistic approach to environmental protection and putting ethical issues at the heart of sustainable development necessitates a political framework as complex as it is ambitious. But the successful incorporation of these objectives into research practices is a platform on which a new vision of science can be built, as we redefine our relationship to the social and natural worlds as well as our ways of working.

The contributions included in this volume all provide examples, in their respective fields, of research practices, institutional collaborations, social engagement

and scientific results in keeping with this new paradigm. They all contribute to the creation of new milestones, a model of science developed and put into practice with constant reference to four key requirements:

– the need to take into account the complex interactions between ecological and social dynamics;

– engagement with the world beyond the research community, the only way of effectively identifying the challenges faced by today's societies and finding effective solutions;

– the ability to tackle both global problems, in the holistic sense of that term, and specific contexts, where universal solutions will not do;

– research practices in which the ethical dimension is ever-present, from the individual positioning of researchers to institutional objectives, with a special focus on collaboration and partnerships.

The structure of this volume allows these four dimensions to emerge from the various experiments and research projects presented herein. This book approaches biodiversity *via* four major themes: tools for study and observation, the challenges of protection, connections with questions of human health and links to food and diet.

The tools used and developed by IRD to study biodiversity are focused on large-scale data gathering, something which is too often lacking in the Global South, as well as improving practices in the field and encouraging the dissemination and appropriation of these tools among stakeholders in our partner countries. Cross-sector approaches allow for the combination of biodiversity data with the study of other phenomena: climate change, soil usage, deforestation etc. Similarly, the complexity of the ecological processes in play have incited us to turn to innovative technologies such as artificial intelligence in order to better understand their workings, or else to original approaches such as acoustic measurements to assess the condition of biodiversity. But these tools are also designed to act as interfaces with biodiversity stakeholders, in the mould of the Nagoya Protocol which sets out conditions for the scientific use of biodiversity resources and the need to share the benefits of such uses. Other exciting instruments include tools combining the observations of naturalists with new image analysis software, as in the Pl@ntNet application.

Here at IRD, we understand that protecting biodiversity is not simply a matter of conservation focused on uninhabited spaces. On the contrary, we are acutely attuned to the protective potential of certain anthropic practices (such as the recycling of used water for fertiliser), the risks that other activities may pose to protected areas (such as wildlife tourism to isolated islands) and, above all, the importance of ensuring that regulatory and legislative measures are commensurate with the attendant challenge of social appropriation. At the same time, IRD has also taken a close interest in the protection of mobile species, from the impact of fishing on marine birds to the eco-technical networks formed by invasive species.

Health is undoubtedly one of the fields in which recent advances have been most impressive, and most closely entwined with biodiversity, as unfortunately illustrated by the present Covid-19 crisis. IRD has been involved in research in this field for many years, for example in projects exploring the negative correlation between biological diversity and the risk of animal-to-human diseases transmission, or examining the connections between infectious diseases and the intestinal ecosystem known as the microbiota. IRD has also taken a close interest in the connections between medical research and social issues, not least in the form of studies in ethnopharmacology.

Food is another domain in which the interactions with biodiversity are multiple and multi-faceted, with consequences which go to the very heart of sustainability policies. IRD is particularly involved in the study of socio-ecosystems which might appear marginal in relation to the dominant trends in biodiversity policy, but which may well prove to be of crucial importance to both biodiversity and food production in the areas in question. Examples include agro-forests, mangroves and even the unique pastoral practices associated with the grassy zones just below the glaciers of the Andes. Sustainable food systems need to be adaptive (the study of fishing in Peru provides a good example), integrated (witness the experiments conducted in sustainable aquaculture or efforts to recognise the biological diversity of soils) and political (e.g. researchers all over the world working to sequence the genome of rice to avoid the risk of a private patent). Meanwhile, IRD has taken a keen interest in the protection and diversity of genetic resources and

the exploration of mechanisms capable of reducing our dependency on petrochemicals, for example by studying cases of plant-bacteria symbiosis capable of yielding natural fertilisers.

Taken together, the contributions to this volume make it abundantly clear that biodiversity can no longer be treated as a scientific topic specific to any one discipline or sector; it is a phenomenon which cuts across all of the principal dynamics, human and non-human, which continue to shape the global and local changes we face today. The commitment to sustainability made by IRD is, we hope, a modest contribution to this daunting but fascinating endeavour!

Swimming in a stream of information

The quantity of satellite imagery available, and the data it provides on biodiversity, is so substantial that new avenues of research are opening up, requiring specialists from the fields of biodiversity, remote sensor technology and artificial intelligence to work together. This proliferation of new knowledge represents a major opportunity for the global South, where biodiversity has been less thoroughly inventoried.

Vegetation survey, Cameroon.

Since the 1970s, researchers have been monitoring biodiversity by analysing satellite images. The continuous diversification and multiplication of signals and sensors over the intervening years has opened up vast new possibilities in terms of detecting species, habitats and natural or man-made variation in natural environments. But this technical progress also poses a certain number of new challenges. The exponential flow of information and the growing power of artificial intelligence means that two formerly separate scientific disciplines now need to coexist: data analysis and data interpretation.

The risk we now face is that the never-ending flow of data, the complexity of the processes and the problems inherent to data access, management and storage will overshadow the issue itself: how can we better understand the dynamics shaping landscapes and vegetation? The priority now must be to restructure research efforts to allow for a lasting dialogue and collaboration to emerge between biodiversity and data processing specialists.

As they all seek to answer the same questions, these specialists must bring to bear the expertise of their respective disciplines, while adapting their methodologies to produce knowledge which is precise, pertinent and attuned to the demands of sustainable development. New methods of data analysis are already giving rise to new ways of approaching and understanding the plant kingdom.

In fields which require the analysis of complex processes such as deforestation, carbon storage capacities and the dynamics reshaping

PARTNERS

University of Brasilia, Brazil

Federal Rural University of Amazonia, Brazil

Antananarivo University, Madagascar

National Centre for Environmental Research, Madagascar

University of Yaoundé I, Cameroon

··· New collaborations are needed between researchers in the fields of data processing, life sciences and the humanities in order to capitalise on this mass of data and develop a biodiversity mapping system which is innovative, robust and tailored to users' needs ···

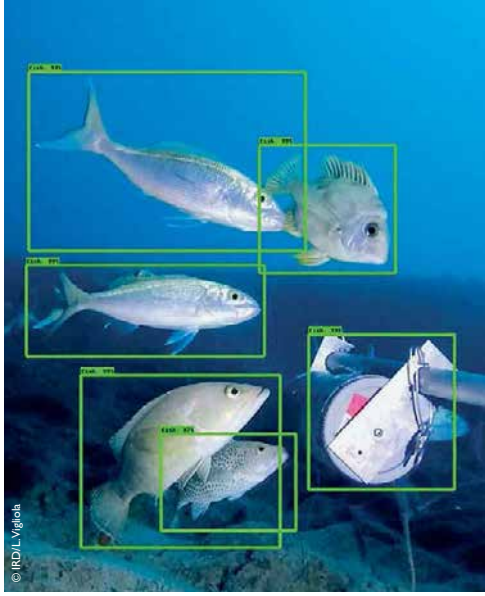
Betsiboka Estuary, Madagascar. Image Sentinel 2, MSI sensor.

agricultural and agro-forestry landscapes, new approaches are beginning to take shape: systematic cross-comparison of data from multiple sensors (optical, lidar and radar), each of which offers insight into a specific facet of the complex overall picture; establishing rigorous processes for generalisation, allowing information gathered in the field to be scaled up for mapping on a regional or even continental scale: this approach makes it possible to identify individual species (palm trees, for example) within different forest formations, while also studying the dynamics at play in major forests on a global scale.

In the long term, the goal is to set up automated observation systems capable of measuring the impact of climate change and nature conservation policies, with reference to societal pressures.

Artificial intelligence to the rescue for biodiversity

Climate change is already upon us. It is a global phenomenon whose multifaceted impact is particularly hard to assess, especially when it comes to estimating the decline in biodiversity.



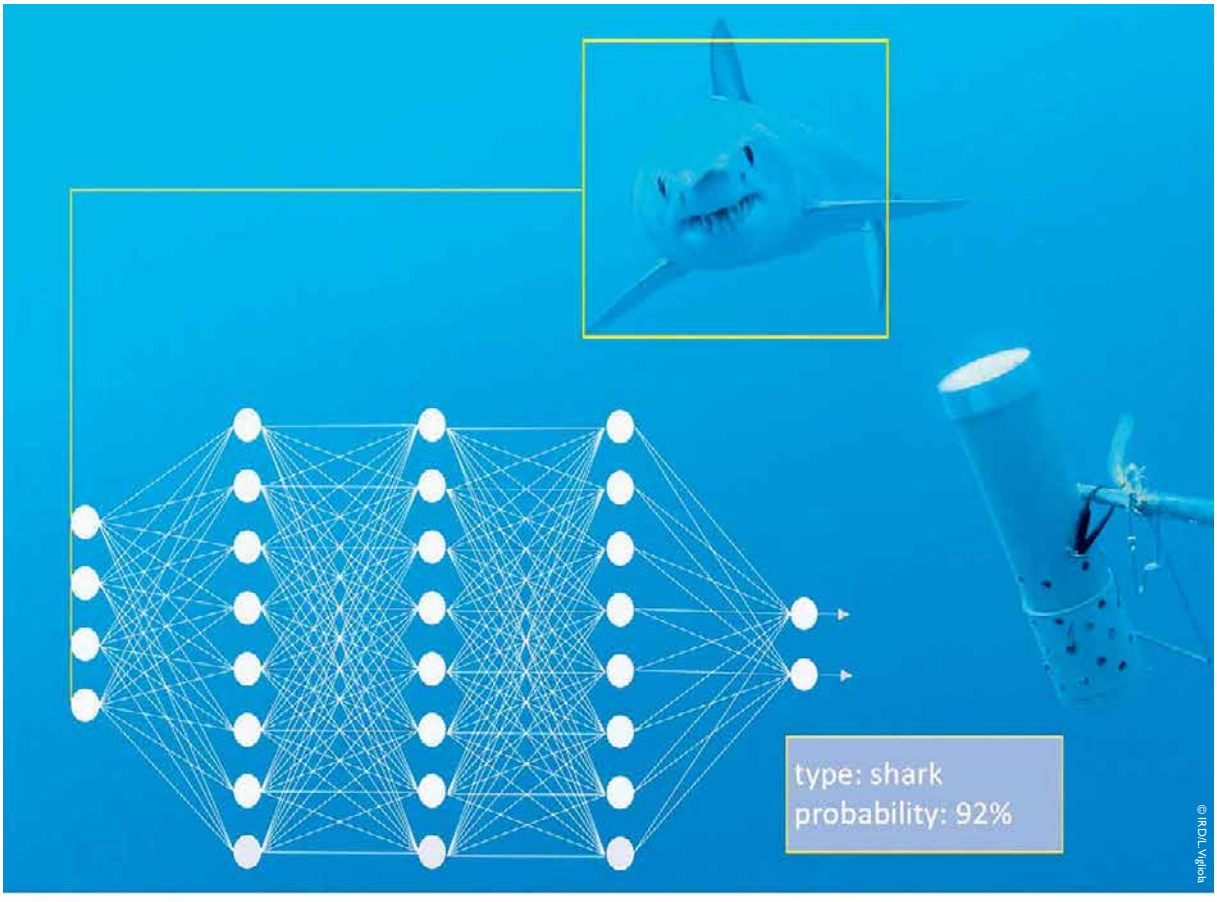
Detecting deep-sea fish using deep learning, New Caledonia, South Pacific.

It is a phenomenon which first emerged a decade ago, and over the past five years has opened up new horizons for the conservation of biodiversity: the rise of artificial intelligence (AI). Thanks to AI, computers are now capable of extracting the maximum potential of databanks, image libraries and sound recordings gathered by researchers from the four corners of the earth.

More specifically, deep learning is a technique which offers numerous benefits when it comes to analysing data recorded by sensors. It allows computers to detect and classify animals in photographs and videos taken on land or in underwater environments. The performances attained are equal or even superior to what human analysis can achieve, with the added advantage that computers can analyse millions of images very quickly. This technique has already been used to estimate the biodiversity of fish in the vicinity of coral reefs, the pelagic zone and the underwater mountain ranges of the South Pacific.

The possibilities are so vast that it is now more effective than ever to collect biodiversity observations *in situ*, then use AI to extract the useful information. One of the most interesting databases in this field is the Global Biodiversity Information Facility (GBIF), which gathers together all open data on life in all its forms, from bacteria up to large vertebrates. An accumulation of heterogeneous data that artificial

··· New applications utilising artificial intelligence may help experts to analyse fluctuations in biodiversity more effectively, and preserve it better ···



Identification of sea fish using deep learning, shown here is a pelagic Mako shark, New Caledonia, South Pacific.

intelligence – and innovative data sorting methods more broadly – can process effectively, helping researchers to better comprehend the spatial and temporal dynamics at play between climate, land usage and biodiversity. A godsend for scientists and those responsible for looking after the world's natural resources.

But that's not all, since AI can also be used to enrich data collected in the field and identify unexpected connections between species, reconstructing networks of interactions and revealing their sensitivity to environmental variations. AI can even be used to make predictions for the future, and identify pertinent indicators. A raft of useful features simply not available with classic methods. For biodiversity as a scientific field, the arrival of artificial intelligence is a major turning point whose impact is only just becoming clear. Hence the prominent participation of IRD in the GBIF project, and our decision to create a new data warehouse. Named DataSuds, it is used to host and share all types of data from IRD researchers and their scientific partners, on a voluntary basis.

PARTNERS

Ginger-Soproner, New Caledonia

Bluecham, New Caledonia

Ginger-Burgeap, France

University of Montpellier 2, France

The Nagoya Protocol, reconciling ambition with effective action

Putting an end to the unremunerated exploitation of the biological resources and know-how of the global South is a major priority which international agreements have thus far struggled to put into practice

Scientists collecting indigenous plant species in the forest, Peru.

Awareness of this issue began to grow in the 1980s, with concerns raised by threats to biodiversity, the new economic perspectives opened up by advances in biotechnologies, the first patents registered for living things and the growing political mobilisation of indigenous peoples. This groundswell of pressure finally led to the adoption of a Convention on Biological Diversity (CBD) in 1992, establishing the first ever regulatory framework governing access to biological resources, heretofore considered as an element of humanity's shared heritage. From now on, these resources were to be subject to the sovereignty of national governments, who would take responsibility for controlling access. When resources are used, there must be "fair and equitable sharing of benefits arising from their utilisation" between the suppliers and the users. This sharing may involve a monetary transaction, in the form of commercial profits, or it may take non-monetary forms such as sharing of knowledge, technology transfer or capacity building.

Nevertheless, this virtuous principle has been hard to implement in practice. After twenty years of negotiation, a further extension of the CBD was approved in 2014. Known as the Nagoya Protocol, it offers a more precise definition of the ABS principle (Access to genetic resources and Fair and Equitable Sharing of Benefits Arising from their Utilization) and makes this commitment legally binding on signatories. Henceforth, whenever genetic resources and their associated traditional expertise are utilised, or even when a request is made to access such resources, a contract must be drawn up between the supplier and the user of the resource or knowledge, in accordance with the regulations in place in the country of origin. This adds up to a serious legal and administrative headache, since each government has its own approach to implementing the Nagoya Protocol.

PARTNERS

Biodiversity Research Foundation, Paris, France

National Museum of Natural History, Paris, France

Centre for International Cooperation on Agronomic Research for Development, Paris, France

Collecting ferns, part of the traditional Madagascan pharmacopeia.

While researchers are fully on board with the ethical principle of ABS, and share the non-monetary benefits of their work as a matter of course, the complexity of the procedures involved can be off-putting. This system seems particularly ill-suited to the urgency of the current situation, and the ease with which biological materials and information are now shared within the globalised research community. A substantial amount of support and awareness-raising work is thus required in advance, led by research institutions such as IRD for whom ABS is a key component of ethical and responsible partnership policy.

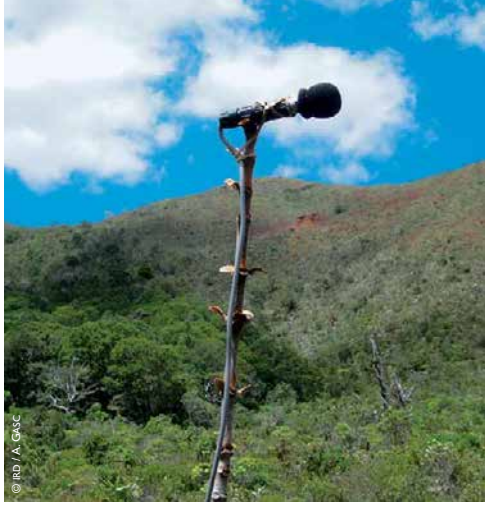
Other stakeholders would like to see the current system made more efficient. In purely financial terms, the total benefits received by the governments or indigenous peoples who hold these resources and knowledge have proved to be paltry in comparison with initial estimates. The inclusion of genome sequencing data in the category of resources subject to ABS regulations is up for discussion at the upcoming COP summit, and seems likely to stoke existing tensions.

We can only hope that these discussions also provide an opportunity to reflect on new ways of making ABS an instrument which genuinely contributes to the preservation of biodiversity.

··· The complexity of the regulations, and the disconnect from actual research practices, are undermining the effectiveness of this crucially important convention ···

Listening to the environment

Biodiversity is being eroded all over the planet, creating new and unprecedented challenges. How can we keep track of a phenomenon on such a scale? Perhaps we need to stop and listen…



Sound recorder to assess the impact of an invasive species of ant on local fauna, New Caledonia.

Sparrow nesting in a wall, France.

PARTNERS

Mediterranean Institute for Biodiversity and Marine and Continental Ecology, University of Aix-Marseille, University of Avignon, Marseille, France

Institute for Systematics, Evolution and Biodiversity, National Museum of National History, Paris, France

University of Urbino Carlo Bo, Department of Applied and Pure Sciences, Urbino, Italy

Environmental Geography, University of Toulouse 2, CNRS, GEODE, Toulouse, France

Machine Learning & Deep Learning, IMT Atlantique, CNRS, Lab-STICC, Brest, France

University of Bristol, School of Biological Sciences, Bristol, UK

You can see biodiversity, of course, but did you know that you can also hear it? When they noticed substantial variations in sound levels in disturbed environments, one group of biologists working in the field had the idea that sound could be used to detect disruption to the equilibrium of ecosystems. Back in 2013, research conducted in New Caledonia demonstrated that the presence of an invasive, highly-aggressive species of ant (*Wasmannia auropunctata*, also known as the "little fire ant") led to a decrease in the cricket population, ordinarily a source of much noise. By installing microphones in the field, the team succeeded in monitoring the territorial progression of the little fire ant.

The method was conceptualised in 2015 by a team of Franco-Italian researchers, who dubbed their new technique "ecoacoustics." The practice has continued to thrive ever since, becoming a fully-fledged component of biodiversity monitoring systems alongside genetics and field observations. It allows researchers not only to detect modifications in the natural milieu, but also to conduct inventories in hard-to-reach environments such as the canopy of tropical forests, where our only knowledge of some species comes from the sound they make. Another great advantage of ecoacoustics is the measurement timeframe. The acoustic sensors can be programmed and installed for long periods of time, providing information on the daily or seasonal activities of species or whole ecosystems.

For the moment, the task of analysing these soundscape recordings falls mostly to human ears, with the exception of some easily recognisable species which can be detected automatically. In the more or less distant future, we might easily imagine the creation of environmental acoustic data banks allowing us to monitor developments on a regional, national or even continental scale. This could enable researchers to study the environmental impact of climate change, invasive species

··· Eco-acoustic methods can be used
to monitor the evolution of ecosystems ···

Sound recorder to assess the impact of fire on local fauna, Arizona, USA.

and pollution, as well as more unexpected events. During the Covid-19 pandemic, for example, scientists launched a collaborative project called "Silent Cities," encouraging researchers and citizens living under lockdown and equipped with a recording system to track the evolution of their acoustic environment, consisting primarily of noise generated by human activity and the biodiversity found in urban environments (birds, amphibians and insects).

A botanist in my smartphone

To observe how ecosystems develop under the effect of global changes and learn how to manage them optimally, up-to-date information on the distribution of species, particularly plant species, is a necessity.

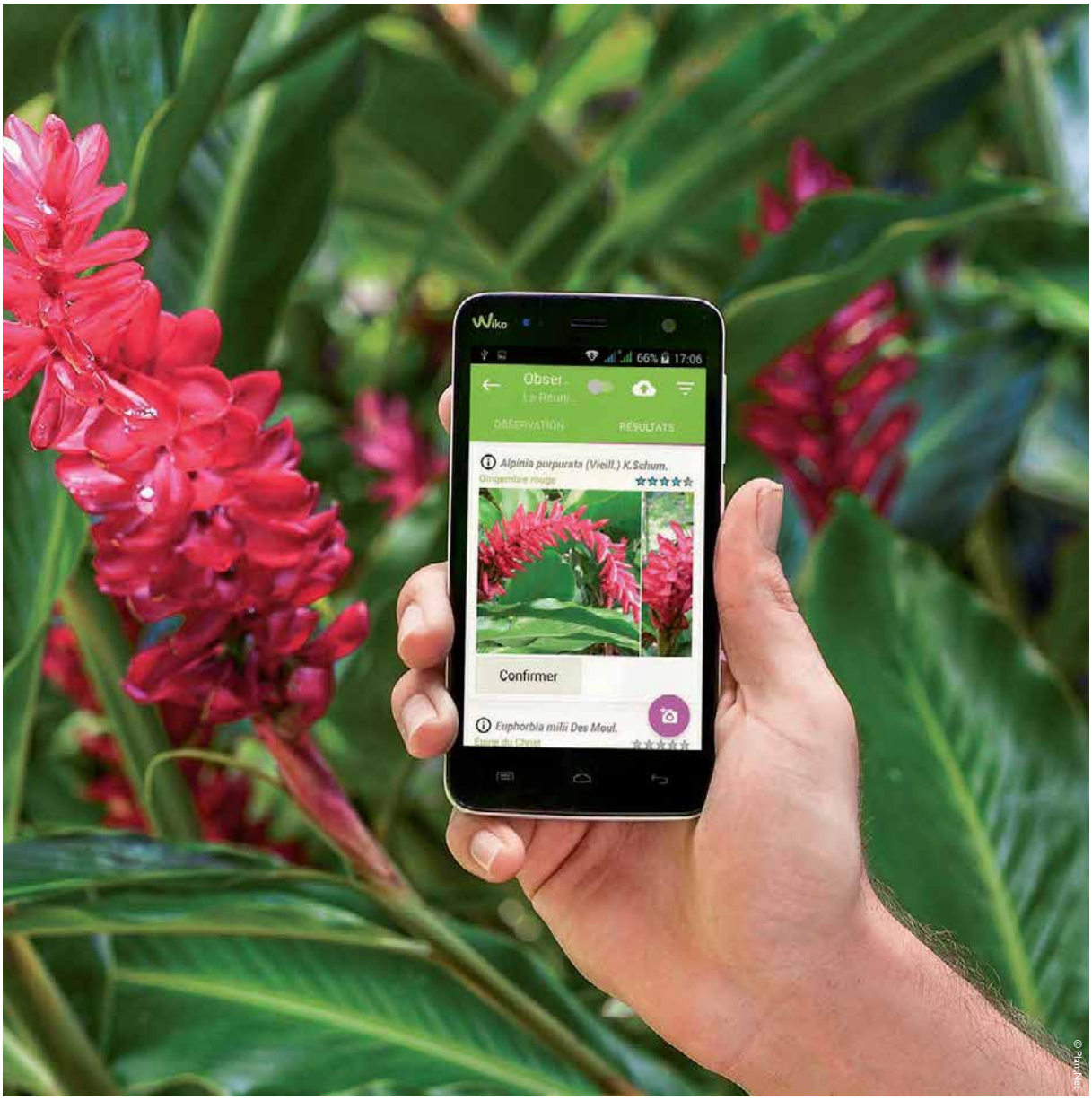
Flowering frangipani tree, Madagascar.

Eight million downloads since 2013, 55 million daily connections by approximately 100,000 users from 171 different countries, the Pl@ntNet application, designed to identify a plant based on a simple photo, is a worldwide success. This success was born out of interactions between botanists, ecologists and agronomists from IRD, Cirad, Inra and the Tela Botanica community network, as well as the chance encounter, in 2008, between the director of an IRD botany unit and the head of an IT team at Inria, who at the time was working on software capable of analysing and comparing images. A decision was made to use a similar approach to create a collaborative platform allowing anyone to recognise and determine plants.

This initially took the form of a private website where Internet users could send their photos. In 2013 however, the application was put within everyone's reach, with the first version of the smartphone application. At first, the application only covered the flora of Western Europe, before it was extended to other regions in 2015, including overseas and tropical regions. Entirely free and translated into nine languages, the application is fun to use and intended for the general public.

It relies on a computer programme and an extensive database of images. It is also underpinned by a network of botanists who contribute to the data validation process. In addition, every photo sent by users is geo-referenced, retained by the platform and added to an ever-expanding database which now features tens of millions of

··· An application transforms citizens into custodians of plant biodiversity ···



Pl@ntNet application on a smartphone.

observations. A valuable resource for ecology studies, the monitoring of biodiversity and invasive plants.

World leader in its field, Pl@ntNet has also developed an online game, *The PlantGame*, to allow as many people as possible to build skills in botany while contributing to validating images taken by users. This is an effective virtuous circle as the identification success rate exceeds 90%, for a total of 17,000 species listed in the database.

PARTNERS

Inra, Cirad, Inria, France

Tela Botanica, France

Numerous partnerships in Latin America, Africa and the Indian Ocean

Using genetics to identify the adaptative capacities of coral

Creating marine nature reserves to protect coral is all well and good. But what if we were to go one step further and help the coral to adapt to future changes in the climate? The idea is making headway.

Coral bleaching, New Caledonia.

Coral sampling, south-west lagoon, New Caledonia.

25% of the world's coral has disappeared over the past few decades. The blame lies squarely with climate change, which has led to modifications in the marine environment (temperature, pH and salinity) and caused the "bleaching" and premature death of swathes of coral. At least, in most cases… Over the years, researchers have noticed that certain coral reefs are actually quite resistant to our increasingly capricious climate. However, these resistant reefs are not found within protected zones and are therefore at constant risk of various other types of damage.

In 2017, inspired by previous research conducted on trees in Switzerland, and on lobsters in Canada, a team from New Caledonia and a team based in Switzerland set about attempting to resolve the problem with the help of landscape genomics. But how? They hoped to detect specimens with the capability to resist climate change, and then disseminate their genetic heritage within coral populations in protected zones, in a bid to boost the overall adaptive capacity of the species.

In order to achieve this goal, the researchers used satellite data to identify zones which have suffered substantial environmental change but where coral, in spite of the pressures, has resisted. They then visited these areas in order to take samples and analyse the genome of the surviving coral.

They succeeded in identifying a number of alleles associated with resistance to climate change, and set about studying how these genes are transmitted from one generation to the next. That information is now being used to develop a management tool which will simulate the way in which, following the implantation of resistant coral "cuttings", the resistance alleles are likely to spread throughout the population.

PARTNER

Aquarium des Lagons, New Caledonia

Coral landscape in Papua New Guinea.

Once validation testing is complete, the most resistant individuals will be cultivated in coral nurseries ready to be reintroduced into marine protected areas.

The process has already been completed for two species of coral, and work is now in progress on a third. The scheme could soon be expanded to sea cucumbers, soft-bodied echinoderms which, unlike coral, trees and lobsters, are sedentary. This approach could leave them better genetically equipped to face the climate challenges of the future.

··· By steering the genetic diversity of coral, it may be possible to boost resistance to climate change. ···

Converting waste water into fertiliser for leafier cities

The quality of human water management has a decisive impact on the biodiversity of natural habitats. And vice versa, since ecosystems also have the capacity to purify water with their myriad micro and macro-organisms.

Open sewer, Rufisque, Senegal.

In 2014, a report published by the World Bank warned that water treatment plants alone will not be sufficient to process the waste water of a rapidly-growing global population. These facilities are too costly to build, and their capacity is soon exhausted. The World Bank instead stressed the importance of developing alternative approaches to managing the waste water produced by cities, particularly in the global South.

This call was taken up by the eco-hydrologists at IRD, who decided to take the autonomous filtration systems used by small rural communities in France since the 1970s, and to adapt them to contexts defined by their extreme population density. These systems, known as "vertical planted filters," are composed of large, sealed tubs filled with gravel and planted with a variety of vegetation. They are capable of mineralising the organic matter found in domestic waste water, meaning that the water itself can be safely discharged into the natural environment. The problem is that these systems take up room: 1.2 to 2m² per user, space which is simply not available in densely-populated urban settlements.

Nevertheless, in tropical climes the natural processes of mineralisation operate more rapidly, simply on account of the air temperature. At these latitudes, the surface area required for each residential user falls to 0.8m². By optimising the way in which the plants, invertebrates and microbiome contribute to the mineralisation of organic matter, the

··· Researchers have reworked a fifty-year-old autonomous filtration solution to allow for the reuse of domestic waste water, reducing water consumption in the process ···

Example of a vertical planted filter for processing domestic waste water, with outflow directly into the river, France.

researchers hope to cut this surface-per-user ratio in half. A promising start indeed, with all signs indicating that automating the system which refills the tubs with waste water could slash the required space to as little as 0.2m² per user.

Furthermore, managing the flow of waste water to the filter also makes it possible to produce water enriched with nitrates, suitable for use as fertiliser for green spaces and urban farms. This could be a real boon in many African cities, where waste water could be used to create new parks which would help to cool and clean the air, putting soil quality and biodiversity at the heart of sustainable urban development. With these goals in mind, researchers have launched pilot schemes at the universities of Hanoi (Vietnam) and Saint-Louis (Senegal). In Senegal, planted filters are connected and monitored remotely by sensors, taking the perfection of these "old systems of the future" to the next level.

PARTNERS

Gaston Berger University (UGB), Saint-Louis, Senegal

University of Science and Technology of Hanoi (USTH), Hanoi, Vietnam

University of Toulouse 3, Toulouse, France

University of La Rochelle, La Rochelle, France

University of Barcelona, FSUB, Barcelona, Spain

EPURTEK, TPE, Toulouse, France

Of dams and fish

All over the world, the number of dams is set to explode over the coming decades, particularly in the global South. This new infrastructure will be a significant source of electricity with low greenhouse gas emissions, but will also pose an array of social and environmental problems.

Rio Pitinga dam, Brazil.

Hydroelectric dams generate electricity, but they also constitute insurmountable obstacles to the free movement of many types of fish. While certain solutions have been envisaged for migratory species, no such system has been tested or assessed for sedentary species whose population numbers have suffered as a result. What impact will this have in the long term?

The issue is receiving attention in France, where preliminary results indicate that some species can now only be found in isolated stretches of rivers, while the population numbers of other species appear to oscillate wildly. The complex mechanics which underpin these variations are still being studied, with a view to determining the minimum distribution range required for a fish population to stabilise and survive in the long term. This information will then be used to make adjustments to dams, or even remove them altogether. But the results will also prove very useful when designing future dams.

Further research is attempting to predict the impact of the growing number of dams being erected in South America. In the Amazon Basin alone, 142 dams have already been built and 160 more are on the way. This proliferation of obstacles risks transforming the interconnections which make up the river system, and thus represents a threat to the survival of aquatic species which constitute a primary source of dietary protein for over 30 million people. Researchers are now using the Amazon Fish database, updated by the various biodiversity observatories, as well as the design properties of the dams, in order to model the impact on fish populations of dams which are in place, under construction or still in the project phase. And all while taking the effects of climate change into consideration. The goal is to identify in advance those hydroelectric dams which pose the greatest risk to species survival, and to propose adjustments or, for those still in the project phase, to rethink their location.

PARTNERS

French Office for Biodiversity, Paris, France

Pontificia Universidad Javeriana, Bogota, Colombia

Universidad Nacional Mayor de San Marcos, Lima, Peru

Instituto National de Pesquisas da Amazônia (INPA), Brazil

Universidad Mayor de San Simon, Cochabamba, Bolivia

Florida International University, Miami, USA

••• Predictive models are still grappling with the question of how existing and future dams will impact the distribution, and even the long-term survival, of fish •••

Fishing for recreation, subsistence and occasional commerce on the Rio Madeira, Brazil.

Cataloguing the French Guiana forest

The forests of French Guiana account for one third of the total surface area of French forests, a huge, largely uninhabited territory, two thirds of which are managed by the National forestry office (ONF), with the French Guiana Amazonian Park (PAG) covering the southern third of the territory. Hence the need for an overview of the diversity and fragility of the forest cover.

Inselberg in the French Guiana forest.

The Amazon forest is not homogeneous. It consists of a mosaic of habitats that managers are striving to map out, an objective field surveys were unable to attain. In French Guiana, this observation resulted in a partnership between ONF, IRD and Cirad in the early 2000s, with a view to developing remote detection techniques and extrapolating the knowledge gained from the field.

Researchers decided to use data from the *SRTM* US satellite, whose radar waves provide access to geomorphology, i.e. the spatial organisation of the relief and soil on the scale of the territory. This approach echoes the research in soil science which, in the 1970s-1980s, showed that variations in the physical-chemical properties of soil impact the species composition of the community of trees that settles thereon. These variations are caused by the alteration, due to surface erosion, of very ancient soils which were formed under different climatic conditions from those of today.

In fact, geomorphology can be used to determine not only the nature of soil but also the type of forest that develops thereon. This methodology, combined with field surveys, made it possible to draw up a catalogue of around twenty forest habitats in French Guiana. Published in 2015, it has quickly become instrumental in devising forest management plans. This document drew the attention of forestry managers in neighbouring countries, including Suriname and the Brazilian State of Amapa, with whom IRD is currently working to implement the same approach. More recently, the same kind of mapping process was initiated in the Congo Basin in central Africa, which features the world's second largest tropical rainforest.

PARTNERS

Inra, Cirad, ONF, ONCFS

French Guiana Amazonian Park, SBB (forest management, Suriname)

IEPA and EMBRAPA, Brazil

··· Field surveys and remote detection tools are used to map out forest habitats in French Guiana ···

Aerial view of the French Guiana forest.

Birds and tourists as research topics

Ecotourism is booming, especially in distant corners of the globe where animal species are as attractive to tourists as they are ecologically vulnerable.

Brown booby (*Sula leucogaster*), Entrecasteaux reef, New Caledonia.

Pair of great frigatebirds (*Fregata minor*) mating on Surprise Island, New Caledonia.

More and more of us dream of exploring far-flung lands, observing first-hand their rare wildlife and pristine ecosystems. And those dreams can be converted into cold hard cash, providing a lucrative revenue stream for tourism agencies, as well as the organisations responsible for the natural resources in question. By way of an example, the industry that has grown up around yellow-eyed penguin watching in New Zealand is estimated to be worth $100 million annually, equivalent to around $60,000 per mating couple. The wildlife tourism sector is also a major driver of economic development, particularly for small island nations in the tropics whose biodiversity is as stunningly rich as it is fragile.

The tension between protecting biodiversity and capitalising on its economic potential requires us to look more closely at the ecological impact of tourism, particularly in isolated areas. For example, in the case of the most spectacular – and thus highly-prized – colonies of seabirds, such unwelcome intrusions can lead to stress, perturbed behaviour, abandoned nests and even increased mortality.

In New Caledonia, this issue is at the heart of a multi-disciplinary research project which aims to better understand both the behaviour of the perturbed animals and the behaviour of the humans involved (visitors and environmental resource managers). In order to get to grips with the stakes and consequences of tourism, ethno-ecologists are seeking to ascertain how tourists, cruise passengers, fishermen and tourist agencies comprehend these endangered species, and how they assess their own impact.

Meanwhile, eco-biologists are working to measure and quantify the impact of the presence of visitors on the population numbers of seabirds nesting on islands at different distances from areas inhabited by humans. They will then attempt to estimate respectful interaction

PARTNERS

The Government of New Caledonia

Coral Sea Nature Reserve, New Caledonia

Deakin University, Australia

Tourists on the island of Lifou, New Caledonia.

distances for each species, while also assessing their capacity to adjust to the presence of humans. The researchers are also working to scientifically describe the behaviour exhibited by tourists (travel routes, types of disturbance, number and duration of visits etc.).

Their goal? To compile data for use in a practical, effective management tool which can be deployed by local environmental agencies. The idea is to give them a clearer idea of potential safe approaches and at-risk situations depending on the season, the species in question and the frequency of visits. A manner of assessing and testing the sustainability of ecotourist projects which, on paper at least, promise that they represent no threat to the long-term economic, social, cultural and environmental integrity of the regions that host them.

••• Researchers are looking at the ways in which tourism impacts wildlife, and weighing up whether or not it is truly possible to reconcile the protection of biodiversity with its economic exploitation, particularly in parts of the world where biodiversity is a major resource •••

Making sure that regulation rhymes with appropriation

All too often, there is a gulf between biodiversity regulations and the actual practices of local people. As we look to move beyond this rift, recent experiments in New Caledonia offer an instructive example.

Workshop with young people in Lifou, New Caledonia.

Establishing a clear policy for managing natural spaces and species is all well and good. But what's more important is to ensure that this policy is appropriated and applied by local people. The three provinces of New Caledonia are currently experimenting with a variety of approaches to creating environmental policies which are more relevant to the social and ecological challenges they face.

The environmental codes in place in the North (2008) and South (2009) provinces include special dispensations for the catching of certain protected species for use in "customary ceremonies." These dispensations recognise the values and practices associated with certain species by local people, including the green turtle *Chelonia mydas*. Nevertheless, implementing this law is no easy matter either for the customary authorities responsible for processing the requests, or for the technical agents in the provinces who are responsible for assessing them. How do we define what constitutes a customary ceremony? How many individual animals should they be allowed to take? Who has the authority to make such requests?

In order to provide legitimate answers to these questions, researchers must be capable of precisely describing and analysing the environmental values at stake, allowing for an informed discussion. In the Southern province, for example, before the process of local consultations was launched a team of anthropologists and geographers conducted a study

··· In New Caledonia, new approaches are being pioneered based on dialogue between researchers and key stakeholders such as the provincial institutions, customary councils and local people. Their goal is to regulate the use of environmental resources, on land and at sea. ···

Fishermen with nets in Belep, New Caledonia.

based on lengthy, semi-directive interviews with local residents and provincial agents. This study allowed the researchers to establish precisely which events required one or more turtles and why, and to grapple with the factors which have caused these practices to change over time. The study also provided an insight into the diverse array of potential misunderstandings and mix-ups liable to lead to conflict. The presentation of this study to local residents – in conjunction with a study led by a biologist which highlighted the imbalance in the local turtle population – paved the way for a subsequent consultation between the provincial and customary authorities focused on the fine details of the regulations and criteria for the size of individual turtles to be caught.

Loyalty Islands Province has adopted an even more innovative approach, making Kanak culture and lifestyles the basis of the province's environmental code. To achieve this, the province turned to specialists in environmental law and a broad array of scientists, working to reconcile existing local practices with constitutional and international standards.

Taking local knowledge and know-how on board and co-constructing regulations in a negotiated manner can help us to make more sustainable choices, achieving consensus rather than compromise, and ensuring that environmental rules are appropriated and integrated into the lives of local people.

PARTNERS

Loyalty Islands Province

North Province

South Province

The Customary Consultative Council for Environmental Issues

The New Caledonia Agronomical Institute

Fondation de France

The proportion of birds

A war of figures is raging between sustainable fishing and overfishing. What is the acceptable harvesting threshold to ensure the renewal of fish stocks and the conservation of the ecosystem? This is a key issue.

Anchovy fishing and seabirds, north of Lima, Peru.

The research published in 2011 in *Science* magazine did not cost much. All it took was two meetings. It all started with a discussion between two scientists. One of them, from South Africa, was convinced that the overfishing of anchovy and sardine stocks had an impact on the breeding success of sea birds. This theory was supported by his data but said data was very localised, so it was not enough to convince local authorities to change the harvest rate. The other one, an IRD researcher, had an idea. Why not gather all worldwide data on the monitoring of sea bird populations and the monitoring of fish caught, and find out whether there is a link between the two?

The researcher tapped into his network and all those likely to be in possession of long-term observations – 20 to 40 years – of the survival or breeding success of sea birds in correlation with fishing data. As these experts were reluctant to share their data, a pragmatic solution was found. The idea was to organise a meeting during which everyone would bring and temporarily share their own data to verify whether or not there was an effect. The strategy worked and scientists discovered the existence of a fish harvest threshold above which the breeding success of sea birds is affected due to lack of food. This effect was analysed in detail during another meeting.

By comparing data from seven marine ecosystems in the Arctic, Antarctic, Pacific and Atlantic, covering fourteen species of coastal birds and 483 cumulated years of observation, researchers found that the abundance of forage species (sardine, anchovy, herring, krill, etc.) cannot be less than one third of the maximum abundance observed in the long term, otherwise the breeding success of birds starts declining. Since then, this threshold has been integrated into the various fisheries management policies across the world. The sharing of international data provided an opportunity to review the optimal harvest rate for pelagic fish such as sardines and anchovies.

PARTNERS

Marine Research Institute and Zoology Department, University of Cape Town, South Africa

Ministry of Fisheries and Marine Resources, Lüderitz Marine Research, Lüderitz, Namibia

Farallon Institute for Advanced Ecosystem Research, California, USA

Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden

British Antarctic Survey, Cambridge, UK

Atlantic puffin, Farne Island, UK.

··· Data pooling on an international scale has made it possible to estimate optimal fishing quotas for sardines and anchovies ···

Nature's abundance protects us against pandemics

The global crisis caused by Covid 19 has forced us to look seriously at the increasing frequency with which humans are contracting diseases originating in animals, otherwise known as zoonoses. What if biodiversity was actually our best protection against these phenomena, which pose a threat to both our health and the international economy?

Stretch of forest cleared to plant coffee trees, Indonesia.

Since the 1950s, the frequency of animal-to-human disease transmission has almost doubled. Various explanations have been proposed to explain this phenomenon, including the massive increase in movements of goods and people, and the fact that climate change has expanded the habitat range of disease vectors such as mosquitoes. But, ever since the SARS and H5N1 epidemics in the 2000s, researchers are increasingly looking to less obvious explanations, with a particular focus on wild animals as reservoirs of infectious diseases.

It now seems that the declining biodiversity of ecosystems is a factor conducive to the emergence of zoonoses. The hypothesis, which seems counter-intuitive at first sight, is as follows: in nature, viruses tend to target the most abundant species. When biodiversity declines, these species which help to transmit pathogens disappear less rapidly than others, meaning that they become proportionally more significant, increasing the level of transmission and the risk that the parasites will be passed on to humans. When biodiversity is flourishing, on the other hand, the presence of other species serves to dilute dominant populations. This dilution effect can limit the risk of viral propagation by up to 80%. Comparative studies focusing on Lyme disease (transmitted between different species of mammals by ticks), hantaviruses

··· Loss of biodiversity may be a factor conducive to the propagation of zoonoses ···

Crested owls, Ecuador.

(viruses transmitted between different species of rodents) and the West Nile virus (transmitted between different species of birds by mosquitoes) have demonstrated that zones of strong biodiversity have significantly lower levels of pathogen circulation, thus helping to protect neighbouring human populations.

In order to test this theory, researchers are working on a number of approaches: using databases to observe the relationship between declining biodiversity and the emergence of zoonoses; modelling the system to understand the impact of the dilution effect on the propagation of diseases; and, finally, observing situations on the ground at a local level.

For the past three years, a field research team has been observing the connections between biodiversity and viruses in Mexico, in a context where environmental management efforts are highly heterogeneous. Their goal is to observe how different strategies of biodiversity conservation affect the propagation and diversity of viruses coming into contact with human populations. In the future, our work to protect nature could well play a pivotal role in preventing further zoonotic outbreaks.

PARTNERS

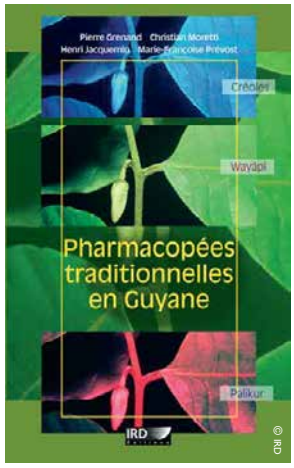
Universidad Nacional Autónoma de México (UNAM), Mexico City, Mexico

Instituto Nacional de Antropología e Historia (INAH), Mexico City, Mexico

EcoHealth Alliance, New York, USA

At the cutting edge of ethnopharmacology

With the rural exodus and globalisation, traditional knowledge is facing the threat of extinction. This fact prompted the WHO to launch a major survey of local pharmacopoeias from 2000 to 2010. This inventory had long been anticipated by IRD.



Pharmacopées traditionnelles en Guyane publication, 2nd edition.

Huaraz medicinal plant market, Peru.

In 1987, IRD published the first French-language book on ethnobotany. While this field of research has existed for nearly a century in the English-speaking world, it only appeared in France in the 1970s. At the time, anthropologists and a plant chemist joined forces in the field, in French Guiana. In 1974, they began to work together to survey medicinal plants used by the Creole peoples of Cayenne, as well as Palikur and Wayampi indigenous peoples, who lived on the Oyapock river. They analysed the chemical composition of the plants used in their pharmacopoeia,

after which researchers published the results of their research in the form of a book. The objective was to ensure the sustainability of this ancestral knowledge. In the years that followed, researchers drew from the *Herbier de Guyane* and advances in botany to improve the identification of plants forming part of Creole, Palikur and Wayampi pharmacopoeias. A second, updated edition of the book was published in 2004, documenting the use of 620 medicinal species.

In 1992, scientists undertook to collect traditional knowledge among six other Amerindian and Andean ethnic groups. The results were published in agreement with local populations, who were keen to prevent the loss of oral knowledge which forged their identity. These societies were undergoing rapid developments, which were not conducive to the transmission of actions and knowledge to younger generations, in whose education the elders were less and less involved. The survey and publication of this knowledge ensure the maintenance of ancestral knowledge, but also its protection, particularly against patents. In India, a patent on turmeric was cancelled as ancient texts proved prior knowledge of its properties.

PARTNERS

Universidad Mayor de San Andrés (UMSA), Bolivia

Consejo indigeno de los pueblos Tacanas (CIPTA), Bolivia

Unicef/Ministry of Health of Bolivia

Universidad Nacional Mayor de San Marcos, Peru

Universidad Peruana Cayetano Heredia, Peru

Communidades yaneshas de San Pedro de Pichanaz, Peru

Plants collected for therapeutic steam bath, Peru.

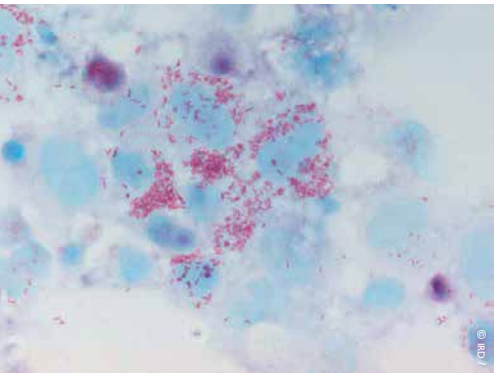
··· Review of medicinal knowledge among nine Amerindian groups from the Amazon and Andes ···

BIODIVERSITY AND HEALTH

Tracking infectious diseases

The Covid 19 crisis has reminded us all of a stark reality: infectious diseases are still the leading cause of human mortality, particularly in the global south. Diseases are carried by parasites, viruses and bacteria, but their pathogenic capacity also depends on the health condition of the infected host.

Village of Dielmo, epidemiology and sociodemographic research centre, Senegal.



Diplorickettsia, a pathogenic intracellular bacterium.

If you can't look for it, you'll never find it. Or rather, we can only find that which the tools at our disposal allow us to see. Which helps to explain why, throughout history, biologists have frequently struggled to identify pathogens. The first to be discovered were parasites such as worms, visible to the naked eye. Thereafter, the invention of the microscope and the development of growth media made it possible to identify bacteria, and molecular methods allowed scientists to analyse micro-organisms which cannot be easily cultivated in growth media. More recently, the advent of PCR 16S has allowed for further progress in detecting bacteria which are very hard to cultivate using more traditional techniques.

But researchers are a long way away from achieving anything like a comprehensive inventory of infectious diseases, especially since the line between what does and does not constitute a pathogen is often a blurry one. Perhaps the most famous example is staphylococcus aureus, a bacterium frequently found on the skin where it is generally harmless, but which can provoke violent infections in certain circumstances. In fact, in many cases a pathogen only becomes a pathogen when its host is in a particular state or situation: the pathogenicity of an organism is defined by the complex relationship between man and micro-organism.

This observation has prompted researchers to look more closely at the human body's most substantial bacterial reservoir: the intestinal flora. The idea behind this approach is that certain pathologies could

••• New methodological approaches are allowing researchers to gain a new perspective on the concept of pathogenicity. •••

Village of Landieni, where malnutrition is still a serious problem for local children, Western Senegal.

be connected with the bacteria in our gut, something which has only recently been demonstrated for two diseases commonly arising in connection with malnutrition: kwashiokor and nutritional marasmus. These conditions are both widespread in Mali, affecting 10% of children under the age of five. Worldwide, these diseases afflict more than 50 million children and cause hundreds of thousands of deaths every year.

Analyses have revealed that these deadly conditions are connected with changes in the internal microflora, which make it impossible to cure some cases even when the sufferers receive emergency nutrition. But, according to researchers, a simple faecal transplant could help to rebalance the intestinal flora and boost chances of survival.

Discoveries like this are the reason why researchers have now embarked upon a project to establish a full inventory of the intestinal microbiota, not necessarily to identify potential pathogens, but rather to study and better understand the composition of a healthy digestive flora. This would simplify the process of identifying irregularities which might help to explain certain chronic fatigue symptoms, or even more serious illnesses whose causes still remain mysterious.

PARTNERS

University of Aix-Marseille, Marseille, France

Assistance Publique Hôpitaux de Marseille, Marseille, France

Malaria Research and Training Center, University of Sciences, Techniques and Technologies of Bamako, Bamako, Mali

Controlling the inevitable

Now considered to be one of the greatest threats to biodiversity at a global level, the spread of invasive species is, just like pandemic diseases, a direct consequence of human activity.

Dissection of rodents in a laboratory setting, Benin.

In 2020, ten billion tonnes of goods will be transported globally by a fleet of maritime freight vessels that has more than tripled in size since the 1970s. The number of air passengers, and the corresponding aircraft capacity, are also set to double by 2037. This massive increase in the international flow of people and goods has led to an unprecedented commingling of global biodiversity, with many species finding themselves regularly or coincidentally transported to lands unknown. Once there they may disappear or else prosper and proliferate, with consequences for existing ecosystems, agriculture, the economy and the health of animal and human populations, particularly with regard to the emergence of new diseases.

It is therefore crucial to trace the routes by which such invasions spread, and their points of entry to new territories, but also to understand the mechanisms of such invasions and the characteristics shared by species which we consider to be invasive. This is no small task, not least because it is not always easy to catch invasions early. Furthermore, their routes of entry are often varied and complex. For example, some parasites and insects which cause crop damage were initially introduced as part of organic farming methods, only to invade their new territory with disastrous consequences for the existing biodiversity.

In West Africa, researchers have traced the spread of the black rat, believed to have arrived in Europe by sea during the colonial period. Starting from the continent's port cities, the black rat gradually spread at the expense of endemic rodent species, causing considerable damage to food stocks and contributing to an upswing in the transmission of the various parasitic diseases of which it is a known host, including leptospirosis.

In Benin, researchers working in partnership with the local authorities have set up a laboratory dedicated to monitoring invasive species at the port of Cotonou. In accordance with the recommendations set out in the International Health Regulations, the laboratory is focused

PARTNERS

École Polytechnique of Abomey-Calavi, Benin

Institut Pasteur of Antananarivo, Madagascar

Institut Pasteur of Dakar, Senegal

Cotonou Port Authority, Benin

Gaston Berger University of Saint-Louis, Senegal

··· Thanks to a multi-disciplinary approach combining law, economics, the study of transport and infrastructure development, ecology and population genetics, researchers are retracing the paw-steps of invasive rodents and assessing their impact. ···

Black rat in a trap in a warehouse on the docks in Cotonou, Benin.

on analysing rodents in order to observe their movements, identify risk factors which might lead to further invasions of black rats, house mice or brown rats, and also to monitor the pathogens carried by these rodents which might spread within cities or countries. An early warning network has also been put in place, with local agents trained to detect the presence of invasive species.

Work of a similar kind is underway in Senegal, where the progress of the black rat is being monitored by analysing rat traps in villages. The aim is to better identify the terrestrial routes followed by the rodent, as well as the parasites it carries, with regular sample-gathering campaigns. Lest we forget, this rat still carries the bacterium responsible for the bubonic plague in Madagascar, along with any number of viruses and bacteria which can be passed on to humans.

Trees, the backbone of agriculture

For several decades now, intensive agriculture has shown its adverse effects: pollution, deforestation, impoverishment of farming communities, etc. With this in mind, we have much to learn from the traditional techniques used by farmers in the tropical world, which combine trees with crops, forest and agriculture.

Harvesting fruit in an agroforest holding, Sumatra, Indonesia.

In 1980, a team of tropicalist geographers published *L'arbre en Afrique, la fonction et le signe* and brought about a paradigm shift. For the first time, trees were no longer perceived as a hindrance but as a central element in African agricultural practices. This was an unexpected wake-up call for agronomists of the Global North. Up until then, trees were best left to foresters or soil scientists who, depending on the case, were seeking to log or replant them to prevent soil erosion. In the 1990s however, researchers found that trees also play a genuine role in traditional agricultural practices. The term "agroforest" began to be used to refer to these farming systems which include trees. For example, in some agroforests of Sumatra, rubber trees and fruit trees are planted simultaneously. In the early years, they supported rice crops, before producing fruit, rubber or firewood. Other agroforests account for 80% to 90% of the island's animal biodiversity, including a rhinoceros which was thought to be extinct.

Studies conducted later in Brazil or Cameroon confirmed the prominent role of trees. What outside eyes believed to be isolated trees or natural forests were in fact agroforests. Researchers rediscovered that trees fertilise soils, facilitate the flow of water and carbon storage, or enable biodiversity conservation. By mimicking

··· Studies point to the central role of trees in the agricultural practices of the Global South ···

Agroforest in Ethiopia.

the ecological model of the tropical rainforest, farmers of the Global South managed to use biodiversity as a way to control crop diseases. Having been overlooked by experts from the Global North, this expertise is now recognised as a model for the future, including in temperate regions. For once, innovation in the Global North takes its cue from practices of the Global South.

PARTNERS

Centre for International Forest Research (CIFOR), Indonesia

World Agroforestry Center (ICRAF), Kenya

Cadi Ayyad University, Morocco

Instituto Nacional de Pesquisas da Amazônia (INPA), Brazil

Institute of Agricultural Research for Development (IRAD), Cameroon

Moving towards sustainable aquaculture

For the past fifteen years, aquaculture no longer just aims at producing large quantities of fish; it also seeks to be more environmentally friendly.

Floating fish farms, Vietnam.

This is the great paradox of aquaculture: it offers a solution to overfishing while at the same time being one of its drivers, when it uses fishmeal to feed fish farms. Its effluents can also be a source of water pollution.

These findings prompted researchers to conceive alternative strategies to counteract the adverse effects on the environment. In Indonesia, studies made it possible to replace fishmeal with an insect powder resulting from a bioconversion process. To make this powder, researchers used and recovered organic, household or agro-industrial waste that the larvae of diptera nicknamed "black soldier" (*Hermetia illucens*) feed on. Once ground into a powder, these larvae form a cheap protein-rich meal which can replace fishmeal, at least in part.

To reduce pollution, researchers designed fish farms involving several fish, plant and/or mollusc species, whereby waste from one species becomes inputs for another. This "integrated multi-trophic aquaculture" (IMTA) principle was developed in pangas farms in Indonesia, by adding a floating plant to production ponds. This duckweed (genus *Lemna*) grows by purifying the water of breeding ponds. It is also eaten by a herbivorous fish species, the giant gourami, whose production complements that of pangas, improving the farm's economic benefits. A similar approach was used in Senegal with an artificial, closed-circuit ecosystem which combines euryhaline tilapia with zooplankton and single-celled *Chlorella* algae.

To limit the use of antibiotics, an inventory was conducted of plants traditionally used by fish farmers in northern Vietnam and on the island of Java to care for fish. Fifteen of these plants are currently being examined.

PARTNERS

Hanoi University of Agriculture, Vietnam

Agency for marine Affairs and Fisheries research and development (AMAFRAD), Jakarta, Indonesia

Centre for Oceanographic Research, Dakar, Senegal

Cirad, France

Pisciculture in Indonesia, with two different species of fish and water lentils used to help purify the milieu.

··· Scientists are using biodiversity to make pisciculture more environmentally respectful. ···

Adaptive fishing in Peru

Peru has the world's most productive sea area for fish… but also the most fickle. This variability required a unique adaptation of the fisheries management system. Should this example be emulated?

Oceanographic campaign, Peru.

Off the coast of Chile and Peru, the Humboldt current causes the upwelling of cold water, very rich in nutrients responsible for tremendous fish productivity. The Peruvians have monitored these stocks since the 1960s, notably through express assessment campaigns conducted simultaneously by fifteen vessels equipped with acoustic sounders.

This is due to the economic importance of fisheries in Peru, but also to the extreme variability of this area, where the yield can decrease sharply during El Niño events, e.g. in 1972-1973 or 1982-1983, when the anchovy population collapsed, durably affecting the ecosystem and society. Hence the idea suggested by the Instituto del Mar del Perú of changing the approach and managing fish stocks in real time, taking into account the wide variety of ecosystem parameters.

When IRD started working there in 2001, Peru was already doing a better job of managing the consequences of the El Niño event of 1997-1998, but scientific know-how was somehow lacking to process the vast amount of data collected. To this end, IRD helped set up multidisciplinary teams and embarked on cooperation which contributed to training one hundred or so Peruvian scientists in fifteen years. Knowledge was updated, thereby basing conceptual or numerical models on validated processes.

Tools were also developed to improve predictions of El Niño events, view the location of water bodies, track ship and bird movements by GPS or detect the formation of ocean eddies by satellite. With these tools, Peru's fisheries management system is now the most responsive in the world: quotas are reviewed every six months and, in the event of anomalies, fishing operations can be halted within hours. This responsiveness is unrivalled.

PARTNERS

Instituto del Mar del Perú (IMARPE)

··· IRD is helping to implement adaptive fishery management techniques in Peru ···

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Peruvian seiners, artisan fishing method.

Pastures and humans drip-fed by glaciers

In the tropical Andes, downstream of glaciers, a unique ecosystem, vital for local communities, is endangered by climate change. Thanks to satellite images, combined with field data, long-term projections can be carried out.

Grazing alpacas in *bofedales*, Bolivia.

2012: in the Bolivian highlands, researchers were studying a potato pest moth, when they heard about *bofedales*, verdant oases which follow streams and contrast with the arid landscapes of the region. These little known ecosystems are less complex that those located further downstream, as they are dominated by a plant species, which could help model their interaction with the physical environment, notably rainfall and glaciers.

This is how researchers began to work on *bofedales*. It appeared that these ecosystems were vital for local populations, who graze their cattle there. Predicting how they will change, against the backdrop of climate change, is therefore a major issue for the region. This is why researchers decided to piece together their recent developments, through close interactions with water and therefore the glaciers rising above them. These glaciers have been monitored by scientists for thirty years.

By cross-referencing field data with satellite images, researchers found a link between the surface area of the 1,700 *bofedales* studied and the melting of glaciers observed since the late 1970s. *Bofedales* located near glaciers are supplied with water throughout the year, even in the

··· Data models are helping us to understand the connections between glaciers and *bofedales* ···

Biodiversity study, Bolivia.

dry season, and are therefore doing particularly well. They are larger and can withstand high grazing pressure.

This "state of grace" will come to an end once glaciers are gone. The absence of water during the dry season should reduce the surface area of *bofedales*, which may no longer be able to withstand grazing. This warning signal was received by local populations, who are already testing protection strategies, by restricting access to certain *bofedales* during the rainy season or attempting to retain water via a variety of processes.

PARTNERS

Pontificia Universidad Católica del Ecuador, Ecuador

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Custodians of agricultural diversity

In the 1960s, the advent of intensive farming triggered an unprecedented rescue operation. The objective was to prevent the genetic resources of cultivated species and their wild relatives from being lost.

Cryopreservation of seeds.

Wild and hybrid millet, Niger.

The "green revolution" was active from the 1950s to the 1980s: improved plants, selected for their high yield, took over the fields. As reduced crop diversity sparked fears of an irreversible erosion of genetic resources, the FAO asked international organisations, including ORSTOM, to participate in sampling operations and develop collections, the purpose of which was to safeguard the genetic diversity of crops and their ability to evolve.

From 1966, researchers went on field trips to Ethiopia to sample wild forms of the Arabica coffee plant. From 1970 to 1990, rice species were collected in West Africa and Madagascar, while millet and sorghum surveys, cereals found in arid regions, were conducted in Sahelian countries. Other species (yam, cassava, cowpea, okra) were also surveyed.

Cereals produce seeds which can be perfectly preserved in cold storage rooms but must be regenerated every twenty to thirty years. For other species which do not produce seeds or with seeds which are difficult to preserve, alternative solutions were sought. This is why field collections were set up, biotechnologies (micropropagation, meristem culture) were developed, as was the liquid nitrogen storage technique (cryopreservation).

··· Seed collections act as a solution to the erosion of genetic diversity among cultivated plants ···

Coffee plant flowers, Côte d'Ivoire.

The emergence of molecular biology in the 1990s shed light on the organisation of diversity, giving rise to new management strategies. IRD researchers developed the "Core collection" principle, making it possible to dramatically reduce the number of duplicates.

In the early 2000s, genome sequencing options opened up new opportunities, notably with regard to adaptation to climate change. A genome comparison between millet sampled in 1973 and 2003 helped researchers identify a major gene involved in drought resistance. Studying the rice genome helps understand the genome of other cereals. Similarly, the sequencing of the Robusta coffee plant, an African species, enhances the understanding of the extraordinary diversity of Malagasy species.

PARTNERS

National centre for agricultural research, Abidjan, Côte d'Ivoire

AfricaRice, Bouaké, Côte d'Ivoire

National centre for applied research on rural development, Antananarivo, Madagascar

Niger National Institute of Agricultural Research, Niamey

University of Abomey-Calavi, Benin

Rice as a common good

In the 2000s for the first time, an international team sequenced the DNA of a model plant, *Arabidopsis*, largely studied by biologists. This triggered a race against the clock between public and private research. The challenge was to sequence the rice genome.

Improving rice varieties in Vietnam.

The announced sequencing of the first plant genome in 2000 struck fear into the heart of the scientific community. What would happen if a private consortium were to sequence the DNA of a plant of agronomic interest, a plant as vital as rice? In 1997, an international consortium, financed by public funds and involving 10 countries, was created in an attempt to accomplish a scientific feat. At the time, technology was costly, slow and complex. One country alone would have been unable to complete rice sequencing, the genome of which is equivalent to four times that of *Arabidopsis*.

This is why IRD, who had been working on the diversity of wild and cultivated rice varieties since the 1970s, turned to the *Génoscope*, responsible for the sequencing of the human genome, to ensure France's involvement in the consortium. The different participating States shared the rice genome between them. It was incumbent upon France to sequence chromosome 12. This investment paid off: in 2005, the entire rice genome was published by this consortium in *Nature* magazine, while the sequences obtained by the private sector were incomplete or of poorer quality.

Thanks to technical progress and a drop in sequencing costs, other species such as millet or the coffee tree were later sequenced by IRD and its partners. Better still, thousands of individuals from the same species were screened, notably for rice or millet, after which it became possible to reflect genetic diversity within species and identify genes likely to be selected to increase productivity, adaptability or disease resistance. This research enabled scientists to identify genes of interest in the African species of cultivated rice which were transferred to Asian rice, such as resistance genes to combat rice yellow mottle virus, a viral disease which affects rice paddies in Africa.

PARTNERS

Génoscope (National Sequencing Centre), France

"Plant development and genome" laboratory (LGDP), CNRS-UPVD UMR University of Perpignan, France

"Genetic improvement and adaptation of plants" UMR, Cirad-Inra, Montpellier SupAgro, France

··· IRD, CNRS and *Génoscope* sequenced rice chromosome 12 ···

Rice panicle.

The potential of the world beneath our feet

One quarter of terrestrial biodiversity exists underground. In spite of these riches, the world beneath the soil has long been neglected by ecologists and agronomists. And yet, it could well prove to be a priceless source of effective alternatives to intensive agriculture.

Giant Madagascan earthworm: *Kynotus giganteus*.

Soil ecology was long considered a sort of poor relation in the ecology family, for reasons both methodological and historical. Almost all subterranean organisms are microscopic, living in dense, opaque and highly heterogeneous milieus. Their lifestyles and interactions are thus notoriously difficult to study. Furthermore, ecological theories are primarily constructed with reference to life "above ground," without taking much account of the specificities of the world "down below." Nevertheless, we largely have this thriving subterranean fauna to thank for imbuing the soils with the properties we know and value, performing a variety of essential functions (e.g. breaking down organic matter, maintaining soil structures, perpetuating the nutrient cycles).

In today's world, the narrow, productivist vision of agriculture has reached its environmental limits (soil deterioration, erosion, pollution etc.). As such, scientists are beginning to devote much more attention to the life beneath the surface, home to over 25% of total biodiversity. In order to preserve and restore this biodiversity, under threat from practices such as intensive ploughing and the use of chemical products, we first need to correctly identify the ecosystemic functions and services which it provides. But these functions are often the fruit of interactions between different components of the fauna, interactions which elude simple taxonomic classification. Measuring the biological health of soils thus requires us to develop a more holistic approach which takes this level into account.

··· Researchers are attempting to understand how subterranean fauna allows the soils to function ···

Earthworm study, Vietnam.

For researchers, the long-term objective is to develop more functional approaches to soil biodiversity in order to better understand the connection between biological interactions and/or combinations and the broader functions of the soil. This would enable us to propose solutions which might improve soil health while also maintaining productivity, stimulating this biodiversity indirectly (with a "cocktail" of organic material designed to modify the biological make-up of the soil) or directly (biological reseeding). In Madagascar, for example, a three-year project to introduce earthworms to certain rain-fed rice paddies succeeded in boosting harvests by 44 %. This improvement was primarily a result of an increase in the release of nutrients (particularly phosphorous, a common problem in these soils) available to the plants.

Although this approach is still in its infancy, it offers a first glimpse at the vast complexity of the world's subterranean systems. The challenge now is to preserve that biodiversity while harnessing its functions to make the agriculture of the future both sustainable and productive.

PARTNERS

Ecological Research Centre, University Nangui Abrogoua, Abidjan, Ivory Coast

Radio Isotope Laboratory, University of Antananarivo, Madagascar

Land Development Department, Bangkok, Thailand

Mangroves, a new eldorado?

Shifting marshlands found in inter-tropical zones known for their distinctive forests, mangroves have now become the subject of increased speculation and communication.

Mangrove, Galápagos National Park, Ecuador.

Long dismissed by westerners as sterile, mosquito-infested swamps, mangroves are now recognised as rich and fragile ecosystems; an increasing number of them are protected by international conventions, such as the Ramsar convention on wetlands.

In spite of this political progress, between 1970 and 2000 the total surface area of mangroves shrank by a third, largely as a result of the explosion in the number of shrimp farms. Researchers eventually began to recognise the multitude of roles and functions played by these atypical ecosystems: they help to mitigate coastal erosion, protect against typhoons, purify water systems and provide vital breeding grounds for fish.

Furthermore, mangroves are often inhabited by local populations who live off their resources, relying on the mangrove as a source of fish, firewood, tannins, salt, oysters and a place to grow rice. Entire civilisations have prospered in mangroves, reflecting the vast potential of these natural milieus which may be in constant movement, but are nonetheless rich in resources.

However, these traditional practices are now under threat. Not from climate change directly, but rather by the societal response to climate change. In the interests of offsetting, carbon capture and reforestation, governments are allowing private companies to manage mangroves which have always been considered community property. These companies often plan a single, fast-growing variety of tree in order to achieve rapid results and publicise their efforts to bolster their green reputation.

In Senegal, for example, vast swathes of *Rhizophora* have been planted by a Senegalese NGO, with financial backing from various international private and public-sector organisations, since 2006 in the Casamance region and since 2008 in the Saloum Delta. The results have

··· Recent research has explored the shifting perceptions of mangroves over the ages, and highlighted some contemporary malpractices ···

Oyster farmers, Casamance, Senegal.

been mixed, both in terms of the surface area actually planted and the capacity of these milieus to capture carbon and restore biodiversity. Not to mention the negative consequences for local women, who are no longer able to harvest oysters from the roots of the mangrove trees or shellfish from the replanted shoals.

These replanting campaigns have in fact had a negative impact on local people, who find themselves shut out by fences and cut off from resources upon which they once depended. Researchers have already raised the alarm, urging politicians and resource managers to rethink their approach and make sure that the mangroves lose none of their rich diversity.

PARTNERS

University Assane Seck of Ziguinchor, Senegal

Can Tho University, Vietnam

National Museums of Kenya, Kenya

Regional Partnership for the Conservation of the West African Coast and Marine Area (PRCM)

Instituto Superior d'Agronomia, Portugal

Plant symbiosis

Certain plants are capable of producing their own fertiliser through symbiosis with bacteria. Understanding this process opens up the possibility of improving it, using it and possibly transferring it to other species.

Nodosités de niébé, Sénégal.

Legumes (soybeans, peanuts, beans) produce seeds which contain up to 30% protein, which makes them nutritionally attractive. This is not their only benefit as they are also capable of enriching nutrient-poor soils. How? Through natural symbiosis with bacteria which, in exchange for carbonaceous sugars, produce nitrogen for the plant.

In Asia and South America, farmers have long been familiar with this property, as they inoculate their legume fields with empirically selected bacteria. This practice does not exist in Africa, even though many legumes such as peanuts, soybeans or cowpeas are grown and fertilised with costly chemical fertilisers. Hence the idea of developing these practices on the African continent and helping select bacteria adapted to African crops.

In other contexts, this symbiosis has also been used to fertilise nutrient-poor soil, for example in Thailand where legumes/bacteria combinations have helped enrich rice fields. As some bacteria help plants adapt to certain toxic substances, they are used for the revegetation of polluted soil, notably in New Caledonia on nickel contaminated land.

Researchers also examined molecular mechanisms which allow the plant to incorporate foreign bacteria. Since the 1990s, it had been believed that there was only one recognition mechanism to accomplish this symbiosis. A "key lock" system believed to be universal… until 2007 when a team of researchers discovered, in an African legume, a far simpler process which could be transferred to non-leguminous plants such as rice, wheat or maize. This is one of the avenues currently being pursued by researchers.

PARTNERS

Cheikh Anta Diop University of Dakar, Senegal; Senegalese Institute of Agricultural Research

University of Suranaree, Thailand

Rice preparation for transplantation, Thailand.

The Hidden Agriculture of the Amazon Forest

The image of agriculture in the Amazon is often shaped by colonisation fronts encroaching on the forest. But other forms of agriculture such as those practised by Amerindian peoples and traditional populations can help preserve the forest cover, subject to a long fallow cycle.

Cassava tubers and cuttings, Río Negro, Brazil.

The cultural diversity of the Brazilian Amazon, where more than 200 languages are spoken, also encompasses a huge diversity of agricultural systems with different practices, knowledge, cultivated plants and resulting food systems. Many plants such as cassava, yams, achiote, sweet potatoes, which now form an integral part of the nation's eating habits, are the result of domestication, selection and conservation processes conducted over the centuries by Amerindian populations. These populations' contribution to the variety of cultivated plants is still too often unrecognised, particularly by public authorities, while at the same time the advance of colonisation fronts, increasing urbanisation and new dietary habits are threatening the existence of these local agricultural systems, and therefore related biological resources.

A first step was taken in recognising the importance of these forms of agriculture in 2010, with the inclusion of the Rio Negro traditional agricultural system in Brazil's cultural Heritage. This inclusion, resulting from interactions between Amerindian associations, Brazilian and French researchers and non-governmental organisations, gave national exposure to local production methods and the tremendous range of plant genetic resources managed in agricultural systems which are all too often considered to be archaic. This

··· Research highlights the symbiotic relationship between humans and the Amazon rainforest ···

Felled trees, an area rich in cultivated plants, Río Negro, Brazil.

variety of resources, for example dozens of varieties of cassava in a single pile of felled trees, stems from the expert knowledge of women farmers, practices focusing on diversity and the dissemination thereof through ongoing exchanges on the scale of the Río Negro basin. Other elements including the famously fertile dark earth, the distribution of useful species such as the Brazil nut, cacao or others illustrate the Amazon forest's rich cultivation history. In this era of ecological transition, it is essential that we understand the foundations of these sustainable agricultural systems while ensuring their continuity and adjustment to new socio-economic and ecological demands.

PARTNERS

State university of Campinas (UNICAMP), Brazil

Association of Indigenous Communities of the Middle Negro River (ACIMRN), Brazil

National Historic and Artistic Heritage Institute (IPHAN), Brazil

Brazilian Agricultural Research Corporation (EMBRAPA), Brazil

New tools for studying biodiversity

Swimming in a stream of information

Anne-Elisabeth Laques, landscape geographer, UMR Espace-Dev
Stéphanie Carrière, ethno-ecologist, UMR Gred
Danielle Mitja, ecologist, UMR Espace-Dev
Pierre Couteron, ecologist, UMR Amap
Éric Delaitre, specialist in the use of remote sensors for terrestrial analysis, UMR Espace-Dev

Artificial intelligence to the rescue for biodiversity

Morgan Mangeas, mathematician specialising in artificial intelligence, UMR Entropie
Corina Iovan, specialist in remote sensing and artificial intelligence, UMR Entropie
Laurent Vigliola, marine biologist, UMR Entropie

The Nagoya protocol, reconciling ambition with effective action

Jean-Louis Pham, plant geneticist, Nagoya scientific advisor, UMR Diade

Listening to the environment

Amandine Gasc, eco-acoustician, UMR IMBE

A botanist in my smartphone

Jean-François Molino, ecologist, UMR Amap

Using genetics to identify the adaptative capacities of coral

Véronique Berteaux-Lecellier, geneticist, UMR Entropie
Gaël Lecellier, geneticist, UMR Entropie
Oliver Selmoni, geographer, UMR Entropie and EPFL
Stéphane Joost, geographer, EPFL

Protecting biodiversity

Converting waste water into fertiliser for leafier cities

Didier Orange, eco-hydrologist, UMR Eco&Sols

Of dams and fish

Pablo Tedesco, biologist, specialist in aquatic ecology, UMR EDB

Cataloguing the French Guiana forest

Raphaël Pélissier, ecologist, UMR Amap

Birds and tourists as research topics

Martin Thibault, ecologist and population biologist, UMR Entropie
Philippe Borsa, population geneticist, UMR Entropie
Catherine Sabinot, ethnoecologist and anthropologist, UMR Espace-Dev
Éric Vidal, ecologist and population biologist, UMR Entropie

Making sure that regulation rhymes with appropriation

Catherine Sabinot, ethnoecologist and anthropologist, UMR Espace-Dev
Jean-Brice Herrenschmidt, geographer, GIE Oceanide, UMR Espace-Dev
Gilbert David, geographer, UMR Espace-Dev
Fabrice Brescia, ecologist, Institut Agronomique Néo-Calédonien (IAC), Arboreal team

The proportion of birds

Philippe Cury, marine ecologist, UMR Marbec

Biodiversity and health

Nature's abundance protects us against pandemics
Benjamin Roche, biologist, specialist in the ecology of pathogenic agents and health threats, UMR Ummisco and Mivegec

At the cutting edge of ethnopharmacology
Geneviève Bourdy, ethnopharmacologist, UMR Pharma-Dev
Christian Moretti, eethnopharmacologist, UMR EIO, retraité

Tracking infectious diseases
Oleg Mediannikov, microbiologist, expert in infectious diseases, UMR Mephi

Controlling the inevitable
Laurent Granjon, biologist, UMR CBGP

Biodiversity to feed the world

Trees, the backbone of agriculture
Geneviève Michon, ethnobotanist, UMR Gred

Moving towards sustainable aquaculture
Marc Legendre, fish physiologist, UMR Isem

Adaptive fishing in Peru
Arnaud Bertrand, marine ecologist, UMR Marbec

Pastures and humans drip-fed by glaciers
Olivier Dangles, ecologist, UMR Cefe

Custodians of agricultural diversity
Serge Hamon, plant breeder, UMR Diade
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Rice as a common good
Alain Ghesquières, geneticist, UMR Diade

The potential of the world beneath our feet
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Mangroves, a new Eldorado?
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The Hidden Agriculture of the Amazon Forest
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Designed to reach the widest possible audience, this volume showcases some of the research projects which best illustrate the commitment of the French National Research Institute for Sustainable Development (IRD) to biodiversity and sustainable development. Among today's many pressing environmental challenges, protecting biodiversity is probably one of the most complex, since it cannot be understood independently of its interactions with the human societies who live with it, use it, manage it, destroy and, occasionally, protect it. As the examples contained herein demonstrate, biodiversity can no longer be confined by narrow academic boundaries. On the contrary, it is a subject inextricably linked with all of the major dynamics, human and non-human, which shape the global and local changes we currently face. In this respect, the present volume is testament to the commitment demonstrated by IRD and its partners to a vision of scientific endeavour which yields tangible, utilisable knowledge for the Global South, sustainability science in the strongest sense of the term, allowing our planet and its biodiversity to thrive in the long term.

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