SCIENCE and sustainable development

75 YEARS OF RESEARCH IN GLOBAL SOUTH

IRD Éditions

INSTITUT DE RECHERCHE POUR LE DÉVELOPPEMENT
French National Research Institute for Sustainable Development
Marseille, 2020

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Preface

PROFESSOR FABIOLA LEÓN-VELARDE SERVETTO
President of Peru's National Council for Science, Technology and Technological Innovation (CONCYTEC), chair of IRD's Strategic Orientation Committee

I am very honoured, both professionally and personally, to have been asked by IRD to write this preface, a challenge particularly dear to my heart. It is an honour for me to preface this publication, which celebrates 75 years of partnered research on the development and well-being of Global South countries. It is also a pleasure as a substantial portion of my career has been closely linked to France. I truly appreciate this opportunity in light of my attachment to and affection for this country and IRD.

It now falls to me to attempt to briefly trace the rich history of IRD's 75 years of research. This is an opportunity to look back at this rich scientific history, but also at the road which lies ahead. I would particularly like to emphasise partnerships, a specific focus of the research conducted by IRD on development.

IRD implements development research programmes by posting its researchers to the partner country on a long-term basis. These researchers are present on a daily basis within the institutions of their strategic partners or within joint research laboratories. In recent years, nearly 10 seminal interdisciplinary programmes have been developed as partnerships in Peru. This approach, deeply attached to human values, is both flexible and effective, and provides the partner country with unique technical assistance. The continued presence of its researchers enables IRD to share its international expertise. This specific vocation for training and sharing knowledge means that this research organisation has achieved undisputed successes, is much appreciated by its partners, and has contributed to real progress in the 50-odd countries where it has developed its activities.

Cooperation methods with IRD range from support for interdisciplinary research centres to participation in scientific projects and programmes defined in conjunction with third countries. Research is conducted within joint research units (UMR), international joint units (UMI) or joint service units (UMS) integrated into five scientific departments.

Another key factor lies in the nature of IRD's contribution and technical support, which focus on the production of scientific knowledge while also constituting development priorities. The richness of IRD's research has made it a major scientific player in Peru and worldwide. In Peru, a volcanology research unit was created in Arequipa in 1988, with support from IRD, and the first telemetry seismic monitoring network of the Misti volcano was set up in 2005. IRD has therefore contributed for the past 50 years to the development of Latin America, notably Peru, the first country on the continent where the Institute a permanent presence.

Over the past few years, IRD's representation in Peru has included more than 20 researchers based in Lima, Callao and Iquitos, with others on long-term missions or involved in joint research units, and more than 60 agents on short-term missions. IRD is currently conducting programmes in partnership with 12 research institutes including the Instituto del Mar del Perú (IMARPE), 10 universities – among which Peru's largest university, the Cayetano Heredia University, with whom IRD has a special connection, as well as with various ministries, Unesco and a number of private companies.

Having served as Vice President for Research for four years, and then President of the Cayetano Heredia University, I have witnessed the benefits of IRD's model first hand. IRD has been a leading partner in the development of a specific culture of partnered research.

In my current capacity as President of Peru's National Council for Science, Technology and Technological Innovation (CONCYTEC), it is up to me to coordinate IRD's various activities in Peru, with a view to contributing to the progress of Peruvian and South American science, thereby developing research on desert areas and ecosystems in the Andes and the Amazon, while ensuring that collectively acquired knowledge contributes to the economic and cultural development of neighbouring countries. The creation of the Franco-Peruvian Doctoral School of Life Sciences exemplifies the partnership between IRD and CONCYTEC: this school is a unique initiative in Peru, allowing French and Peruvian research teams to work together to train the professionals the country needs.

In the past decades, IRD has worked tirelessly to promote the sharing of knowledge and provide the human resources needed for the development of research and training activities. It also has to be said that these activities have helped expand our perspective and knowledge of our own country, in all of its variety and complexity.

I should mention significant contributions such as the implementation of the programme on the epidemiology of Chagas disease, a widespread tropical disease in Latin America, and the development of an application used to process data on micropollutant concentrations and improve water quality control.

This book takes stock of 75 years of research and presents the results of various programmes, practices and methodologies developed by IRD and its partners; the culmination of the hard work and efforts of its managers and researchers making science serve the needs of development through excellence in research. As you will see in the following pages, IRD has helped make decisive inroads into the scientific, environmental, health, social and economic fields worldwide. In South America in particular, it has helped raise the profile of certain scientific disciplines which were only in their infancy, while laying the foundations of their future development. I am talking about research in disciplines such as geology, seismology, climatology, oceanography, hydrology, and the study of glaciers and ecosystems, which has made IRD a major scientific partner for all countries concerned. For example, I should mention the many results from research in geology and the survey of tectonic and structural maps in the Andes, which would not have been achieved as quickly had IRD not been involved.

Now, after 75 years, IRD can look to the future with the satisfaction of having accomplished its mission thanks to the skills of its leadership and its continuous commitment to building its partners' scientific and technological capacity. Consequently, IRD has become a major scientific reference to address the challenges of sustainable development. I am convinced that the next 75 years will provide new partnership opportunities, ultimately resulting in major breakthroughs for France, partner countries and the world.

Preface

PROFESSOR MARY TEUW NIANE
Former Minister of Higher Education,
Research and Innovation in Senegal

The French National Research Institute for Sustainable Development is celebrating its 75th anniversary. This age is a subject of debate, essentially because of the changes in the different structures which, once aggregated, eventually gave birth to this institution in its present form and name. This institution, after several decades, facilitated the gestation and development of applied research in the countries of French-speaking sub-Saharan Africa. Some of our young and brilliant researchers are probably unaware how much our national research policies owe to the Institute. While its reputation, which remained unrivalled for a long time, is now mitigated among our scientific communities or challenged by new entrants whose policy and resources have definitely instilled competition in an environment which is increasingly open to market forces, one of the merits of IRD is to have survived the rise to independence of African countries.

The access of new States to international sovereignty, with the hopes and excesses inherent in such shifts, suggested that the powers that replaced those of the former metropolitan country would depart from this type of research organisation and management, as it might be reminiscent of the harsh colonial rule. This was not the case. Instead, the Institute adapted to the new political context in the form of a structure assigning a primary objective to research: to serve the community. This social utility is undoubtedly the reason behind IRD's exceptional stability and surprising longevity.

In fact, we no longer have a choice. Research has little to do with its initial idea, designed as an organisation made up of researchers enjoying privileges and immunities, in areas protected from influence of all kinds, from public authorities and lobby groups alike. We can no longer do without a debate on the profitability and effectiveness of the investments made in research. These new requirements are backed by ethical principles and considerations, as well as the social utility of researchers, their findings, the inventions they develop and the commercialisation of this entire intellectual production activity.

The research policy only draws its legitimacy from its social utility. It is within this framework that IRD carries out its activities.

I did not just write this preface out of friendship. I personally participated in a whole range of research activities, which I coordinated as part of teams set up with IRD, notably via UMMISCO, an International Joint Unit under the authority of seven academic institutions in France, Morocco, Senegal, Cameroon and Vietnam. Collaborative work between French and Senegalese researchers on this occasion allowed us to envisage new research avenues, more in keeping with public policies. This gave us great satisfaction, notably the training of a scientific elite capable of driving national research policies. This collaboration between IRD and the research laboratories of Senegalese universities resulted in a number of doctoral thesis defences. This was achieved thanks to the international institutional framework provided by such an organisation, as well as the technical platform making it possible to conduct research in accordance with global standards.

A lot has been done and a lot is being done by IRD. The breadth and depth of the Institute's involvement, reflected in its website, do not show all the social ties established within young African and French research communities. The demonstration effect, combined with scientific collegiality, allowed us to introduce rules and standards within our academic and scientific domains; as a result, various higher education and research systems were integrated, to which the same assessment criteria were applied. It is pleasing to note that academics, researchers and other stakeholders of the education, research and innovation system agreed to share the same repositories as part of their activities, and to encourage the assessment of the pertinence, regularity, consistency, quality and effectiveness of the research conducted and the results obtained.

This is what we opted to do in Senegal. It is a civilised form of development as it promotes sustainable development, respect for human rights and good governance. It is a costly, difficult and unprecedented development paradigm. But it is the only way to build a society with a strong scientific and technological culture. And it is the price to be paid so that the only development route left for Africa is not a cul-de-sac, an opportunity to invoke Africa's so-called "refusal to develop" as an excuse.

The initiatives taken by IRD and African research centres and structures to fill the knowledge gap between developed and developing countries are important. I am convinced that Africans, based on their

views and interests, should propose new definitions for a number of indicators used to rank countries. More importantly, I am convinced that our political commitment to the broad dissemination of knowledge will ensure accelerated development. Disseminating knowledge and skills is not only instrumental in the integration into the knowledge-based economy and the creation of a positive image for Africa; it is above all essential for the development of an African perspective based on the interests of the continent and Africa's perception of its own future, in particular its relationships with the rest of the world.

In fact, scientific discoveries and advances, along with their technological applications, are the driving force of economic growth. The role of science, technology and innovation in the transformation process, sustainable economic development and poverty alleviation is recognised and accepted. The countries that have emerged and reached a level of growth whereby they have become role models have gone through this arduous process of scientific and technological knowledge acquisition. We have no other option. There is no alternative. We must therefore continue to work together to bring about cost-effective and useful science, capable of taking practical account of the population's aspirations and laying the foundations of sustainable economic growth.

The book published by IRD for its 75th anniversary takes us into the heart of all these concerns which feature strongly in Sustainable Development Goals (SDG). By working towards fairer societies; considering ways to deal with uncertainties, risks and vulnerabilities; establishing a sustainable form of agriculture guaranteeing food security; stabilising the dynamics of ecosystems and biodiversity conservation; and sharing knowledge, we find ourselves promoting useful and accessible science. The topics covered reflect the communities' major concerns by linking theoretical analyses to empirical reality with a view to better emphasising the substance of the lessons learned from this dual approach, which delves into major development issues.

This is one of the merits of IRD, whose clearly stated ambition for Senegal, as part of the Senegal UMMISCO team, is to address social and environmental issues, by developing mathematical and computer modelling methods and tools which create increased awareness and understanding of the emerging underlying dynamics so as to address the concerns of local players and state representatives in the West African sub-region.

This is the only way for us to cope and avoid further economic misfortunes leading to shortcomings and multifaceted crises. We will find salvation in the implementation of quality programmes for the development of human capital, capable of promoting and meeting development goals. The economic and social development of any nation requires the implementation of an effective higher education, scientific, technological research and innovation system.

These have been the common threads of higher education, research and innovation reforms over the past five years, with the support of our partners, first and foremost IRD, to whom I wish a happy anniversary. Long may we continue to benefit from its institutional guidance and scientific infrastructures and equipment.

Introduction

IRD: science committed to sustainable development

PROFESSOR JEAN-PAUL MOATTI
CEO
French National Research Institute for Sustainable Development (IRD)

This publication is one of the many initiatives which, throughout 2019, will celebrate the 75th anniversary of *Institut de Recherche pour le Développement* (IRD, French National Research Institute for Sustainable Development). It presents the most significant contributions from research conducted by the Institute and by the organisations which created it, both to universal science and to improving the living conditions of people in countries that were long referred to as the "Third World" and are now known as developing countries. The term "developing countries" encompasses increasingly diverse realities, ranging from "emerging" countries which are already major world powers, such as Brazil, China and India, to the so-called "less advanced" countries where the majority of the population continues to live below the absolute poverty line[1].

Like all the events organised to observe this anniversary, this book illustrates the historic continuity of our Institute over a relatively long period that included two formative milestones over the last 75 years: the first was the end of "colonial sciences" and the second was the founding of the research mission focused on sustainable development and an equitable scientific partnership. As a result of this history, IRD today is an original, if not unique, body in the French, European and international scientific landscape. France is the only country in the world to have, in the form of IRD, a public, multidisciplinary research organisation that is wholly dedicated to scientific cooperation with developing countries in the tropical belt and in the Mediterranean. This institution is backed by

1 – As defined by international institutions, less than USD 1.90 per person per day in purchasing power parity.

Cirad, another entity specialising in this kind of cooperation in the realm of agronomic research.

This historical truth compels us to acknowledge that celebrating the 75th anniversary of IRD in 2019 is the result of a conscious choice. It would have been possible to trace the origins of the Institute back further, for example, to the *Congrès de la recherche scientifique dans les Territoires d'Outre-mer* (Congress for scientific research in overseas territories) held in September 1937 to coincide with the International Exposition and to the subsequent formation by the Popular Front government of a *Comité Consultatif des recherches scientifiques de la France d'Outre-mer* (Advisory committee on scientific research in overseas France) within what would become one year later the *Centre national de la recherche scientifique* (CNRS – French National Centre for Scientific Research)[2]. Two highly respected scientists, Irène Joliot-Curie and Jean Perrin, who successively held the position of Under-Secretary of State for Research for the Popular Front, advocated from the start for addressing the specific characteristics of what was then referred to unapologetically as "colonial science", and for the need to formalise it within an institution with a certain degree of autonomy relative to the "non-specialist" organisational mechanisms of public research.

Their view sparked a controversy that endures to this day with those who favour a simple Global South variant on classic scientific disciplines.

One readily understands the unwillingness to refer to the creation in 1943, by the Vichy regime, of the *Office de la Recherche Scientifique Coloniale* (ORSC – Office for Colonial Scientific Research), the first independent public entity devoted to research in the French colonial empire.

The decision logically fell to the reconstitution of the ORSC by the Ordinance of 24 November 1944 by the interim government born out of the resistance to Nazi occupation. To make 1944 the founding moment of the process that would initially lead, in 1953, to the *Office de la Recherche Scientifique et Technique Outre-mer* (Orstom – Office for Overseas Scientific and Technical Research)[3] and then to IRD is to affirm

2 – C. Bonneuil, *Des savants pour l'Empire, les origines de l'Orstom*, *Cahiers pour l'Histoire du CNRS*, 1990, p. 10.

3 – Five years later, the ORSC became ORSOM (Office of Overseas Scientific Research), then Orstom in 1953 (Office of Overseas Scientific and Technical Research).

our adherence to the democratic and progressive values which underpin our Republic. Beyond that, and most importantly, it was in the period 1944 to 1945 that research teams from the future Orstom headed to Africa, Madagascar, French Guiana, the Pacific and Indian oceans, and the colonial territories that, for the most part, had until then been excluded completely or significantly from all forms of scientific investigation.

From "colonial science" to equitable scientific partnership

Over the past four years, I have had the opportunity, as chair and Chief Executive Officer of the Institute, to travel to many of our partner countries and to take part in various forms of "commemoration" of Orstom's involvement, such as the 70th anniversary of IRD in Madagascar in May 2018 and its 60th anniversary in Tunisia in October 2017. Each time, I have been struck by the fact that our colleagues in higher education and research (HER) in these countries unflinchingly acknowledge the *full* story of their relationships with researchers from our Institute, including its colonial past. After all, the work carried out by botanists, entomologists, plant physiologists, geneticists, geologists, marine biologists, fisheries experts, hydrologists, soil scientists and agronomists (the term used was "crop protection" rather than agronomy) from Orstom – soon to be joined by anthropologists, ethnologists and researchers in other human and social sciences[4] – enabled the rudimentary compilation of a priceless body of knowledge about the flora and fauna, river basins and water resources, soils and agricultural potential, mineral and natural resource and, of course, the social structures of the tropical belt and the Mediterranean. Nevertheless, during the first 15 years of existence of Orstom, the geopolitical field in which researchers went about their work was first the colonies, then the overseas territories. The purpose of the research conducted – in the eyes of the French government if not in the

4 – E. Sibeud, *Les sciences sociales à l'épreuve de la situation coloniale*, *Revue d'Histoire des Sciences humaines*, 2004/1, 10, pp 3-7.

minds of the researchers themselves – was to enhance and exploit the resources of these territories to benefit the interests of mainland France.

Beginning in the 1960s, the massive upheavals wrought by the acquisition of independence by the African and Malagasy colonies of the French Empire translated to the expansion of Orstom's geopolitical scope to numerous countries in English-speaking Africa, as well as Latin America, South-East Asia and the South Pacific that had never been under French colonial rule. More significantly, these upheavals fed a gradual but definitive process that culminated in an initial, radical break with the colonialist origins[5]. Formally represented in 40 countries in the Global South and working in collaboration with more than twice as many, IRD today is the exact opposite of a neocolonial institution. In fact, its mission is dedicated entirely to strengthening the capacity of higher education and research in its partner countries to contribute to advances in universal science, while also meeting the needs of their populations, especially the poorest and most vulnerable groups. Contemporary IRD researchers share with their Orstom predecessors the value of living and working as close as possible to projects with their colleagues in the Global South and in the Mediterranean and tropical regions, but they work under an original expatriation model that has few equivalents anywhere else, especially in the Anglo-American scientific world. They all work on a daily basis at the laboratories, research centres and universities of their partners in developing countries.

This crucial distancing from any form of condescension or domination vis-à-vis the scientists and, of course, the people of the Global South with whom the Institute collaborates does however require ongoing vigilance and continuous reflection and self-critiquing about our research practices. Thus, the work of IRD has played an important role in acknowledging the need for flexibility in the international rules governing the protection of intellectual property, to facilitate access by developing countries to medicines and other essential goods, or to bridge the digital gap between rich and poor nations[6]. Similarly its efforts have largely contributed to

5 – M.-L. Sabrié, *Histoire des principes de programmation scientifique à l'Orstom (1944-1994)*, *in*: *Les sciences hors d'Occident au XX^e siècle*, éditions de l'Orstom/Unesco, 1995, vol. 2, pp. 223-234.

6 – F. Orsi, M. P. Carrieri, B. Coriat, É. Delaporte, J.-P. Moatti, B. Spire *et al.*, Call for action to secure universal access to ART in developing countries, *Lancet*, 2010, vol. 375, issue 9727, pp. 1693-1694.

the recognition of traditional knowledge, not least that of so-called "First Peoples", and to changes in the international rules intended to ensure a fair "sharing of benefits" stemming from research results and the innovations they spawn[7]. Nevertheless we must continue to adapt our practices, such as our patent filing procedures, to remain compliant with these changes brought about by our very own research, as is notably the case with the 2010 Nagoya Protocol on access to genetic resources and biological diversity[8]. Along the same lines, IRD now actively responds to requests to return scientific collections of various types or items of cultural significance to its partner countries, which it supports in their endeavours to reclaim their heritage and arrange long-term conservation. In this vein, the Institute will soon give the Republic of Gabon hundreds of hours of recordings of music and oral traditions collected in Gabon in the 1950s by two ethnomusicologists working for Orstom.

Contributing on an equal footing to building the capacity of researchers, academics and research institutions in developing countries – the very core of the equitable scientific partnership that guides IRD's actions today – is not just an imperative for international science. A recent bibliometric analysis showed that co-publications with researchers in the Global South are the only realm in which the scientific output of all of France's HER does not align with the seemingly inevitable downward trajectory of its impact and visibility, because of increasingly sharp international competition, with the ramping up of research in emerging countries and China in particular[9]. The inadequacy of scientific capacities and infrastructure in many developing countries also impedes their entire development strategy. Therefore, the fact that sub-Saharan Africa barely accounts for 2% of worldwide scieentific output (with Nigeria and South Africa alone making up nearly half of this figure)[10] undermines its

7 – F. Thomas, *Les éthiques du partage des avantages dans la gouvernance internationale de la biodiversité sauvage et cultivée*, *Éthique Publique*, 2014, vol. 16 (1).

8 – G. Bourdy, C. Aubertin, V. Jullian, É. Deharo, Quassia "biopiracy" case and the Nagoya Protocol: A researcher's perspective, *Journal of Ethnopharmacology*, vol. 206, 12 July 2017, pp. 290-297.

9 – *5 ans de production scientifique des unités mixtes de recherche de l'IRD. Analyse bibliométrique 2012-2017*, IRD, Marseille, 2018. http://www.ird.fr/media/ird.fr/actualites/photos-actualites/2017-1er-semestre/rapport-bibliometrique

10 – UNESCO Science Report: towards 2030, Unesco, Paris, 2016. https://unesdoc.unesco.org/ark:/48223/pf0000246417

capacity for technological innovation, to wield influence in international negotiations and, above all, to train the managers and entrepreneurs who are essential to sustainable growth on the continent[11].

From development aid to critical analysis of sustainable development

The decolonisation process initiated in the 1960s was also accompanied by a redefinition of the purpose of research programmes, which would henceforth be framed in terms of "development assistance" for fledgling nations. However, after independence, when the first national science institutions were being set up in developing countries, this "research for development" covered forms of technical assistance, as well as implementation programmes in poor countries that were essentially funded by wealthy countries. The urgency of curtailing poverty, the dictates of growth, agricultural and manufacturing needs and the establishment of health systems determined research priorities. Research in the countries of the Global South was conceived as a socio-economic development tool with a view to catching up with wealthy nations. This trend came to an end in the 1980s with the debt crises in Latin America, Africa and Asia, the push-back against the structural adjustment programmes that international financial institutions tried to impose on developing countries, and global health crises such as the AIDS epidemic – which coincided with the end of the bipolar geostrategic configuration between the Western and Soviet blocs that emerged in the post-war period and the shattering of the centre-periphery model. This approach was not without a certain paternalism and neocolonialist temptations, which seeped into development assistance programmes, including in the field of research.

IRD is currently in the midst of a second radical change brought about by the emergence, over the past 50 years – first in the scientific realm,

11 – African Union, Agenda 2063: the Africa we want. https://au.int/fr/agenda2063

then in multilateral policy arenas – of an increasingly critical view of the notion that development is a linear process in which developing countries must race through the major historic stages that punctuated the growth of OECD countries[12]. Endorsed in 1987 by the publication of the *Our Common Future* report, written by the UN World Commission on Environment and Development and known as the *Brundtland Report* after its chair, the idea of a change towards sustainable development was the first incarnation of this critique. It conceived sustainable development as "development that meets the needs of current generations without compromising the ability of future generations to meet their own needs". It features two key concepts: "the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs"[13]. Adopted nearly 30 years later, in September 2015, by the 193 member countries of the United Nations, the 2030 SDG are the result of multiple compromises between different and sometimes contradictory interests, stakeholders and countries. However, scientific research has played a major role by expanding awareness of the urgent social challenges, with the unprecedented rise in inequality, and environmental challenges, from global warming to other worldwide environmental changes – challenges that are medium-term threats to the future of the planet. It has helped to define these objectives as the frame of reference for a multilateral dialogue and proposed solutions to profoundly shift the untenable growth models which continue to dominate the world economy and international relations[14]. As this research focuses on the tropical and Mediterranean regions where the greatest ecological, social, and political vulnerabilities are combined for current development models, research conducted by IRD in partnership with the Global South often almost naturally ends up on the front line of debates about the implementation of SDGs.

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12 – S. Anand, A. Sen, Human Development and Economic Sustainability, *World Development,* vol. 28, issue 12, December 2000, pp. 2029-2049.

13 – World commission on environment and development, *Our common future*, éditions du Fleuve/Publications du Québec, 1989.

14 – J.-P. Moatti, *Dépasser les ambiguïtés et les limites des ODD : la science en première ligne*, in: *Un défi pour la planète. Les Objectifs de développement durable en débat*, IRD Éditions/éditions Quae, 2017.

Although, as demonstrated by many of the projects described in this publication, IRD is now aligned with the reference framework outlined by SDGs, under no circumstances does it abdicate the vital combination of a critical mindset, methodological rigour and a robust defence of the independence of research from the powers that be. This combination remains at the heart of the scientific approach and has characterised the Institute since the outset, sometimes coming at the cost of difficult relations with authorities in the host country or even those in our own country. Much like the fight for access to essential medicines for AIDS, tuberculosis and malaria for patients in the Global South, with which I have been personally involved during my research career[15], this publication abounds with examples that show that the research conducted by IRD has often had the greatest transformative impact when it challenges preconceived notions, including within the international scientific community which is not always immune to the excessive hegemony of Anglo-American thought.

An aptitude for pluralist discussions and for critical thinking, therefore, is embedded in the DNA of our Institute. It is, in fact, what makes it so rich. While they do not always meet with unanimous approval in our ranks, just as in the broader international scientific community, many of the research projects currently under way with our partners in developing countries explicitly refer to the notion of "Anthropocene". This notion postulates that human activity has reached such a degree of development that it has ushered the Earth into a new geological era[16] and that the global environmental and social changes in progress threaten to exceed the limits of the planet's lithosphere and biosphere[17]. Other projects come under the critical perspective of "Capitalocene"[18], according to which it is not human activity in and of itself that threatens to destroy the planet, but rather human activity as generated by the social dynamics of capitalistic production and domination, especially in its phase of predominance in the financial sphere.

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15 – J.-P. Moatti, I. N'Doye, S. M. Hammer, P. Hale, M. Kazatchkine, Antiretroviral treatment for HIV infection in developing countries: an attainable new paradigm, *Nature Medicine*, 2003, vol. 9, pp. 1449-1452.

16 – P. J. Crutzen, W. Steffen, How Long Have We Been in the Anthropocene Era? *Climatic Change*, 2003, vol. 61, issue 3, pp. 251-257.

17 – W. Steffen, K. Richardson, J. Rockström *et al.*, Planetary boundaries: Guiding human development on a changing planet, *Science*, 2015, vol. 347, issue 6223, 1259855.

18 – A. Malm, *Fossil Capital: The Rise of Steam Power and the Roots of Global Warming*, Verso Books, London & New York, 2016.

The two formative milestones referred to above had an institutional impact: first in 1984, when Orstom was renamed "French Institute of Scientific Research for Development Cooperation" (although still referred to by its Orstom acronym) and designated as a public scientific and technological establishment (EPST), then in 1998 with the creation of the *Institut de Recherche pour le Développement* (IRD – French National Research Institute for Sustainable Development) with an EPST status similar to that of other public research institutions such as CNRS, Inra and Inserm which oversee its current function[19]. As fate would have it, this 75th anniversary year for the Institute also coincides with the 20th anniversary of the founding of IRD in its current iteration.

There have been other institutional changes since the creation of IRD in 1998. The most recent one saw all the Institute's laboratories become "joint research units", linking them with universities and, in the vast majority of cases, one or several other public research entities (Cirad, CNRS, Ifremer, Inra, Inserm, Irstea), which further advances the consolidation and projection of French HER efforts to the Global South. These pairings with "non-specialist" science organisations and establishments enable the IRD teams to be more effective than ever at applying the latest advances and discoveries in major scientific disciplines, with their in-depth and long-standing knowledge of the contexts and specific characteristics of developing countries.

By doing this, IRD is now better equipped to manage and overcome the tension inherent in its dual role, from the original debates that pre-dated even the Second World War to discussions about the role of science in today's multipolar, digital world. This tension goes beyond the traditional division between fundamental research and applied research and opposes the contribution of research to universal science – many of the big questions asked by research, from climate change to migration to inequality, cannot be solved without the insight provided by data observed in the tropical belt and the Mediterranean region – and its contribution to generating innovations and solutions better suited to the essential needs of people living in developing countries. There is also tension between its role as an impartial producer of scientific knowledge, which in its very essence is a global public asset serving all humanity, and its role in service

19 – Ph. Lazar, *Quelle science pour les pays en développement ?, Science*, 1999, 99 (4), pp. 59-62.

of "scientific diplomacy" and the influence strategy of France and, more broadly, the Francophone world. However, it is not the institutional aspects of IRD that will secure its future and the future of all research advancing sustainable development; rather, it is IRD's steadfast attachment to a third major era that is currently forming in the scientific realm itself.

At the cutting edge of *"sustainability science"*

A new scientific field emerged in the 1980s. Dubbed sustainability science in the international literature, it became a priority for the National Academy of Sciences (NAS) in the United States at the beginning of this century and for its Chinese equivalent shortly thereafter[20]. It is now central to the activities of the International Science Council (ISC), which coordinates international scientific unions[21], and large-scale research programmes and international scientific partnerships such as Future Earth[22] and the Belmont Forum[23]. The US Academy defines sustainability science as "dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems"[24]. Over the past 20 years, this field has been boosted by the creation of several specialised scientific journals and, more recently, by its recognition by leading "general interest" scientific publications (*Nature, Science, Lancet*, etc.)[25].

20 – R. W. Kates, W. C. Clark, R. Corell *et al.*, Sustainability Science, *Science*, 27 April 2001, vol. 292, issue 5517, pp. 641-642.

21 – https://council.science/

22 – http://www.futureearth.org/

23 – http://www.belmontforum.org/

24 – W. C. Clark, Sustainability Science: A room of its own, PNAS, 6 February, 2007, 104 (6), pp. 1737-1738.

25 – M. A. Bettencourt, J. Kaurc, Evolution and structure of sustainability science, PNAS, 6 December, 2011, vol. 108, no. 49, pp. 19540-19545.

Sustainability science is notable in particular for the fact that its goals and research topics are primarily derived from the need to tackle the problems that the world, ecosystems and communities face, rather than from the specific dynamics of the scientific disciplines whose work it involves. It therefore aims to be intrinsically interdisciplinary and intersectoral in its approach, as it focuses on achieving a better understanding of the complex chains of causation that explain the changes and imbalances that eco-socio-systems are currently experiencing, and on producing solutions and innovations that create a pathway towards sustainable development[26]. It expresses, right within research practices, a particular focus on "participatory science", namely co-constructing research programmes from the outset together with the communities and social groups that are the most concerned by the problems research is attempting to solve[27]. Being grounded in the territories (in the field) should make it possible to combine the development of generic science fronts with a recognition of the problems faced by societies in their daily lives in their environments.

The preparation of the SDG 2030 Agenda, followed by its adoption in 2015 and subsequent implementation, sparked a formidable surge of interest in sustainability science, within the scientific community and beyond. In particular, there have been major advances in the analysis of interactions between the multiple phenomena addressed by SDGs, as well as between the policies and actions that seek to promote them. The idea is to prevent the "vertical" pursuit of any single objective from adversely affecting the others, and to maximise positive synergies between policies driving SDGs[28]. To mention but one example among hundreds, efforts are being made to ensure that food security is achieved not, as is currently the case, by exponential growth in the use of chemical inputs and pesticides in farming but, on the contrary, by increased soil capacity for carbon storage through the promotion of agro-ecology, which

26 – J.-L. Chotte, J.-P. Moatti, *Une science interdisciplinaire au service du développement durable. The Conversation*, July 2018. https://www.ird.fr/toute-l-actualite/communiques-et-dossiers-de-presse/cp-2018/une-science-interdisciplinaire-au-service-du-developpement-durable

27 – *Nature Editorial*, 3 October 2018. The best research is produced when researchers and communities work together. https://www.nature.com/articles/d41586-018-06855-7

28 – *International Science Council, A Guide to SDG Interactions: from Science to Implementation*, 2017. https://council.science/cms/2017/05/SDGs-Guide-to-Interactions.pdf

simultaneously helps reduce the greenhouse gas emissions that cause global warming and improves agricultural productivity[29].

The United Nations launched the institutional recognition of sustainability science by entrusting, for the first time in its history, the critical assessment of SDGs to a group of 15 independent scientists (IGS), to which the author of these lines belongs, rather than to other UN agencies. The goal is to enable the UN to escape the habitual inter-governmental negotiations and compromises that characterise multilateral institutions. The first of these quadrennial reports, known as a "GSDR" or *Global Sustainable Development Report,* is scheduled for September 2019, to be followed by regular updates through to the 2030 target date set for SDGs[30]. In the current geostrategic context of crisis in multilateralism this is a rare opportunity for scientific evidence and rationality to positively influence public policy.

Upon reading this publication, one can certainly argue that IRD, over its 75 years of existence, did not wait for the emergence of sustainability science to practise interdisciplinary cooperation, to contribute to solving the major problems faced by developing countries and to involve local populations – including the most vulnerable – in development research programmes. Other areas of French research could undoubtedly make the same claim. As a result of having practised sustainability science without naming it or explaining it, without staking out a position in this camp in discussions and decision-making bodies and perhaps sometimes without even knowing it, the French and Francophone scientific community runs the risk of seeing its impact diminished, both in the face of international scientific competition and in its ability to influence public policy and the behaviours of key players in sustainable development.

IRD is especially well positioned to pursue sustainability science, on the strength of 75 years of partnering with countries and territories in the tropical belt and the Mediterranean region, which are the most exposed to global imbalances and frequently the most motivated, out of necessity, to identify and disseminate "frugal" innovations that could

29 – https://www.4p1000.org/fr

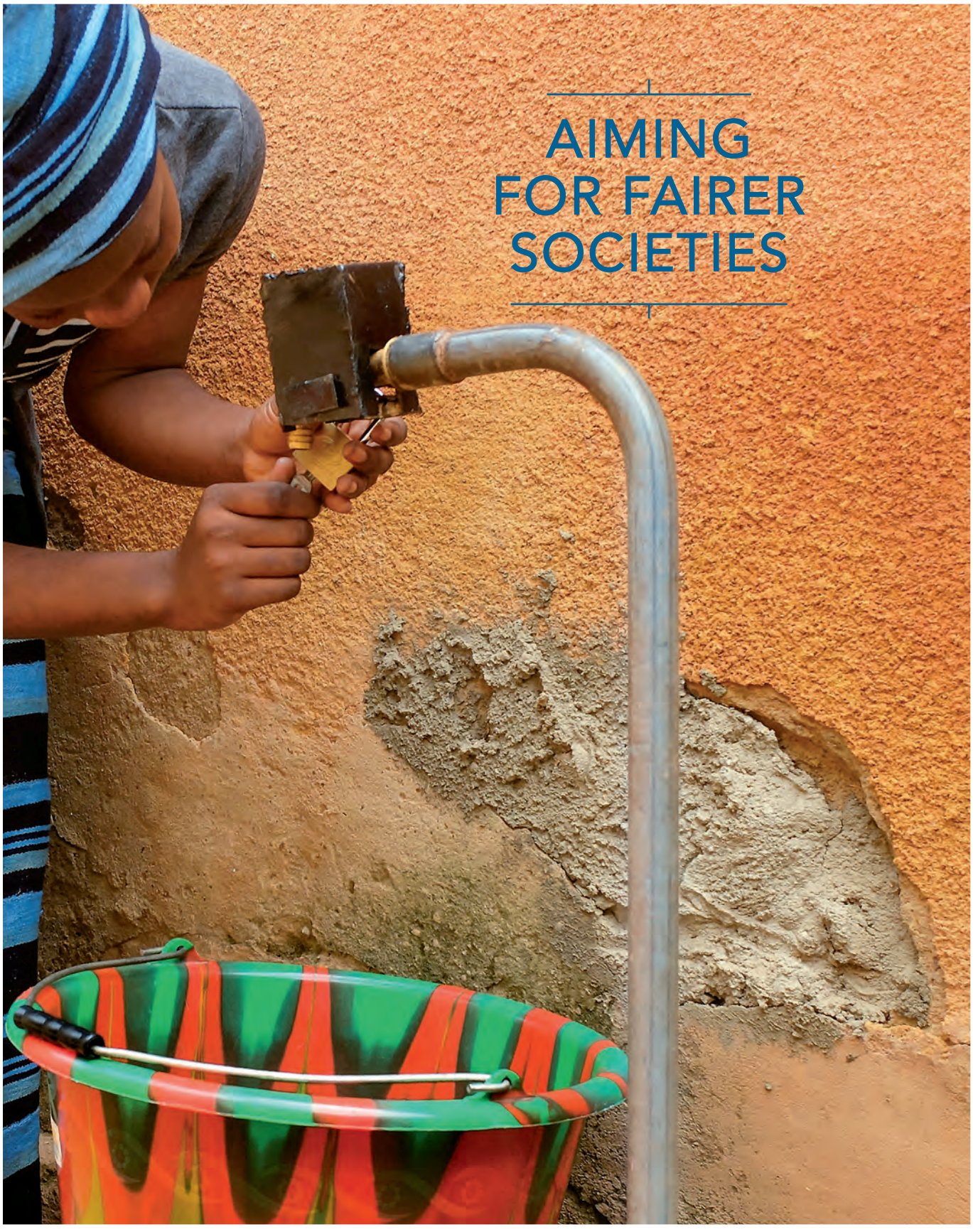
30 – https://sustainabledevelopment.un.org/globalsdreport/2019

prompt reorientation toward sustainable development pathways[31]. This 75th anniversary is therefore an opportunity for our Institute to put itself at the forefront of this science as a driving force and source of momentum for French and French-language research as a whole, particularly among scientists from the Global South. The future of IRD over the next quarter-century depends on it, as does, to at least a small extent and with all due modesty, the future of our planet.

31 – R. Adams, S. Jeanrenaud, J. Bessant, D. Denyer, P. Overy, Sustainability-oriented Innovation: A Systematic Review, *International Journal of Management Reviews*, vol. 18, issue 2, pp. 180-205, 2016; M. Hossain, H. Simula, M. Halme, Can frugal go global? Diffusion patterns of frugal innovations, *Technology in Society*, vol. 46, August 2016, pp. 132-139.

PART 1

Research conducted by IRD on changes in societies of the Global South is a valuable source of knowledge for improving social justice, gender relations, the combat against poverty, access to employment, education and healthcare. It is underpinned by long-standing programmes on governance, inequalities, mobility and barriers to growth in the Global South. The land and cultural issues, social and spatial dynamics of societies in the Global South, compared with those of the North, are also the focus of research conducted by IRD and its partners.



AIMING FOR FAIRER SOCIETIES

Microlending and maximum debt

At the start of the century, the global aid sector was enthusiastic about the concept of microlending, which was awarded a Nobel prize in 2006. This keen interest waned when researchers and NGOs found out about the foibles of these "small loans".

In 2002, an innovative project was set in motion in India: groups involving the State, future beneficiaries, NGOs and banks working together to provide the poor with small amounts of money and facilitate a project or purchase. A form of microlending. Interested in this initiative, IRD researchers began to assess it and took a look behind the scenes. By carefully examining the situation of borrowing families, they realised that all of them were already indebted, not to banks but to other family members, loan sharks, local leaders or pawnbrokers.

This informal debt, which was completely overlooked at the time, can be significant. In the rural area studied, certain families sometimes accumulate up to 10, 20, 30 debts, i.e. a total of one to three annual salaries. When the income stream is irregular and social protection virtually non-existent, overindebtedness is therefore massive. Against this background, receiving contractual microcredit, with fixed monthly repayment terms, only weakens the most destitute populations, whose income is as irregular as it is unpredictable.

"IRD's research on debt, conducted in India and South Asia over a long period of time and sometimes in difficult circumstances, is exceptional insofar as it captures the unique features and reality that characterise the essence and perpetuation of household debt. In an ever-shifting landscape, research reveals hidden patterns overlooked by public interventions and weaves a superb narrative, making sense of the continuing and structural exclusion and exploitation of people through debt, as well as the ambivalence of debt and the limits of microlending policies. This is why IRD's work is extremely important to the International Labour Organisation, in its effort to improve the effectiveness of public policies on the fight against vulnerability in the workplace."

Coen Kompier, International Labour Organisation, India

••• In developing countries, microlending
makes poor, already indebted populations more vulnerable •••

Taking out microcredit, Pakistan.

This trend is not specific to India as it can be found in numerous developing countries. Furthermore, this excessive debt has ambiguous consequences. It may be a sign of family solidarity or, on the contrary, of becoming trapped in a vicious circle likely to lead to prostitution or servitude. While fewer NGOs have partaken in microlending since then, private financial companies have taken over, partly because they realised that the poor too can be creditworthy.

Since then, other, more promising initiatives have been monitored by IRD, such as small cooperative banks in Brazil which finance and support projects generating wealth at local level. Watch this space…

PARTNERS

French Institute of Pondicherry, India

Gujarat Institute for Development Studies, India

CIESAS-Occidente, Guadalajara, Mexico

Federal University of Bahia, Brazil

Hassan II University, Casablanca, Morocco

An economy based on precarious employment

Informal economy does not necessarily mean black or illegal economy. It corresponds with unreported precarious jobs, which in some countries may account for the overwhelming majority of jobs. Hence the importance of quantifying it.


© IRD/J. Lumsson

Loincloth vendor, La Paz.


© IRD/C. Blein

Precarious job, Togo.

In developing countries, resourcefulness is of paramount importance. In the absence of opportunities, decent jobs and social assistance, the poorest people develop, exchange and occupy home help or itinerant positions. While this massive informal economy is tolerated, the authorities find it difficult to quantify. And for good reason: official surveys identify companies thanks to their physical address, but this method is unsuitable to describe the reality of this economy, where only moderately successful businesses can afford to move to actual premises. Until recently, this bias allowed governments to give the impression that the informal economy was the economy of dynamic micro-enterprises and start-up companies. This is a particularly embellished view of reality.

To address this issue, from 1986 to 1988 in Mexico, researchers came up with a new approach to improve the detection of those involved in the informal economy. Their idea was to conduct surveys not in businesses but within families, to find out where the money that supports them comes from. A few years later, in 1993 in Cameroon and Madagascar, this approach was enhanced, resulting in the so-called "1-2-3" surveys. They consist of mixed questionnaires combining questions about families and the informal micro-enterprises they run and which, as their name suggests, feature three components: the first aims at understanding the different types of job held by household members, and therefore identifying the small informal units they have created; the second is a questionnaire on the business(es) detected; and the third relates to the consumption of households who often purchase from small informal businesses.

Having become an international standard, these 1-2-3 surveys have shed light on the importance and above all the functioning of the informal economy, which represents 70% of jobs in developing countries and up to 90% in sub-Saharan Africa, 80% in South-East Asia and 55% in Latin America.

PARTNERS

University of Antananarivo, Madagascar

Universidad Catolica, Peru

Vietnam Academy of Social Sciences

National statistical institutes, labour ministries, regional and international organisations

"Surveys on the informal sector and micro-enterprises conducted with the scientific support of IRD's researchers are of critical importance to Vietnam. They help address the knowledge gap on this subject. They also have significant implications in terms of contribution to public policies for disenfranchised populations, against a background of increasing international integration and the accelerated rate of technological change. For the first time in Vietnam, the Prime Minister recognised the existence of the informal sector and the need to place it at the top of the official agenda, with the formulation of targeted policies which should allow these populations to participate in the inclusive growth process the country intends to promote."

Doctor Nguyễn Thắng, Vietnam Academy of Social Sciences, Hanoï, Vietnam

Street vendors, Vietnam.

••• Mixed surveys are used to quantify the informal economy •••

The missing proportion of women

Gender is often viewed through the prism of social or economic discrimination. However, demographic discrimination which prevents girls from being born or surviving, is a greater determinant as it dramatically reduces the proportion of girls in some countries.

Group of female secondary school students, Indonesia.

While the one-child policy in China and the huge cost of dowry in India are often the two factors used to explain the lower female birth rate worldwide, the situation is in fact far more complex than that. This has been demonstrated by a team of demographers who, in 2008, compared the situation between the two countries. There seemed to be other mechanisms in place. To gain a better understanding of these mechanisms, the researchers examined the situation in other nations around the world, thus adding Vietnam, Albania, Kosovo, Armenia, Georgia and Indonesia to the map of prenatal discrimination against girls.

This comparative study gave rise to a theoretical framework in 2009, featuring the three pillars leading to the emergence of these practices, i.e. social preference for boys, access to technology capable of determining the sex of unborn children and fertility decline. When these three factors come together, demographic discrimination is set in motion, with varying intensity and temporality. The shortage of women is currently estimated at 120 million, either because they were not born or because they died in childhood due to lack of care.

This is not without consequences for the future, as indicated by projections. In countries such as China or Azerbaijan, records show 115 boys born for every 100 girls. This surplus of men could result in the saturation of the marriage market, and this trend will only worsen with the accumulation of successive generations of single men. These results helped bring the discussion on prenatal discrimination out in the open. They prompted governments to enact policies ranging from public awareness campaigns to the training of ultrasound operators, and sometimes even a ban on parents-to-be being told the sex of their child.

PARTNERS

Geostat, National Statistics Office of Georgia, Tbilisi, Georgia

General Statistics Office, Hanoi, Vietnam

Agjencia e Statistikave të Kosovës, Pristina, Kosovo

Jawaharlal Nehru University, New Delhi, India

Beijing University, Beijing, China

United Nations Population Fund, New York, USA

WorldVision, New York, USA

Population Council, New York, USA

London School of Economics, London, UK

••• China and India are not the only countries where more boys are born •••

Young women on the beach, India.

"In a country such as India, this major research on sex selection at birth or excess female mortality has shed light on this form of discrimination from an international viewpoint. These studies encourage Indian decision-makers to take steps to tackle these issues. The results of this research are often used by Indian stakeholders who work in this field."

Nandita Saikia, Assistant Professor, Jawaharlal Nehru University, New Delhi

Governance and corruption seen from the bottom

Improving confidence in institutions, guaranteeing the safety of citizens and controlling corruption are among the goals of the international agenda. However, developing indicators to monitor these goals is an enormous challenge.

Anti-corruption poster, Niger.

PARTNERS

University of Antananarivo, Madagascar

Universidad Catolica, Peru

Vietnam Academy of Social Sciences

National statistical institutes, labour ministries, regional and international organisations

In the 1990s, economists looked into the bottlenecks inhibiting the Malagasy economy. Madagascar is the only country at peace which has been getting poorer without interruption since its independence. To document the link between economic and political cycles, investigations are carried out into everyday socio-political governance. This issue is addressed in the form of statistical survey modules conducted in conjunction with the National Institute of Statistics of Madagascar. The goal is to gain an understanding of the population's perception and experience of corruption, discrimination and insecurity, while assessing the level of confidence in institutions.

This was a first as, until then, corruption or governance indicators were essentially calculated by international organisations such as the World Bank or Transparency International, based on expert opinions often far removed from the reality experienced by ordinary citizens. With this ground-breaking work, IRD notably provides an alternative indicator to measure the level of bureaucratic corruption suffered by the population on a daily basis, using a system of *ad hoc* surveys. This system is based on a series of questions which relate to the entire population.

The publication of the level of corruption monitored by this indicator forced the authorities to recognise the magnitude of the phenomenon (one third of the population affected), put measures in place and set up anti-corruption institutions. Since this initial experience in Madagascar in 1995, the methodology has been tested in many other countries. In 2013, it served as a basis for the harmonised system designed to measure and monitor governance, peace and security (GPS) indicators, adopted by the African Union and validated by all the national statistical institutes (NSI) of African countries. This approach has also been adopted by the NSIs of Global North countries (Italy, France).

CE1 class (Year 3 equivalent), Burkina Faso.

Developing public education in the cities

An integral part of the international agenda, improving access to education is one of the development priorities. The objective is to reduce disparities between countries as well as within each country.

In Burkina Faso, the increase in the public educational offer – primary and secondary schools – in rural areas has been a priority of the education policies rolled out at the start of the century. The idea was to reduce inequalities between urban and rural areas. The capital, Ouagadougou, where enrolment levels are the highest in the country, has failed to attract political attention. However, this privileged school situation conceals major intra-urban geographical inequalities. A partnership initiated in 2015 helped produce a digital atlas for the educational offer, based on a unique database which cross-references the location of all primary and secondary schools in the capital with the characteristics of each school.

This atlas showed a clear deficit in the public educational offer: it only represents 31% of primary schools and 25% of secondary schools. Public schools are concentrated in the central districts of the capital, when school-age populations mainly reside in outer suburbs. The private sector, dominated by secular institutions, is geographically heterogeneous: well-equipped and expensive schools are located in central districts and intended for affluent populations, while under-resourced, less expensive schools are essentially found in peripheral areas inhabited by the poorest populations. While in Burkina Faso education was made compulsory for children aged 6 to 16 by the 2008 Act, in the capital the issue of equality arises due to the shortage and geographical distribution of the public educational offer. Families in peripheral areas who wish to send their children to school have no choice but to go for private schools, which are usually low-quality.

This digital atlas of the educational offer in Ouagadougou, used to identify the most disadvantaged urban territories and under-resourced schools, is a valuable tool for monitoring, assessing and managing the education system, which should now be made permanent. This tool could also be extended to other cities and capitals.

Private school in Ouagadougou, Burkina Faso.

PARTNERS

Higher Institute of Population Science, Ouaga 1 University, Burkina Faso

Social Science Institute, Burkina Faso

Directorate General for Sectoral Statistics and Studies: Ministry of National Education and Literacy, Ministry of Secondary and Higher Education, Ministry of Social Action and National Solidarity, Burkina Faso

The multilingualism textbook

In French Guiana, 75% of the population does not speak French before starting school. However, teaching is delivered in French with no specific adjustments. This results in massive academic failure. 56% of the French Guianese leave school without a diploma. Local advocacy groups took a stand against this sad reality in the 1990s.

Training of bilingual mediators, French Guiana.

In French Guiana, school enrolment is a recent phenomenon among Amerindian and Maroon communities, whereas it goes back several generations for coastal Creole communities, who are therefore more francophone. In this french department, 40 different languages coexist, 10 of which have been described by Orstom since the 1990s following local political demands to take these local languages into account in school. This is why, in 1998, researchers drew from experiments conducted in Brazil and Colombia to implement an experimental, bilingual scheme whereby French coexists with minority languages such as Kali'na, Wayana, Nengee or Hmong. These languages were recognised as "languages of France". These schemes, which became widespread in 2017, largely facilitated the integration of pupils into the education system.

••• Two programmes contributed to adapting school to specific French Guianese characteristics •••

At the same time, from 2000 to 2013, a major sociolinguistic survey was initiated to determine the geographical distribution of the languages of French Guiana, where 80 schools were visited. It appeared that there is not just one minority language spoken within each class but several. By the age of 10, most children can speak up to four different languages. These findings led to a second scheme, based on the pupils' multilingualism. The idea is to use all languages spoken in the classroom as resources and use learning aids to build bridges and draw parallels between languages, in order to accelerating learning. These techniques, used by linguists and in migrant holding centres, have been integrated into French Guiana's university teacher training programmes since 2010. This helps build a more inclusive society. These measures, combined with the arrival of the Internet in remote areas, have allowed the first generations of trained Amerindian and Maroon elites to emerge.

PARTNERS

University of French Guiana

French Guiana Education Authority

Directorate of Cultural Affairs, French Guiana

"Over the past twenty-five years, IRD with its social science laboratory (CELIA) and, later, SEDYL, has contributed to the promotion of poorly documented or undocumented languages (including Amerindian and Businenge languages), resulting in a better understanding of French Guiana's sociolinguistic context. This research has helped find a place for local languages in the education and teacher training system, while gaining recognition for the population's multilingualism, with a view to reducing inequalities within the department and promoting greater social inclusion."

Antoine Primerose, President of the University of French Guiana

At school in French Guiana.

Questioning the development process

In the 1980s, the development community realised that many initiatives in favour of Global South countries were partial successes, sometimes even blatant failures.

Poster for development project, Benin.

In the 1980s, IRD geographers, sociologists and anthropologists working throughout Africa realised the absurdity of certain development projects and the limited effects of many others. From then on, they started viewing development policies and projects as a research subject in its own right. They questioned the notion of development and conducted research on the interventions themselves and, more generally, on the development community, its stakeholders and institutions. Their aim was to understand how international aid and State projects became an integral part of the everyday life of societies, and what their effects were. Far from an idealised vision, they reconsidered interventions within their local context and history. They analysed the resulting conflicts.

Showing the diversity of interests in projects, questioning the political issues at stake and the inherent concept of "progress", this innovative research contributed to a renewed understanding of what "development" is. It led to the creation, in 1991, of the Association for the Anthropology of Social Change and Development (APAD), with nearly 300 members in Africa and Europe.

Researchers subsequently explored the dynamics of local organisations, the implementation of decentralisation policies, the practical operation of national administrations and health centres, public policies, etc., making major contributions towards understanding the relationships between States, societies and the aid sector, in Africa and elsewhere. This research helped engage in critical and constructive dialogue between researchers, State agents and development professionals, in the Global North as well as South. Certain development stakeholders no longer hesitate to bring in anthropologists to study the effects of their actions, and sometimes further define them.

PARTNERS

National Centre for Scientific and Technical Research, Ouagadougou, Burkina Faso

University of Abomey-Calavi, Benin

Laboratory of Studies and Research on Social Dynamics and Local Development (Lasdel), Niamey (Niger) and Parakou (Benin)

Boudouma women, Lake Chad.

The Mega-Chad network

The Lake Chad basin is a crossroad of cultures, a hotbed of plant domestication and a biodiversity hotspot, where extensive research programmes relating to life and human sciences are conducted.

In 1977, a small group of human science researchers – initially linguists and geographers – created the International Network of Multidisciplinary Research in the Lake Chad basin. This network has considerably expanded since then and now involves more than 350 researchers from more than 20 different countries. The objective of this informal network is to stimulate research on current and past populations of the Chad basin, while encouraging exchanges between researchers working on this region.

To do this, it publishes an annual newsletter online, runs a website and regularly organises scientific events touching on themes ranging from the history of metallurgy to gender relations, from economic and political organisation to death rituals, from vegetation to insecurity to educating children. The network features many disciplines and gathers knowledge of the Lake Chad basin acquired before local universities were established. By doing so, it has contributed to improving their scientific output.

The data collected by the network over the past 30 years, along with that of young local universities, is the only data available since the Boko Haram uprising and the ban on accessing this region in 2010. Projects to monitor the populations on the shores of the lake – where two million people live – can be envisaged on the strength of this database. In fact, the research conducted by this network continues to inform development programmes in this region plagued by insecurity.

In the context of the current crisis and insecurity, research on policies and local authorities, on the region's demographic challenge, on youth and communication technologies, appear to be priorities for many scientists.

Smoked fish stall, Doro Léléwa, Niger.

PARTNERS

Universities of Chad, Cameroon, Niger and Nigeria

Securing the peasants' land rights

In formerly colonised countries, the land issue is often a difficult one. Since the 1990s, the structural adjustment imposed on certain States combined with the demands of farmers and breeders have made the issue of land rights in rural areas a highly controversial topic.

Potato harvest, Ecuador.

Herder and his cattle, Benin.

In many countries of the Global South, since the colonial era only some local, national or foreign elites have been able to access property ownership, and unregistered land is considered State-controlled by law. In rural areas however, most of the land is governed by local or customary norms, which are highly dynamic but based on different principles from State law, and are not recognised under said law. The transmission of land or property does not involve any official deed. These conditions can sometimes result in the dispossession of rural populations by the State, political or economic elites. How can one prove or establish land possession in such a situation?

This dichotomy between State law and local norms became a matter of concern in the 1990s, when "informal" land rights began to be regarded as obstacles to agricultural development. There are two conflicting views. The prevailing view advocates the issuance of private property title deeds in order to reassure economic stakeholders and encourage them to invest. The other view questions the alleged links between private property and investment, and warns about the risks of dispossessing peasants. It tends to advocate the protection of the rights of farmers and breeders over the land and natural resources

"IRD's land research resonated with numerous researchers and West African experts, encouraging them to think outside the box. It served as a basis for my contribution, as land expert, to Burkina Faso's land policy; it also drove my involvement in the formulation of the African Union's guidelines on land policies in Africa."

Hubert Ouedraogo, lawyer, international consultant, former land expert for the African Union's Land Policy Initiative

••• Researchers are working to secure land rights in rural areas •••

Sorghum fields in Bassari Country, Senegal.

they cultivate, by building the capacity of the local institutions that govern land tenure.

By studying land dynamics on the ground as well as land policies and their reforms, and showing that these policies can create more land insecurity, anthropologists, economists and geographers have largely contributed to highlighting the relevance of this alternative view and have provided food for thought on how to put it into practice. Drawing from their field research, they have contributed to the debate on land policies, by developing methods to describe local rights, examining the consequences of the strategies deployed by governments, disseminating their analyses via scientific reports and publications, and participating in think tanks on land reforms, both nationally and internationally.

PARTNERS

Centro de Investigaciones y Estudios Superiores en Antropologia Social, Mexico, Mexico

Félix Houphouet-Boigny University, Abidjan, Côte d'Ivoire

Alassane Ouattara University, Bouaké, Côte d'Ivoire

University of Abomey-Calavi, Benin

Local cultures

In the 1970s, geography relied heavily on quantifiable, visible data, translatable into maps. As a result, it sometimes neglected some of the key aspects of the societies it claimed to study. This observation gave rise to alternative, more culture-oriented approaches in geography.

Kava harvest, Vanuatu.

Meal time, Tanna, Vanuatu.

Geography cannot rely solely on data collection, topographic surveys or maps; it should also take into account the symbolic or sensitive context of societies. Such was the intuition of Joël Bonnemaison, a geographer who moved to Oceania in the 1980s. Having roamed the islands to describe migratory flows and agricultural practices, he eventually focused, through long interviews, on the islanders' stories about the world and their perceptions of the environment.

Departing from the functional sphere of geography up to that time, he took an interest in invisible information, blurring the line between geography and ethnology. By doing so, he tossed aside quantitative and material notions to focus on emotional and qualitative concepts. He opened up a field of research where spatial analysis is enhanced by the vision and symbolism of societies. He promoted a form of geography seen through the prism of local culture.

On Tanna Island, in the Vanuatu archipelago, he heard the founding story of an ogre who was torn apart, whose head, torso and limbs fell in various places on the island, imbuing them with long-lasting symbolism, making it impossible for islanders to conceive of one section of the island independently of other sections. Similarly, long mythical narratives explain the origin of the sacred stones which adorn the entire island and are the source of vital knowledge for the local society.

By focusing of these stories and meaningful locations, the researcher developed the concept of "geosymbols". He explored the carnal link that unite people to their territory. With subsequent analyses inspired by endogenous views of space, he paved the way for a cultural approach to geography in France. His vision was adopted by the academic community in France as well as Quebec and in the rest of the world.

PARTNERS

Communities on Tanna Island

Honey collection by Baka people, Cameroon.

The evolutionary history of mankind

After focusing on human morphology, food and diseases, biological anthropology went on to examine the issue of genetics, exploring the means of adaptation and the origin of populations.

Man is an animal like any other. Human beings evolve and adapt to their environment over the long term. To examine this adaptation phenomenon, a multidisciplinary study was carried out in Cameroon from 1983 to 1993. Why Cameroon? Because the country features most African ecosystems (desert, forest, savannah, high altitude) and 240 different languages and thus different human populations. Over a period of 10, researchers identified the resources available, cooking recipes, the calorific intake, the growth of individuals, the diseases present, etc.

Among other results, they showed that 20% to 25% of Cameroonian children suffered from malnutrition, regardless of their living environment, but for different reasons. Researchers explained this finding by the fact that, while food is plentiful in the forest, so are pathogens, which hamper children's development. In dry environments (savannah or desert), food is harder to come by but the parasite load is lower. Children are healthier even though their diet is not as good. This finding helped adapt targeted strategies to combat malnutrition.

In the early 2000s, anthropologists took an interest in the biological diversity of populations and established a genetic map of Cameroon. Three major groups stand out: Bantus, Sahelians and Pygmies. Working with climatologists, researchers traced the history of Pygmies, a population characterised by their small size who have adapted to life in the forest. As a result of major climate cycles which sometimes reduced and fragmented African forests, Pygmies experienced isolation phases for hundreds of centuries, which explain their dispersion and current morphology.

In the past few years, research has focused on exposure to wildlife, notably the frequency of contacts between apes and humans, the objective being to pinpoint and identify those viruses likely to be transmitted by contact with game, and those which could be responsible for the emerging diseases of tomorrow.

Traditional huts, Baka Pygmies, Cameroon.

PARTNERS

Cameroon's Ministry of Research

Migration in 3-D

Migratory flows regularly hit the general media headlines, but less often those of scientific journals. And yet, innovative scientific approaches are currently revolutionising the understanding of these population movements.

Truck full of migrants returning to Niger.

A migratory flow often comes down to a line or an arrow on a map. This is a very simplistic vision of reality, as attested by the variety of migrants' accounts collected during a field study conducted on Trans-Saharan routes. There must be a way to grasp the diversity of migration situations and reveal the different experiences of migrants, experiences which alter the course of their lives and often make them vulnerable. Reflection was initiated to develop a new representation of migration patterns, notably by visualising the resources consumed by migrants and changes in their status according to the national and international regulations applicable to the countries they pass through.

A partnership was subsequently established with a team of computer scientists to determine how to use the migrants' individual stories to shed light on migration patterns. Extracting a migration pattern from textual data is a major scientific challenge. This information was mined by a number of IT tools and modelled in the form of graphs which notably represent the space, time and resources of the migration pattern. By doing so, the team highlighted points of convergence, i.e. the pitfalls and opportunities which mark migration patterns.

This representation of migration sites and stakeholders, based on the IT ontology model, reflects the actual complexity of migration patterns and shows the diversity of social, political and economic processes involved. It confirms, among other things, that the outsourcing of border control by Global North countries to the border points of the countries of origin and transit is what propels migrants into illegality on southern routes.

PARTNERS

CNRS, France

Paris-Descartes University, France

Artois University, France

University of Poitiers, France

Wood supply in a refugee camp, Kenya.

A world of encampments

The number of migrants worldwide has risen from 150 million in 2000 to 250 million today.

In the late 1980s, demographers and geographers began to develop an interest in the relationships between migrations and development. Then in the 1990s, African crises resulted in the emergence of refugee camps. Researchers showed that these closed structures, managed by non-governmental organisations, had effects on the environment as well as on the local economy, as neighbouring villages indirectly benefit from international aid. Because these were new structures – settlements with a population ranging from a few hundred to tens of thousands, growing and changing in a confined environment – anthropologists undertook to study their internal dynamics from 2000 to 2008.

They made it clear that these rough-hewn towns could have positive effects, notably by encouraging children's schooling or multilingualism, habitat conversion or the emergence of new forms of sociability. They also raised issues about the long-term outcome of confined populations. How can one grow, study or project oneself into the world if one cannot leave the camp? How to envisage a return after such an ordeal?

These questions led the United Nations High Commissioner for Refugees (UNHCR) to create, in the early 2010s, a commission working on alternatives to refugee camps. Camps can be seen as emergency solutions adopted by the States or the international community pending other sustainable solutions, which however seldom materialise. With "encamped" populations left hanging for years, if not decades, marginal forms of urbanisation, politicisation or "ghettoisation" can stem from this confinement. The social, urban and political recognition of the rights of these populations would help open up the camps and improve the integration of the 15 million refugees and displaced persons currently living there.

Somali children, Saint-Annes camp, Kenya.

PARTNERS

Médecins Sans Frontières

African forms of Christianity in Morocco

Religious activities evolve in step with migrations and encounters. This process is currently underway in Morocco, driven by African migrations.

Service at the Evangelical Church of Rabat, Morocco.

Temple in a migrant camp, Morocco.

Morocco is a Muslim country where freedom of religion is only possible for Moroccan Jews and foreigners. This situation was altered by the country's new migration policy which, from 2015 to 2018, regularised the status of nearly 50,000 migrants from sub-Saharan Africa, most of Christian faith, from sub-Saharan Africa. This regularisation enriched the country in many ways, notably by questioning religious practices. Churches, which had fallen into disuse since the end of the French protectorate, started filling up again, and this Christian dynamic had to find its place.

This resulted in the reorganisation of Christianity in Morocco, as well as a theological renewal. To limit the uncertainties generated by the massive influx of Christians, a few Christian religious leaders from France and sub-Saharan Africa created an Institute of Theology in Rabat, training clerics capable of running the country's many, often informal churches. This institute was studied in situ by an anthropologist to understand how religion is shaped by migration realities.

Within the Al Mowafaqa Institute, future leaders are trained in Protestant and Catholic theology for four years while also studying Islam, Judaism, religious history and languages such as Hebrew, Greek and Arabic. The objective is to support Christian leaders in a land reconnecting with Christianity, which had thus far been extinct or remained hidden but is re-emerging with migrations and whose identity is built in relation to others, local society and Islam.

These changes also question the cultural and religious principles of Moroccan society. In March 2019, the King of Morocco, Commander of the Faithful, invited the pope to meet so that they could discuss topics that run through their religions, including issues relating to migrations, welcome and hospitality.

PARTNERS

Movida LMI (Mobility, travels, innovations and dynamics in Mediterranean and sub-Saharan Africa), Morocco-Senegal-Burkina Faso-Niger

International University of Rabat

Invisible health trajectories

People do not fall ill for no reason: the context or life course may have an influence. This is what led health experts to use demographers' tools to detect unsuspected risk factors.

While sub-Saharan immigrants represent 1% of the French population, they account for 40% of new HIV cases detected. For a long time, this fact came as no surprise. As the African continent is particularly affected by the AIDS virus, it made sense that more cases would be found in migrants from this continent. This obvious fact however turned out to be wrong, as demonstrated by researchers in 2015 after they studied migrants' life courses. To this end, they applied tools developed by demographers to the health sector in order to carry out a statistical analysis of professional or family backgrounds. They interviewed approximately 2,500 African migrants and coded their responses for quantitative comparison purposes.

Against all odds, the results showed that one third to one half of Africans living in France with the HIV virus were infected post-migration, i.e. on French soil. The virus is often transmitted in the early years, when the migrant's situation is precarious. Lack of housing is a major risk factor, particularly in women who sometimes enter into transactional sex relationships. In addition, women who were infected with the AIDS virus in France are four times more likely to have been subjected to sexual violence.

These results were used by the French Ministry of Health to better target prevention and screening campaigns. The methodological innovation has gained widespread acceptance, as it was applied to other research fields and showed, for example, that in Cameroon physically or mentally disabled people are at greater risk of HIV infection, with marked differences between men and women.

Furnished hotel in Belsunce, a district with a strong presence of new migrants, Marseille.

PARTNERS

Institute for Demographic Research and Training, Cameroon

Aides Association

Network of African and Caribbean AIDS prevention associations in the Île-de-France region

Medical Committee for Exiles, France

Inserm, France

Migratory links

The links migrants maintain with the families and friends they leave behind are not always easy to qualify or quantify. Analysing these relationships helps us understand migration factors as well as the impact of these displacements.

Returning migrant, Burkina Faso.

To understand the impact of migrations, it is not enough to just focus on the people who migrate. One should also look at what happens to those who stay at home. To understand the links between these two populations, in 2007 a team of researchers took an interest in Senegalese migration, which has a wide variety of profiles. A simultaneous survey was initiated in four hosting countries: France, Italy, Côte d'Ivoire and Mauritania. In each of these destinations, investigators asked 300 Senegalese migrants about their situation and that of their loved ones back home. Based on the information supplied by the migrants, they found the families in Senegal and asked them about the conditions under which the journey was undertaken and their perception of the migrant's living conditions. This was the first time they had managed to obtain a set of matched data for some of the migrants.

In addition to shedding light on the amounts of cash transfers made by migrants and on the processes implemented to guarantee their regularity (including the social control exercised by early settlers in receiving countries), the survey showed that the migrants' perception of the material situation of families back home, and the families' perception of the migrants' lives, were both flawed. While families do not know much about the migrant's situation, migrants tend to overestimate the family's wealth, partly because the money sent to make investments or purchases is not spent as they thought it would be.

This explains the recent development of tools (trading platforms and smartphone applications) allowing migrants to have foodstuffs delivered to their loved ones or collect vouchers from authorised traders, thus making sure they retain control over how the money they send is used. One of these tools is Ethicphone, a start-up company incubated by Bond'innov, of which IRD is a founding member.

PARTNERS

National Agency of Statistics and Demography (ANSD), Senegal

Vivid memory of the bombing, Laos, 1994.

Displaced minorities

Fifteen years after the end of the Vietnam War, part of Laos was a minefield… which was home to highland ethnic groups. The government initiated their mass displacement in the 1990s. This decision had disastrous consequences that international aid was called upon to finance.

In Laos, the Vietnam War did not really end in 1975. For the ethnic minorities who lived in the mountains (50% of the population), particularly in the South, the most heavily bombed region in history, it continued with the presence of more than 80 million unexploded cluster bombs. In 1993, an ethnologist settled in remote villages to study the social and cultural impact of the war. He witnessed the sudden displacement of entire villages to lowlands and their precarious settlement on the roadside. The idea was to facilitate their access to education and health services, which were incidentally non-existent. Having sounded the alarm about the appalling conditions of these large-scale displacements, he managed to get UNDP, in conjunction with Unesco, to entrust Orstom with a survey in 1996 to assess the situation on a national level.

For 10 months, a multidisciplinary team – ethnologists, agronomists and economists – assisted by local education officials studied the fate of more than 1,000 families from 70 relocated villages, in six provinces. This was the first major social survey in a country that was not very open to research. It resulted in an extensive report with catastrophic conclusions. Published in June 1997, it showed the consequences of a hasty authoritarian policy, notably the very high malnutrition and mortality rates among these mountain people, who were suddenly cut off from their ecosystem and cultural environment. As a result of this report, major donor countries made their support for Laos conditional, forcing the government to restrict relocations, justify them or improve their preparation. Furthermore, this research played a pioneering role in the study of contemporary mobility in continental South-East Asia and that of the risk of rapid acculturation associated with the displacement of ethnic minorities.

Forced displacement, Kantu minority, Laos, 1995.

PARTNERS

Ministry of Education, Ministry of Health, Academy of social sciences of Laos

UNDP, Unesco, NGOs (MSF, ACF, ESF, CCL)

CNRS, EFEO, University of Hong Kong

Yes to triple therapy in Africa

In 1996, triple antiretroviral therapy became an effective way to treat AIDS, which was downgraded from a deadly disease to a chronic disease. At least in the countries of the Global North. In the Global South, where the vast majority of patients live, this treatment was not on the cards.

AIDS research, Yaoundé hospital, Cameroon.

Triple therapy was considered too expensive (EUR 1,500/day) and too difficult to manage to be applied to Africa. It was assumed that hospital teams would be unable to manage the administration of medication at regular times or the side effects generated. To put this misconception to rest, in 1998 a Senegalese physician convinced his government to fund a pilot project designed to test triple therapy on 400 patients. With help from IRD, he proved that triple therapy could be implemented in Africa with some minor adjustments, notably in terms of medication to be administered in the evening rather than at lunchtime to protect medical confidentiality. This practice was subsequently adopted by the countries of the Global North. The demonstration came into its own in 2000 when, during the Durban conference, politicians and NGOs managed to drive the price of triple therapy down by 80-90% as part of the Access programme, which targeted Senegal as one of the pilot countries.

Generic triple therapy drugs appeared that same year, although donors and international agencies were reluctant to purchase them for lack of scientific assessment. This is why, from 2000 to 2002, in Cameroon this time, IRD researchers demonstrated the effectiveness of generic antiretroviral drugs, the purchase of which subsequently quadrupled.

In addition, from 2002 to 2004, they showed that the level of HIV must be monitored in treated patients to prevent the emergence of resistance. This analysis was not commissioned by the Worl Health Organisation (WHO) for cost reasons. IRD continues to play a prominent role in AIDS control in Africa as the Institute and its partners are currently assessing first-line therapies, in a continent where patients are still too late in seeking treatment, and where 45% of HIV patients are not treated.

PARTNERS

Senegal National AIDS Programme (PNLS), Dakar, Senegal

Central Hospital of Yaoundé, Cameroon

AIDS prevention campaign, Cameroon.

"The partnership between IRD and developing countries in research into universal access to antiretroviral therapy in Africa, which is well into its second decade, fits into a pattern of performance, proactivity, innovation, efficiency and sustainability. It has helped train high-level French and African researchers: clinicians, virologists, immunologists, epidemiologists, health economists, etc."

Dr Ibra Ndoye, coordinator of Senegal's ANRS site and former director of Senegal's National AIDS programme

Being born without HIV

In the early 1980s, the HIV epidemic was already well established in Africa and was beginning to spread to Asia. In Thailand, it took the form of a generalised, heterosexual epidemic in urban and rural areas. It became imperative to develop simple prevention and treatment methods.

Caring for a baby infected with HIV, Thailand.

In the 1990s, researchers in Thailand initiated clinical research on pregnant women suffering from HIV. With more than one million people infected at the time (2% of the population), Thailand was the Asian country most affected by the epidemic. Inspired by the results of a Franco-American study published in 1994, they devised a simplified method to prevent the perinatal transmission of HIV for the benefit of women in developing countries. This study began in 1997 with the financial support of the US National Institutes of Health (NIH) and the logistical support of the Thai government. The simplified protocol proved to be as effective as the original, relatively heavy Franco-American protocol, which included zidovudine infusions during childbirth and five oral doses per day for five months. Thailand and other countries immediately began to use the results of the new protocol.

••• A medical protocol to prevent mother-to-child transmission of HIV •••

That was when a joint South African and US team showed that administering nevirapine to the mother during delivery and to the newborn child helped reduce transmission by 50%. IRD researchers and Thailand's Ministry of Public Health decided to combine zidovudine with nevirapine in the treatment. This new protocol, which helped reduce the transmission rate to 2%, was recommended from 2004 by the WHO until triple therapy drugs became available in resource-constrained countries to treat the mother and prevent the transmission of HIV to the child.

PARTNERS

Universities of Chiang Mai and Mahidol, Thailand

Inserm, France

Harvard School of Public Health, USA

“Collaboration between Chiang Mai University and IRD was instrumental in accelerating access to the prevention of the perinatal transmission of HIV in Thailand and all resource-constrained countries. It also contributed to a better understanding of underlying mechanisms.”

Wasna Sirirungsi, virologist, Dean of the Faculty of Associated Medical Sciences at Chiang Mai University

Generic antiretroviral drugs distributed in Thailand.

Replaying and changing the scene

At the start of the century, 800,000 women died in childbirth every year worldwide, i.e. 2,100 every day. Of these deaths, 90% occur in Africa, where access to care is often expensive and poorly organised, and thus unaffordable for rural populations.

Health centre in Benin.

Mali and Senegal entered the second millennium with the unenviable record of the highest mortality rate from childbirth. In these countries, 800 women died every 100,000 deliveries, compared with 10 in France, for example. In most cases these were young women, aged 15 to 25, who did not survive the birth of their first child, due among other things to the poor quality of healthcare received. Hence the idea of the "Quarite" project, initiated by IRD and conducted in partnership with local health authorities.

In 2007, researchers randomly selected 46 hospitals in Mali and Senegal and monitored their healthcare system for one year, as well as the mortality rate of women and children. The following year, they intervened in half of these hospitals, reminding teams of good practices and, more importantly, implementing "death reviews". The purpose of these meetings was to piece together the history of the deceased patient, from her arrival to her death. The objective was to identify not so much the guilty parties but the problems that occurred, as well as solutions which could be tested to avoid a repeat performance, for example by facilitating access to certain medications and addressing work overload issues.

In 2011, the assessment of these measures highlighted spectacular results: in the hospitals supported, the mortality rate for women

"As a result of the Quarite project, the quality of care is assessed more objectively, as it is based on standardised quality criteria. It has also prompted individual and collective questioning, as well as a readiness to change attitudes to encourage positive responses."

Sabine Liliou, gynaecologist, Bogodogo district, Burkina Faso

••• The implementation of "death reviews" helps lower mortality rates among women by 15% in the referral hospitals of Mali and Senegal •••

Mural painting at the entrance to the maternity ward of the Popenguine health centre, Senegal.

dropped by 15% on average, and by 35% in rural hospitals, while the infant mortality rate decreased by 26%. This effect was so significant that Malian and Senegalese authorities immediately decided to expand the programme nationwide. And the WHO took up the idea in 2014: death reviews are now conducted in most African countries. Thanks to this type of initiative, the mortality rate from childbirth in Africa has been halved since 2007.

PARTNERS

Ministry of Health of Mali and Senegal

Society of Obstetricians and Gynaecologists of Canada

Malian Society of Gynaecology and Obstetrics

Faculty of Medicine of the University of Bamako, Mali

University of Montreal, Canada

A sugar paste to combat hunger

In the 1990s, 165 million children under the age of five, i.e. one in four children, were underweight.

Plumpy'nut delivery in Haiti.

In 1993, during a conference organised by several NGOs in Paris, IRD presented a food formulation likely to respond to the nutritional needs of underweight children under five. Nutriset, a company based in Normandy, was immediately interested in the idea as they were seeking to manufacture effective renutrition foods readily available to NGOs in hot climates. This marked the beginning of a close partnership between IRD and Nutriset.

While the initial idea was to manufacture a milk-based liquid, the format proved to be difficult to use in the field. After several unsuccessful attempts, the concept of a peanut-based sugar paste eventually emerged and, in 1997, the first Plumpy'nut product was tested in Kenya. A patent was filed by IRD and Nutriset. It was not until 2005 and a devastating famine in Niger, however, that product distribution actually began. In 2007, this sugar paste that children find easy to eat was recognised and certified by the UNDP, Unicef and the WHO.

Very easy to use, Plumpy'nut contains milk, sugar, vegetable oils, mineral salts and vitamins. It can withstand the climatic conditions specific to Africa and can be directly administered by the mother, without water and without medical supervision. In addition, in 2005 a network of entrepreneurs based in the countries of the Global South, PlumpyField, was launched to allow local branches to also produce and distribute this food. In this regard, Nutriset contributed its expertise to the quality assurance of the nutrient-rich paste. In 2010, the patent was made available to developing countries on the Internet. In 2016, more than

"Plumpy'nut is really effective and useful for the treatment of severely malnourished children, who can follow the treatment at home, thereby allowing us to reach many children at once."

Noël Marie Zagré, Unicef Niger's head of nutrition

Manufacturing Plumpy'nut in Niger.

••• In 1997, IRD and Nutriset created Plumpy'nut, a ready-to-use peanut-based paste. A revolution in the fight against malnutrition •••

43,000 tonnes of nutritional products were sold by Nutriset, which helped treat an estimated 2.5 million children suffering from acute malnutrition, a significant contribution to improving the everyday food self-sufficiency of the most vulnerable populations.

PARTNERS

Nutriset, French company specialising in the research, development and production of food for the treatment of malnutrition in the countries of the Global South

Preventing the effects of malnutrition

Every year, malnutrition kills three million children under the age of five and causes stunted growth and limited intellectual development in nearly one in two affected children.

Child eating enhanced gruel, Burkina Faso.

Training in the preparation of fortified gruel, Madagascar.

PARTNERS

Gret NGO (Professionals for Fair Development)

Universities, research centres and government authorities in charge of nutrition

United Nations Children's Fund (Unicef), World Food Programme (WFP), World Health Organisation (WHO), United Nations Food and Agriculture Organisation (FAO)

Local food companies

While chronic malnutrition may go unrecognised, its consequences may not, notably in children under the age of two, whose physical and cognitive growth can become permanently stunted. In 1994, this resulted in the search for a concrete expression of certain results of research conducted by nutritionists from the Institute, by encouraging them to work with the Gret NGO (Professionals for fair development) to launch the Nutridev programme. The three objectives of this programme were to raise awareness of better nutrition practices, make appropriate food accessible to a wider audience and improve health services.

In Madagascar, the initial idea was to develop recipes so that mothers could prepare enhanced gruel themselves, independently and economically, based on local ingredients. However, the required procedures were too restrictive to be followed on a daily basis. Hence a change of strategy, and the agreement signed with a local company in 2002 for the production of flour (Koba Aina) made from maize, rice and pulses, used to prepare gruel intended to supplement breast milk from the age of six months.

Over the same period in Vietnam, fortified rice flour was produced by State-owned and private companies until 2007. In Burkina Faso, the production of complementary foods was entrusted to local small businesses.

••• For the past 25 years, the Nutridev programme has developed innovative solutions for children under the age of two and women of child-bearing age with a view to preventing chronic malnutrition in young children •••

Today, Gret continues to help some 20 local companies worldwide to produce quality fortified foods, developed in conjunction with nutritionists. These very economical foods, tailored to nutritional needs and

"Since 2013, I have run the Nutri'zaza social enterprise, which implements, in close partnership with Nutridev, a sustainable strategy recognised as effective in the fight against chronic malnutrition in Madagascar. To this end, the training I received from IRD researchers in the early 2000s during my Master's internship, combined with the experience I gained subsequently by participating in various Nutridev research-action projects has been really helpful to me."

Mieja Vola Rakotonarivo, head of the Nutri'zaza social enterprise, Madagascar

Production of therapeutic food in Vietnam.

local eating habits, are promoted and sold to families through a variety of distribution channels. In Madagascar, the Nutri'zaza social enterprise, created in 2013, employs approximately 100 women who work in children's nursery and mobile sales networks. Over the past 25 years, the programme has provided children from more than 10 countries with over 30 fortified foods produced by some 40 local companies.

Combating deficiencies

Iron deficiency is a major public health issue which can stunt children's physical and cognitive growth, damage the immune system, cause job losses in adults, and have a significant impact on the development of societies.

Preparation of therapeutic food for the treatment of malnutrition, Vietnam.

"There is no anaemia in Bolivia." In the 1990s, this quote from a Unicef report caught the attention of Orstom, who had just completed a research programme on anaemia in Togo. An epidemiological study was launched, showing that 40% to 60% of Bolivians were actually anaemic and suffered from iron deficiency. If their haemoglobin level is high, it is primarily because they live at a high altitude, which introduces a bias in the diagnosis of anaemia.

A comparative trial was undertaken, whereby Bolivian children were given iron every day or every week, in a pill or in an iron-fortified traditional beverage made from grain. Results suggested that the weekly taking of pills was as effective as their daily intake, which is however the treatment recommended by the WHO to this day. In addition, the fortified beverage had the same impact as the pills. Sold by a local producer, this beverage was not as successful as expected, due to the lack of an information campaign targeting the population.

In 1998, the team continued their research in Vietnam. Several trials were initiated on infants and pregnant women, with new types of supplement. Results showed that a weekly intake of iron/folic acid started two months prior to conception and maintained during pregnancy had a greater impact, in terms of birth weight, than daily supplementation.

Researchers subsequently tested an iron-fortified nuoc-mâm and demonstrated that its consumption under actual conditions within the population helped eliminate iron deficiency within one year. Building on this result, they created and assessed the impact of food supplements for infants and young children based on local products, first in Vietnam and later in Cambodia, with a fish paste that is, very much appreciated in this country.

PARTNERS

Bolivian Institute of High Altitude Biology, Bolivia

Ministry of Health, Vietnam

Ministry of Agriculture, Ministry of Health and Unicef, Cambodia

Organisation for coordination and cooperation in the fight against major endemic diseases, Togo

International institutions and NGOs: ILSI, GAIN, Gret, WFP, Unicef, WHO, IAEA, etc.

••• From Bolivia to Cambodia, fortified local products are used to combat micronutrient deficiencies •••

© Maja Berg

Sale of fortified nuoc-mâm, Vietnam.

"Combating micronutrient deficiencies in pregnant women and young children is the only way to put an end to the generational cycle of malnutrition. The work done by IRD and the National Institute of Nutrition in Vietnam showed that it is possible to tackle this issue in a relatively short time, and was used as a model for other Asian countries."

Professor Le Danh Tuyen, director of the National Institute of Nutrition, Vietnam

Preventing obesity in the Maghreb

Over the past few decades, Maghreb countries have experienced the combination of globalisation, urbanisation and rapid socio-economic development. Related lifestyle changes have resulted in a diet higher in calories, fat, sugar and salt, and with more processed food. As a corollary, there has been a sharp rise in obesity and related chronic diseases (diabetes, high blood pressure, cardiovascular diseases).

Grocery store in Tunisia.

To quantify the burden of obesity and related diseases, joint projects have been undertaken since the early 2000s, primarily in Tunisia but also in Algeria and Morocco. For example, researchers showed that more than one third of women were obese, and more than two thirds were overweight, while for men the proportions are reduced by half. The origin of this discrepancy, which does not exist in Europe, seems to be essentially social, as it decreases noticeably with the level of education and occupational activity. Lifestyles likely to induce obesity do not necessarily protect against nutrient deficiencies: many women with excess body fat also have deficiencies, notably iron-related. However, this nutritional transition may not be all bad: a study of Tunisian adolescents shows that the modernisation of eating habits can improve food quality by increasing its variety, but that said, quality decreases when the proportion of foods which can induce obesity and chronic diseases increases too much.

••• The definition of public health interventions first requires quantifying the problems before analysing the causes and proposing appropriate prevention actions •••

"Action-oriented research in the partnership between IRD and the National Institute of Nutrition and Food Technology contributed to a better understanding of Tunisia's health and nutrition problems, and to the formulation of appropriate intervention policies and programmes."

Professor Jalila El Ati, department head in charge of the SURVEN laboratory (nutritional surveillance and epidemiology in Tunisia), National Institute of Nutrition and Food Technology, Tunis

© IRD/P.Traissac

Cooking oil advertisement, Tunis.

For prevention purposes, in Morocco and Tunisia proposals made by ministries, health centres and the private sector, notably agribusiness, were collected during computer-aided interviews and analysed. The objective was to identify, among a number of potential actions, those that could garner consensus.

All this research was translated into the Tunisian government's national strategy on tackling obesity. A series of measures, ranging from the funding of sports grounds to the certification of bakers making less salty bread, were tested as part of a pilot governorate, prior to nationwide deployment.

PARTNERS

National Institute of Nutrition and Food Technology, Tunisia

National Institute for Public Health, Tunisia

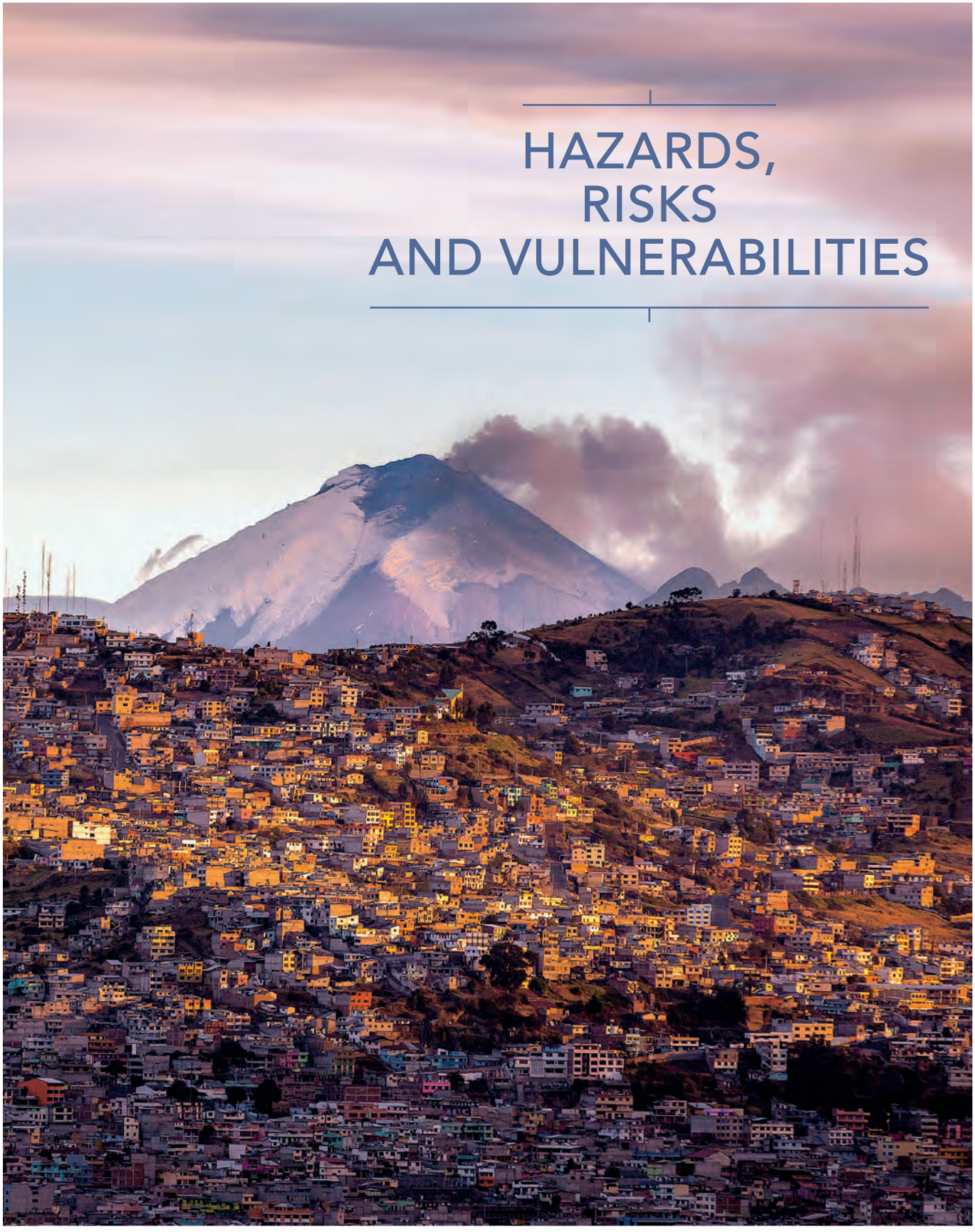
Ibn Tofaïl University, Kenitra, Morocco

National Institute for Public Health, Algeria

PART 2

Malaria, sleeping sickness and, more recently, AIDS, Ebola, chikungunya, etc.: the diseases that ravage the countries of the Global South are the focus of IRD's research. The idea is to understand, prevent and control tropical diseases based on the results of research, but also to assess their environmental, social and human determinants and translate the scientific knowledge gained into operational terms for the populations. Societies of the Global South are also particularly vulnerable to natural disasters. Many IRD programmes are dedicated to these disasters, as well as to the various forms of pollution of anthropogenic or natural origin. All this research leads to concrete improvements in the health, safety and well-being of the populations of the Global South.

HAZARDS, RISKS AND VULNERABILITIES



Niakhar: sentinel area since 1962

In developing countries, reliable demographic and epidemiological data is rare, which undermines the establishment of appropriate health and social measures. Hence the idea of collecting data in geographically localised areas, allowing for long-term monitoring.

Study on infant food, Niakhar.

In 1962, an idea emerged in the basement of the Dakar Statistical office in Senegal: to implement systems, in collaboration with Orstom, to monitor the rural population, whom the authorities knew little about at the time. Two sites, Paos-Koto and Niakhar, were selected and subjected to systematic surveys, where researchers collected data relating to births, deaths, migration and health, but also indicators for nutrition, education, cropping practices and the environment. While the Paos-Koto observatory was shut down in the 1980s, that of Niakhar, south-east of Dakar, is still operational and provides one of Africa's longest and most important sets of data in terms of demographic and epidemiological monitoring.

In 1965, researchers realised that measles caused high mortality. They organised a vaccination campaign and assessed its effectiveness. This was a major success, which was followed by the establishment and testing of other treatment protocols against pertussis, meningitis and malaria. This led to the conversion of the Niakhar observatory into an open-air laboratory, used to assess data collection methods as well as the required health measures.

This tool was also used to study social and family changes, while monitoring trends in a population that increased from 23,000 in 1983 to 45,000 in 2017. It has made it possible, for example, to conduct studies on social networks and their impact on health behaviours, or to assess the quality of nationwide surveys. The Niakhar site was the first of its kind and now belongs to a network of 50 observatories created in the late 1990s in Asia and Africa, three of which are managed in Senegal by IRD: Bandafassi, Mlomp and Niakhar.

PARTNERS

Ministry of Health of Senegal

National Agency of Statistics and Demography, Senegal

Cheikh Anta Diop University, Dakar

Cirad, France

••• The Senegalese government and Orstom created one of Africa's first population observatories •••

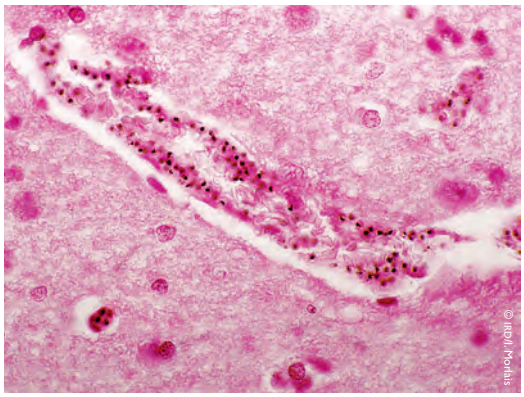
Information meeting for a vaccine trial, Niakhar, 1992.

"The world-famous Niakhar site, through extensive research and multiple scientific productions beneficial to the African continent and beyond, attests to the health, demographic and human history of our country, the foundations of which it was instrumental in building."

Professor Awa Marie Coll Seck, Minister of State to the President of the Republic of Senegal

Genealogy of *Plasmodium*

Malaria affects 220 million people and kills nearly 450,000 people each year. It is the most widespread parasitic disease in the world and 90% of cases occur in Africa.



Brain capillaries affected by *Plasmodium falciparum*.

Ten years ago, it was believed that there were only two *Plasmodium* species, the parasite responsible for malaria. One, *Plasmodium falciparum*, was supposedly specific to humans and the other, *Plasmodium reichenowi*, to chimpanzees. In 2009, a Gabonese researcher detected a third species in the blood of a baby chimpanzee, named *Plasmodium gaboni.* Could there be others yet?

To find out for sure, Gabonese researchers along with their IRD and CNRS partners embarked on a study of parasites found in primates. As primates were difficult to capture, the team initially focused on their droppings. Previous research on HIV had shown that primate faeces could contain degraded versions of the virus. So why not traces of *Plasmodium*?

Despite the doubts of the international community, researchers continued their research and analysed hundreds of droppings from chimpanzees and gorillas living in Central Africa. This is how several new species of *Plasmodium* were discovered, which helped demonstrate that the parasite probably existed at the time of the common ancestor shared by all hominids. Better yet, in 2018 a close "cousin" of human *Plasmodium* was identified in gorillas.

This had major consequences: despite the existence of several species of *Plasmodium*, only *P. falciparum* can infect humans. By comparing the genomes of different species of *Plasmodium*, particularly those found in gorillas, it should be possible to detect the genes specific to humans, the expression of which could then be blocked by a vaccine or drug. This offers immense hope and explains why IRD researchers are currently involved in health monitoring operations carried out in chimpanzee and gorilla sanctuaries. The objective is to collect a little blood in the hope of finding *Plasmodium* so that they can understand the key processes involved in the infection of hosts.

PARTNERS

Franceville International Centre for Medical Research, Gabon

Medical Research Centre, Yaoundé, Cameroon

University of Alabama, USA

Sanger Institute Malaria Programme, UK

CNRS, France

“This research is an example of productive North/South partnership, the Global North contributing its expertise and the Global South the biological material and availability of researchers, which brings about a transfer of technology resulting in an important discovery. This new data on malaria calls for vigilance in endemic areas, because of the possibility of germ transfer between humans and apes, while also giving new hope in the search for a vaccine against this old disease which claims more lives every day in my country!”

Dr Benjamin Ollomo, Franceville International Centre for Medical Research, Gabon

Gorilla, Lékédi Park, Gabon.

••• At least eight species of *Plasmodium*, the parasite responsible for malaria, were discovered in great apes in Africa •••

The mosquito net revolution

With impregnated mosquito nets, IRD invented an effective way to control mosquitoes carrying malaria pathogens, notably reducing transmission, the number of cases and child mortality.

In front of the mosquito net, Benin.

According to a 2015 WHO report, 457 million cases of malaria were averted thanks to the use of insecticide-treated mosquito nets. This remarkable result was partly due to the hundreds of millions of long-lasting impregnated mosquito nets widely distributed in malaria infected areas over the past few years. To this day, pyrethroid-treated mosquito nets are still the only truly operational vector control method, guaranteeing personal, family and community protection.

It all began in 1983 in the medical entomology department of Bobo-Dioulasso's Muraz centre in Burkina Faso, when a team of medical entomologists tested a new control method aimed at killing mosquitoes before the bite, when the conventional method (insecticide on the walls) killed mosquitoes after the bite!

It was a simple technique: soaking mosquito nets in a basin containing water and a pyrethroid insecticide (permethrin). After hanging these impregnated mosquito nets in experimental huts of the Soumousso station, researchers found that they greatly reduced contact between humans and mosquitoes: they limited the amount of mosquitoes coming in, killed many of those who got in and increased the exit rate, thereby preventing sleepers from being bitten. That was the desired goal!

This team then carried out initial epidemiological assessments in Burkina Faso, demonstrating that impregnated mosquito nets reduced the transmission of malaria parasites by 90% and the number of cases in children by 50%. At the time, however, the majority of the scientific

"From 2001 to 2015, more than 663 million cases of malaria were averted thanks to various control operations. Insecticide-treated mosquito nets had the greatest impact, accounting for 69% of averted cases, according to official estimates."

Extract from the WHO's press release, World Malaria Day, 25 April 2017

••• In the 1980s, the development of pyrethroid-treated mosquito nets revolutionised malaria vector control methods. •••

Checking a mosquito net, Benin.

community was sceptical, being more hopeful about the "impending" discovery of a malaria vaccine – which is still pending.

Following the first scientific publication of these results in 1984, researchers from various organisations came to Bobo-Dioulasso to learn about the technique, after which they developed control programmes in several countries, confirming this reduction in transmission and a 50% drop in malaria morbidity.

A wide-ranging study was subsequently conducted in Gambia, Ghana and Kenya, demonstrating that widely used impregnated mosquito nets reduced overall infant and child mortality by 20%. This key argument gave fresh impetus to vector control and the integration of impregnated mosquito nets into national malaria control programmes.

Encouraged by these results, in the 1990s industrial companies started manufacturing "long-lasting" impregnated mosquito nets (lasting three to five years), currently distributed on a very large scale in malaria infected countries with great success.

PARTNERS

Muraz Centre, which became Burkina Faso's Public Institute for Health Research

Preventing malaria intermittently

In the fight against malaria, the prevention battle must still be waged. Vaccination, which is probably essential for the eradication of malaria in Africa, is still unavailable although it has been repeatedly announced for the past 40 years.

Flooding resulting in the development of larval habitats for anopheline mosquitoes, Dakar, Senegal.

Distribution of a treatment to prevent malaria, Niakhar, Senegal.

Malaria kills, particularly children under the age of five. In the absence of vaccine, these children are not easy to protect at birth and as they grow up in malaria endemic areas. For a long time the preferred option was to administer a very stringent preventive treatment children had to take every day, which was not easy… or relevant in the long term, as this approach induced the emergence of resistance. Furthermore, a full year of therapy seems unnecessary in the Sahel region, where the risk of malaria transmission is seasonal, as the malaria-carrying mosquito is only present from September to November.

In the 2000s, this situational analysis prompted researchers to devise a more suitable intermittent treatment. They readjusted the protocol in force for pregnant women and infants, and tested it in Senegal on 1,200 children in 2002 and 2,000 children in 2004. By doing this, they showed that taking one to three doses of artesunate and sulfadoxine-pyrimethamine within one month of each other during the peak transmission period helps reduce the risk of infection in children under the age of five by 86%, without causing any serious side effects. From 2008 to 2010, a larger-scale assessment was carried out on some 200,000 Senegalese children. This protocol was strictly adhered to and helped reduce the percentage of infected children from 30-40% to 2%.

It was such a success that this intermittent approach, referred to as seasonal malaria chemoprevention, has been recommended since 2012 by the World Health Organisation. It is currently implemented in the Sahel as well as all regions where at least 60% of transmission cases occur over a four-month period, with a view to protecting more than 34 million children under the age of five. This preventive approach is now a priority of the national malaria control plans of several countries.

PARTNERS

Cheikh Anta Diop University, Senegal

Senegal's National Malaria Control Programme (PNLP)

London School of Hygiene and Tropical Medicine (LSHTM), UK

Malaria prevention, pregnant women awareness campaign, Benin.

Protecting pregnant women from malaria

Malaria can impede the development of unborn children. This has led the WHO to view pregnant women as a particularly vulnerable population in areas affected by the malaria parasite.

In 1935, in Sri Lanka, a malaria epidemic infected 500,000 people. Pregnant women die twice as other women and those who survived had miscarriages or gave birth to premature babies. In areas most frequently affected by the disease, such occurrences are not due to the acquisition of protective immunity in women in regular contact with the parasite. In the 1960s however, physicians found that infants born to infected mothers had a lower birth weight. This resulted in the implementation of a specific preventive treatment in malaria-prone regions, whereby pregnant women took low doses of chloroquine or a mixture of dapsone and pyrimethamine.

In the 1980s, in Burkina Faso, an IRD team assessed the effectiveness of this so-called chemoprophylaxis approach and revealed that women were failing to take their medication. To attempt to overcome this problem, in 1994, in Malawi, a US team tested an alternative preventive treatment: curative doses of sulfadoxine-pyrimethamine were given to pregnant women as part of the two antenatal appointments which often occurred during the second trimester of pregnancy. Supported by the WHO even before it was assessed, this strategy paid off but was by no means perfect, notably because it failed to protect women during the first trimester of pregnancy. In addition, drug resistance appeared.

These defects led researchers to continue their research in intermittent preventive therapy (IPT), highlighting the inadequacy of taking the medication only twice and influencing the WHO's new recommendations to administer IPT at least four times. As part of a number of tests conducted in Benin from 2005, they also showed that mefloquine could be an effective alternative, albeit not recommended by the WHO because of its moderate but frequent side effects (nausea, dizziness).

Pregnant woman consultation, Cameroon.

PARTNERS

Benin Clinical Research Institute, Cotonou, Benin

Lagune Mother and Child University Health Centre, Cotonou, Benin

Health Science Training and Research Unit, University of Ouagadougou, Burkina Faso

Reconstructing the history of HIV

AIDS, the emerging disease of the late 20th century, is primarily due to a virus, HIV-1, of which there are four variants. More than 80 million people worldwide have been infected since the beginning of the epidemic. Where and how could such a virus emerge?

Child's drawing, Senegal.

In the early 1980s, when the world discovered HIV, several million people were already infected. This immediately raised the question of the origin of the epidemic and virus. A US primate research centre identified a variant in a macaque monkey in 1983. Shortly afterwards, the blood of a large number of monkeys in captivity was analysed, confirming the presence of HIV cousins in 40-odd primate species. In 1987 however, researchers made an even more crucial discovery when they identified a virus very similar to the one responsible for the global pandemic in a chimpanzee in captivity in Gabon.

••• Researchers identified the origin of the AIDS virus in great apes in Cameroon •••

To claim that HIV comes from monkeys however, one should go further and study wild chimpanzees. The problem is these populations are protected and cannot be caught, which makes research more difficult. As they could not access their blood, researchers studied their droppings. In 2002, having verified in the laboratory that the faeces of infected chimpanzees contained viral fragments, researchers began collecting thousands of wild chimpanzee and gorilla droppings in Central Africa.

"These analysis methods based on wildlife droppings helped identify the origin of other pathogens, and will facilitate the in-depth study of pathogens on the level of the human-wildlife interface, to shed light on the emergence of certain infectious diseases."

Eitel Mpoudi Ngole, director of the Research Centre for Emerging and Re-emerging Diseases (CREMER), Yaoundé, Cameroon

Female gorilla, Southern Cameroon.

The results initially revealed a contrasted epidemiological situation: certain populations were not infected: while in others 30% to 50% of individuals were contaminated. More importantly, primate colonies were infected with viruses from the same family but all were specific to the region where they lived. These studies also showed that gorillas from Cameroon were infected with a virus similar to HIV-1.

This made it possible to map the four starting points of the four types of HIV-1 virus (M, N, O, P) and the animal-to-human transmission points. They all came from Cameroon: for types O and P, gorillas from the Central South and West, respectively; for types N and M, chimpanzees in the Central South and East, in the Lobéké region. The HIV-1 M virus, the most widespread, was responsible for the pandemic, whereas the others remained endemic in Cameroon.

PARTNERS

Research Centre for Emerging and Re-emerging Diseases (CREMER), Yaoundé, Cameroon

National Institute of Biomedical Research, Kinshasa, Democratic Republic of the Congo

University of Pennsylvania, Philadelphia, USA

The battle against Ebola

Treatments and vaccines against the Ebola virus are not yet widespread. As a result, control methods are primarily based on health measures aimed at preventing the animal-to-human transmission of the virus while also blocking person-to-person transmission.

Bat capture, Gabon.

Investigating the role of bats responsible for the epidemic, Democratic Republic of the Congo.

In 1976, a Belgian physician, Peter Piot, identified a new virus in a blood sample taken from one of his compatriots who had died in Zaire, formerly known as the Belgian Congo. Taking its name from a river located in the contaminated area, the Ebola pathogen killed 300 people that year. It was the first known outbreak of Ebola, but by no means the last. Since then, in this part of the world, the virus has re-emerged for no apparent reason and at irregular intervals, deep in the forest or in the savannah, in remote or urban areas.

••• A virus transmitted to humans by great apes and bats •••

The animal origin of this disease remained a mystery until IRD researchers and their partners started looking into it. From 1996 to 2005, they found that the virus also decimated great apes in the forests of Gabon and the Congo. These animals were hunted and eaten by local populations. As researchers continued to investigate, they proved that the virus was capable of spreading from primates to humans. Nevertheless, great apes were not the only source of infection, as demonstrated by researchers a few years later when they detected antibodies and fragments of the Ebola virus genome in several fruit bat species, suggesting that these animals were the actual reservoirs of the Ebola virus. A few years later, they realised that certain human epidemics coincided with the migration of fruit bats. As these mammals were also hunted by local populations, they could be responsible for the epidemics: transmission to humans may be due to direct contact with bat blood or through fruit soiled by the saliva of these bats.

These findings resulted in the setting up of wildlife monitoring networks, as well as clear and concrete prevention instructions to local populations, including in terms of hunting, with a view to reducing the likelihood of outbreaks.

PARTNERS

Franceville International Centre for Medical Research, Gabon

National Institute of Biomedical Research, Democratic Republic of the Congo

National Institute for Communicable Diseases, South Africa

Centers for Disease Control and Prevention, USA

Village affected by an epidemic, Gabon.

"The partnership with IRD has stimulated research on Ebola haemorrhagic fever in Gabon in response to the epidemics which have dramatically and repeatedly affected our country since 1995. Thanks to ongoing collaboration between our two institutes, CIRMF has become a world-class centre of excellence in the field of emerging diseases in Central Africa, which is why it was recently designated as WHO collaborating centre for arboviruses and viral haemorrhagic fever."

Professor Jean-Raymond Nzenze, Chair of the Board of the Franceville International Centre for Medical Research, Gabon

Ebola: a predetermined ending?

The characterisation of the immune mechanisms associated with the Ebola virus infection is a prerequisite to the design of treatments and vaccines. Against the background of increased epidemics, the use of effective treatments or vaccines is becoming a health priority.

Handling the Ebola virus, Gabon.

Being infected with the Ebola virus is a death sentence in 80% of cases. This surprisingly stable figure led teams from the Pasteur Institute and IRD, in conjunction with their partners, to look into the action mechanisms of the virus in the human body. In 1997, they started collecting blood from people affected by the Ebola virus to study the immune responses involved during the infection.

They detected a difference in immune responses between the survivors and the deceased, who died after an "inflammatory storm". The initial immune response against the virus, which is non-specific, is so strong that it causes irreversible damage in the body, resulting in a blood clotting disorder which rapidly alters vital functions. The second response, normally more targeted, is then ineffective: immune cells proliferate and die shortly thereafter. However, these two extreme phenomena do not occur in the survivors. This finding could therefore help refine the search for a therapeutic solution.

In addition, researchers found that some Ebola-infected patients were asymptomatic and quickly eliminated the virus. To find out more, they initiated a large-scale study in Gabon, collecting blood from 4,500 randomly selected people. The results showed that 10% to 33% of the population had antibodies against Ebola… although they had never experienced any epidemic. While this diffuse immunity is probably acquired in contact with fruit contaminated with bat saliva, its protective effectiveness has yet to be demonstrated.

PARTNERS

Franceville International Centre for Medical Research, Gabon

National Institute of Biomedical Research, Democratic Republic of the Congo

National Institute for Communicable Diseases, South Africa

Centers for Disease Control and Prevention, USA

Collection of epidemiological data, Gabon.

Humanising biosecurity measures

From 2014 to 2016, during the Ebola epidemic in West Africa, lack of preparation led the authorities to take sometimes extreme health measures which caused some "resistance" within the populations, if not outright opposition.

Ebola is an infectious disease which incites fear due to high case fatality and the anxiety-provoking images it conjures. In affected areas, prevention strategies were hastily implemented, in an inflexible or authoritarian manner, including the closure of borders and schools, the isolation of people who came into contact with a patient… and the isolation of people from infected areas. What were the consequences? To answer this question, anthropologists worked on the perceptions and assessment of health measures in a local context, in Senegal, Guinea and three neighbouring countries.

They identified several factors, starting with the inadequacy of the health messages conveyed to the populations: in Guinea, some patients, convinced that they were the victims of a political conspiracy, refused to take the prescribed medication. In Benin, an Ebola centre was destroyed even before the epidemic hit the country. Conversely, in Senegal the Ministry of Health broadcast clear information via the media on the epidemic flare-up and the population trusted them.

In all cases, the precautionary measures imposed on people who came into contact with an Ebola case were difficult to tolerate. In the survey countries, individuals confined for 21 days were isolated, anxious, incapable of holding a job and they experienced financial difficulties and suffered from social stigma, notably because they were (wrongly) suspected of transmitting the Ebola virus. The study showed how volunteers and front-line workers were able to manage these effects.

These results contributed to humanising biosecurity and isolation procedures while making them applicable to local contexts, notably by introducing psychosocial assistance for confined individuals, and tailoring messages to patients and the population. On a broader level, they were taken into account by the WHO to define recommendations on ethical concerns during global epidemics.

Ebola epidemic treatment centre, Guinea.

PARTNERS

Fann Regional Centre for Research and Training in Clinical Management (CRCF), Dakar, Senegal

Guinea Centre for Research and Training on Infectious Diseases (CERFIG), Conakry, Republic of Guinea

The OCP programme, or how to eradicate "river blindness"

Up until the 1980s, Africa was plagued by a scourge which is now almost forgotten: onchocerciasis or "river blindness", a blinding disease which devastated rural societies and transformed fertile soils into no man's land.

Search for larval habitats, Guinea.

"*Large watercourses will eat your eyes.*" This saying from Burkina Faso will soon be as incomprehensible to Africans as it always was to Europeans. It refers to onchocerciasis, a blinding disease which, up until the 1980s, was rampant near the rivers of many African countries. This is where the black fly vector lives, a haematophagous midge whose painful bite can transmit a parasitic filarial worm.

In humans, adult filariae live under the skin of the knees, hips and ribs, where fertilised females produce vast amounts of microfilariae which invade the dermis, including the eyes, and die after two years by releasing toxins which cause the damage. To continue their cycle, they must be ingested by a black fly which will transmit them to another bitten individual… The intensity of the symptoms is proportional to the number of infected bites received.

In the 1950s, in the absence of treatment, researchers initiated studies on the black fly's life cycle. From 1960 to 1972, in three regions of Côte d'Ivoire, Mali and Burkina Faso, they tested protocols for the elimination of aquatic midge larvae using insecticides.

"The onchocerciasis control programme in West Africa is undoubtedly a success in terms of disease control and environmental protection… This programme was a precursor to the principles of sustainable development."

Dr Boakye A. Boatin, former head of the OCP programme

Woman suffering from onchocerciasis, Cameroon.

The extremely conclusive results became the cornerstone of the OCP international project (Onchocerciasis Control Project). Designed and run by Orstom, OCP controlled the vector in 11 African countries while ensuring the weekly treatment of 50,000 kilometres of rivers from 1975 to 2002, thereby protecting 40 million people and returning millions of acres of land to farmers. The introduction of a therapeutic solution based on ivermectin in the 1980s changed the control strategy, resulting in the virtual eradication of onchocerciasis throughout the African continent.

PARTNERS

World Health Organisation (WHO)

United Nations Development Programme (UNDP)

The effect of insecticides on the environment

From 1973, in order to make riparian areas suitable for agriculture, large quantities of anti-simulium insecticides were discharged into the rivers of West Africa as part of the OCP programme.

Insecticide stock, Benin.

The 1970s saw the launch of a large-scale campaign in West Africa to control the populations of black flies, the vector for human onchocerciasis. Large amounts of insecticide were discharged into the rivers of the region week after week, with a potential environmental impact that researchers endeavoured to study. First of all, they had to understand the initial ecological functioning of ecosystems and the local aquatic invertebrates and fish. This presented a challenge as, at the time, they only had a rather incomplete list of species to work with.

Then they had to define the acceptable limit of the impact of pesticides on the environment. If the slightest effect was observed on fish populations, or when black fly larvae developed resistance, it was imperative to change insecticide, for example by switching from temephos to chlorphoxime, to a bacillus capable of eliminating larvae. This extremely effective strategy involved monitoring the ecosystems treated in real time, to maximise the effect of treatment while minimising costs and the environmental impact.

For the entire duration of the 20-year programme, many African researchers were trained to ensure the ecological monitoring of the environment. Studies ultimately showed that the treatments, on balance, had little influence on the fish populations which provide the inhabitants of landlocked countries with essential protein intake. While initially unforeseen effects were observed subsequently, these are not linked to insecticides: land recolonisation by local peasant communities, combined with the setting up of water-intensive agri-food industries (cotton, sugar cane, etc.), contributed to deforestation and environmental damage, resulting in overall ecological degradation.

PARTNERS

National Centre for Fisheries Science and Polytechnic Institute, Guinea

Institute of Rural Economy, Mali

National Centre for Agricultural Research, Côte d'Ivoire

Universities of Côte d'Ivoire, Benin and Togo

Filariasis screening, Republic of Congo.

Testing before treating

Ivermectin was discovered in the late 1980s, marking the launch of effective onchocerciasis ("river blindness") control programmes. This drug however causes side effects and can, in some cases, lead to death.

Ivermectin, a drug discovered in the 1970s-1980s, is widely used to control onchocerciasis. By destroying the larval instars of the parasite living in the skin and eye tissue (microfilariae), it helps prevent the manifestations of the disease. In the 1990s however, researchers found that some individuals developed encephalopathy within days of the treatment, with potentially fatal coma. These accidents occurred in Central Africa, where onchocerciasis coexists with another form of filariasis called loiasis (*Loa loa* filariasis).

In 1995, researchers initiated a study in Cameroon to assess the incidence of these accidents. 18,000 people were treated with ivermectin and the treatment led to two cases of coma. The two individuals affected had high levels of *Loa loa* microfilariae, in excess of 30,000 per millilitre of blood. This result was not really taken into account by the international community, as the benefits of ivermectin were too great for the treatment to be discontinued. This lasted until 1999, when the treatment of 6,000 patients in Cameroon's Okola district caused 23 cases of coma and 3 deaths. These events, which occurred as the country was launching its national onchocerciasis control programme, led to the definition of specific recommendations for ivermectin treatments in *Loa loa* endemic areas: in these regions, increased medical supervision had to be put in place to limit the risk of death.

This interim solution was not however acceptable in the long run, which is why researchers came up with a rapid detection tool to identify people at risk: the "Loascope". The idea is to quickly count *Loa loa* microfilariae in a drop of blood. These highly mobile microfilariae are counted automatically based on short videos of a very thin tube filled with blood, captured with a smartphone. Microfilarial density appears on screen within two minutes and subjects with more than 20,000 mf/ml, with a risk of encephalopathy, can then be excluded from the ivermectin treatment, while the rest of the population is safely treated. Ten thousand Loascopes should be deployed throughout Central Africa in 2019.

Cow treatment using ivermectin, Burkina Faso.

PARTNERS

Centre for Research on Filariasis and Other Tropical Diseases, Cameroon

University of California, Berkeley, NIH/NIAID, USA

University Medical Center, Rotterdam, Netherlands

Lights out for the tsetse fly?

The scourge of the 20th century, sleeping sickness – or trypanosomiasis – may become a thing of the past thanks to new therapeutic solutions, as well as better control of the main vector for the disease, the tsetse fly.

Glossina, or tsetse fly.

The history of the fight against sleeping sickness in Africa is partly linked to France's colonial past: up until the early 20th century, this deadly disease wreaked havoc in sub-Saharan Africa. It is caused by a flagellate transmitted to humans and animals by a haematophagous fly, glossina or tsetse fly. In an attempt to halt this scourge, in the 1920s French teams systematically screened and treated the patients identified. This was an effective albeit very high-risk strategy, due to the side effects of the treatments at the time, which could lead to death for 5% of the patients.

Hence the scientists' desire to devise another approach, aimed at eliminating the vector, i.e. the tsetse fly, in sleeping sickness outbreaks. Unlike the mosquito, the tsetse fly bites during the day and outside homes, near water bodies, wetlands or forests. In 1975, as they studied the behaviour of flies, two researchers working in Burkina Faso found that they were attracted to white or blue fabric. They created biconical traps made of fabric, mimicking the shape of a man or animal. These traps become lethal when treated with insecticides.

Subsequently, the shape of the traps was diversified to attract each of the 31 species of tsetse fly found in Africa, before being simplified to reduce manufacturing costs, resulting in the 1980s in the wide deployment of large white and blue screens in Côte d'Ivoire and Uganda. In the early 2000s, additional research showed that the size of the screens could be reduced without impairing their effectiveness: if installed properly, they eliminated 80% to 97% of tsetse flies. The number of cases of sleeping sickness dropped from 300,000 in 1990 to 1,500 cases reported in 2017, thanks to the traps which are now industrially produced, but also to the therapeutic advances over the past five years.

PARTNERS

Cirad, France

International centre for research-development on livestock in sub-humid zones (CIRDES), Bobo-Dioulasso, Burkina Faso

Pierre Richet Institute, Bouaké, Côte d'Ivoire

Livestock Research Institute for Development (IRED), N'Djamena, Chad

University of Yaoundé and University of Dschang, Cameroon

Liverpool School of Tropical Medicine, Liverpool, UK

National Human African Trypanosomiasis Control Programmes (NHATCP)

••• From 1975 to 2005, researchers invented various traps to catch or kill tsetse flies •••

© IRD / J. Jamonneau

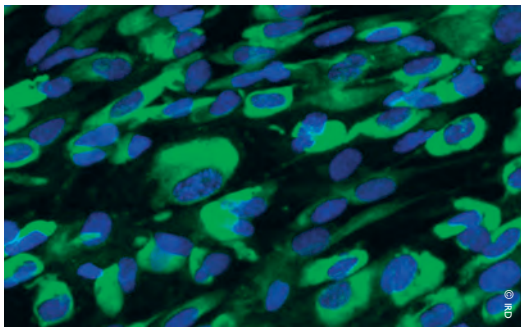
Setting of a tsetse fly trap in a mangrove area, Guinea.

"The impact of these screens is currently clearly felt in human African trypanosomiasis (HAT) outbreaks, for example in Guinea, Chad, Côte d'Ivoire and Uganda, not only in terms of reduced density of tsetse populations but also sleeping sickness incidence, with the added benefit of being easily deployed by the populations themselves. Because of their effectiveness, combined with their ease of use and reasonable cost, several national programmes use these tools, not just in HAT outbreaks but also to control AAT (animal African trypanosomiasis)."

Jean-Baptiste Rayaisse, International Centre for Research on Livestock in Sub-humid Zones, Bobo-Dioulasso, Burkina Faso

Pioneers in the Zika virus

In Global South countries, certain emerging diseases can be confused with dengue or yellow fever. This applies to Zika virus disease, a condition whose effects researchers are still trying to understand, and which is a public health priority.



Human cells infected with the Zika virus.

When the world discovered the Zika virus during the South American epidemic of 2015, IRD had already been on the case since the occurrence of an epidemic in French Polynesia. But the virus itself was identified much earlier, in the 1940s in Uganda, in a Rhesus macaque. It was only detected in humans in 2007, in the middle of the Pacific Ocean on the Yap islands. In most cases, Zika virus disease is characterised by fever, headaches, and hence goes unrecognised, except when it affects a woman during her first trimester of pregnancy, in which case it can cause deformities, including microcephaly in newborns.

However this information was unknown when researchers started working on this virus. Their goal was to understand how the virus entered the body. They were the first to show that the virus does not just contaminate blood: it also infects skin cells. This finding was published in 2015, in the midst of the South American epidemic. The team became one of the world leaders in this field. They subsequently identified, along with their partners, the receptors allowing the virus to infect cells, paving the way for more therapeutic research.

They are currently focusing on the effects of the virus on cultured brain cells, with a view to shedding light on why and how the Zika virus disrupts neurogenesis. It is still very difficult to assess the magnitude and nature of neurological sequelae affecting unborn children but also adults who, in some cases, develop movement disorders and visual impairment.

PARTNERS

University of Mahidol, Thailand

Inserm, France

Pasteur Institute, France

Tiger mosquito larvae.

Developing mosquito factories

Carrying diseases such as chikungunya or dengue fever, the tiger mosquito is found in French overseas territories but also in the south of France. It is therefore essential to control this species, which raises new issues about control methods.

In 2006, Reunion Island was struck by a chikungunya epidemic, underlining the increasing need to regulate the populations of tiger mosquitoes, *Aedes albopictus*. As the use of pesticides was becoming increasingly controversial, researchers opted for another route: the so-called sterile insect technique (SIT). With this strategy, sterile male mosquitoes are mass produced and released into the wild to compete with wild males, thereby preventing females from breeding.

Already used in agriculture to control certain species of fly considered to be harmful to livestock or crops, this practice was tested in the 1960s and 1970s in India and Salvador to eradicate mosquitoes for human health purposes, to no avail. Both tests were short-lived, essentially due to technical difficulties, but also, in India, because of the method used for the chemical sterilisation of mosquitoes, which ultimately harmed their predators and, in Salvador, because of poor communication on the method and objectives of this fight.

These past failures did not however discourage the researchers. And for good reason: in mosquitoes, only the sperm of the first male who inseminates the female can produce eggs. By correctly choosing the timing of releases, it should be possible to reduce the population without using any pesticide. This is why, in 2008, IRD signed a framework agreement with the International Atomic Energy Agency (IAEA) to support the development of this innovation in various member States. They worked together on a project designed to develop expertise in the mass production of mosquitoes, the sexing and sterilisation of male mosquitoes using X-rays.

Further funding is now needed to build the first production unit of sterilised male mosquitoes, to test the principle of SIT on a small scale and assess the effects of releases on tiger mosquito populations on Reunion Island.

Larval rearing on Reunion Island.

PARTNERS

University of Reunion Island

Directorate General for Health, France

European Regional Development Fund

International Atomic Energy Agency

Cirad, CNRS, EHESP Rennes, France

Vaccinating dogs to save humans

Leishmaniasis is a parasitic disease found in 90 countries, 72 of which rank amongst the world's poorest. It is transmitted by a midge that feeds on the blood of various mammals, particularly dogs.

Leishmania stained DNA.

Leishmaniasis kills 62,000 people every year worldwide. It is however a "neglected" disease which is not within donors' priorities. This considerably complicates research conducted on this scourge transmitted by sand flies, midges that bite humans as well as animals, particularly dogs, one of their favourite hosts. Scientists realised this when health authorities launched a campaign in Brazil to eradicate dogs infected with leishmaniasis, thereby creating a spike in human contamination as, in the absence of dogs, sand flies settle on humans instead.

••• Researchers are developing a dog vaccine against leishmaniasis •••

This unexpected result opened a new avenue for researchers. While no one was willing to fund research on human leishmaniasis, the same could not be said for canine leishmaniasis, which threatens 25 million dogs in southern Europe. In 1990, this reality enabled researchers to raise money and finally study the leishmaniasis parasite in dogs. It took five years for them to develop a serum-free culture medium, i.e. without animal contaminant, and allow the pathogen to multiply.

They subsequently studied how the parasite infects cells in the canine immune system and discovered a promising approach with a view to a vaccine. This vaccine does not trigger the production of antibodies but of immune cells capable of eliminating infected cells. In the parasite secretions, they isolated proteins capable of triggering this immune

"The existence of the disease must be acknowledged and integrated into the strategic plans of the ministries of health."

Bashir Mwambi, International University of Health Sciences, Kampala, Uganda

Dog suffering from leishmaniasis, Senegal.

response. After 12 years of research and clinical tests, in 2011 they managed to bring a dog vaccine against leishmaniasis to market. At the same time, they worked together to develop a human vaccine, attempting to reduce production costs to make it available to the populations concerned. An initial human vaccine should enter into phase 1 clinical trials shortly.

PARTNERS

Pasteur Institute of Tunis, Tunisia

Universidad Peruana Cayetano Heredia, Lima, Peru

Detecting drug-resistant tuberculosis

Antibiotic resistance poses a threat to global public health. Tuberculosis therefore continues to progress because of the emergence of multi-drug resistant strains.


© IRD/M Chalay

Research on the epidemiology of tuberculosis, Vietnam.

The drug resistance issue affects the entire bacterial world. Strains resistant to all antibiotics, referred to as "superbugs", have already appeared on every continent. This threat explains why researchers are actively trying to understand the mechanisms of emergence of this resistance. It appears that strains already resistant to one antibiotic are more likely to develop new forms of resistance. These new forms seem to particularly affect Global South countries, where there are few or no regulations on the use of antibiotics for humans and animals. In this context, the setting up in South-East Asia of "One Health" projects, based on the combined study of the environment and animal and human health as part of a holistic have appeared, is essential when devising effective control strategies.

Mycobacterium tuberculosis, the bacterium responsible for tuberculosis, is dangerous and particularly difficult to eliminate. A combination of four antibiotics for six months is required to eradicate it, provided the bacterium has not developed any resistance. Over the years, an increasing number of multi-drug resistant strains have appeared, which require the use of second-line antibiotics.

In order to combine these various therapeutic options, the degree of resistance of *M. tuberculosis* must be determined first. This is far from obvious, as it takes nearly one month to grow and characterise the bacteria.

In 2009, a programme was launched in South-East Asia to map the different forms of tuberculosis found in the region. Several strains resistant to first and second-line antibiotics were identified. This triggered an inventory of all resistance genes found in Asian bacteria. This survey allowed researchers to create a diagnostic tool capable of characterising, in a single experiment and within five hours, the type of resistance (simple or multiple) of an *M. tuberculosis* strain. This was a tremendous achievement. This tool must however be patented and improved before being placed on the market for use by countries of the Global South.

PARTNERS

National Institute of Hygiene and Epidemiology (NIHE), Hanoi, Vietnam

Hanoi University of Science and Technology (USTH), Vietnam

Lao-Christophe Mérieux Centre for Infectiology (CILM), Vientiane, Laos

Pasteur Institute of Cambodia (IPC), Phnom Penh, Cambodia

GeT-Biopuces Platform, LISBP, Toulouse, France

Aedes aegypti, dengue vector mosquito.

Climate-related epidemics

Epidemics are linked to population flows, lifestyles, population densities, vectors, but also the climate. This finding has helped improve the prediction and management of certain epidemics, including meningitis and dengue fever.

In the early 2000s, a team working in Mali made a surprising discovery: there is a link between the occurrence of the Harmattan, a hot and dry wind from the Sahara, and meningitis outbreaks. This finding led researchers to study the two countries most affected by annual meningitis epidemics, i.e. Niger and Burkina Faso.

By correlating epidemiological data collected since the late 1960s with the weather information available, they showed that 25% of the observed variability of meningitis cases are linked to wind intensity. This can be used to better anticipate the occurrence of major epidemics such as that of 1996, which cost 25,000 lives.

A few years later, in 2009, a multidisciplinary team initiated similar research in New Caledonia. The idea this time was to study fluctuations in dengue fever outbreaks. Researchers studied 40 years of epidemiological data, from 1971 to 2011, and showed evidence of very close statistical relationships between climatic temperature and rainfall variables and disease outbreaks. They also highlighted the possibility of predicting epidemics one month in advance using a statistical model with a 70% to 80% reliability rate. This model is currently used in decision-making processes and helps health authorities anticipate these epidemics, by informing populations, forecasting insecticide orders and organising the vector control strategy. Looking ahead to 2100, it suggests that, due to climate change, the frequency of dengue fever epidemics could increase from once every five years to once a year.

Sandstorm, Burkina Faso.

PARTNERS

New Caledonia Hospital (CHT)

Pasteur Institute of New Caledonia (IPNC)

Directorate for Health and Social Affairs of New Caledonia (DASS)

Pacific Community (CPS)

Météo-France New Caledonia

National Meteorology Agency of Burkina Faso

Closely monitored glaciers

Glaciers in tropical and subtropical regions are characterised by specific functions. Their response to global warming cannot be extrapolated from the observations of mid-latitude or polar latitude glaciers alone.

Ice coring, Chimborazo volcano, Ecuador.

In Europe, snow piles up on glaciers in winter and melts in summer. However, this seasonal cycle does not apply to all glaciers, including those in tropical and subtropical regions, as discovered by researchers in the early 1990s, notably as part of programmes covering high altitude glaciers in Bolivia. They measured the glacier's mass balance, installed weather stations on and next to glacier tongues, quantified downstream water run-off and complemented their measurements with satellite images, thereby showing that tropical glaciers behave quite differently to glaciers in temperate areas: snow piles up in summer, during the wet season, and not in winter. This characteristic may give rise to unexpected behaviour when faced with climate change.

This is why, as part of the Cryobsclim project, various glaciers representative of high altitude environments of the tropical and subtropical regions were selected and monitored over a long period in Bolivia, Ecuador, and Peru as well as in the Himalayas. These observations helped track changes in the glaciers and predict their future behaviour under different climate assumptions. The objective was to grasp the possible impacts on people living downstream, whose water supply in winter, during the dry season, depends on the presence of glaciers. Researchers found that, while glaciers are stable in parts of the Himalayas, they are under considerable threat in the Andes, which will have consequences for the countries concerned.

"These analytical tools have allowed us to quantify the current contribution of glaciers to water resources at regional level under extremely dry conditions. Glaciers contribute respectively 15%, 86% and up to 91% of the water for consumption of the cities of Quito, La Paz and Huaraz. This information will help managers improve the planning of actions designed to mitigate the effect of the progressive reduction in this contribution due to climate change."

Marcos Villacis, Quito National Polytechnic School, Ecuador

Weather station at the summit of the Chimborazo volcano, Ecuador.

••• The Cryobsclim network helps monitor the behaviour of tropical glaciers •••

As the only internationally recognised organisation to implement, in conjunction with Andean and Himalayan partners, the long-term monitoring of glaciers in the Global South, IRD has compiled long series of observations since the 1990s, an unrivalled data set for environments difficult to monitor. Current applications range from the quantification of glacial hazards in the Himalayas to innovative water resource management methods in Peru, Bolivia and Ecuador. In Ecuador for example, a comprehensive hydrological model has been implemented to allocate water resources in the city of Quito. It takes into account the water provided by glaciers and is used as a planning tool.

PARTNERS

Tribhuvan University, Nepal

Universidad Mayor de San Andrés, Bolivia

National Polytechnic School, Institute for Meteorology and Hydrology, Ecuador

Geophysical Institute of Peru

National Water Authority of Peru

National Meteorological and Hydrological Services of Peru and Bolivia

Institute of Hydrology, Meteorology and Environmental Studies, Colombia

Watching out for our water

In a context of global changes, the countries in the tropical belt are increasingly exposed to flooding. Understanding and monitoring these trends is a major research issue for the development of appropriate warning systems.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Arrival of the monsoon in Niamey.

For mobile telephone operators, rain is a nuisance which hampers the effective transmission of communications. In 2007, this interference helped Dutch and Israeli researchers find the solution to a completely different problem. Their idea was to convert the fluctuations of the signal emitted and received by relay antennas into data used to detect rainfall in real time. While the approach is of little interest in Europe, it would be relevant for African countries which, although ill-equipped in terms of weather stations and radars, have a well-established network of relay antennas.

••• By using the network of relay antennas, it is possible to monitor the risk of flooding in the tropics •••

In 2012, French and African teams decided to put the principle to the test in Burkina Faso. Working with Telecel Faso, they demonstrated that the analysis of signals from relay antennas helped detect and quantify the level of rainfall. By linking this data to a hydrological model, they managed to create an application capable of mapping the risk of urban flooding. Rain Cell (*Rain Measurement from cellular phone networks*) was born.

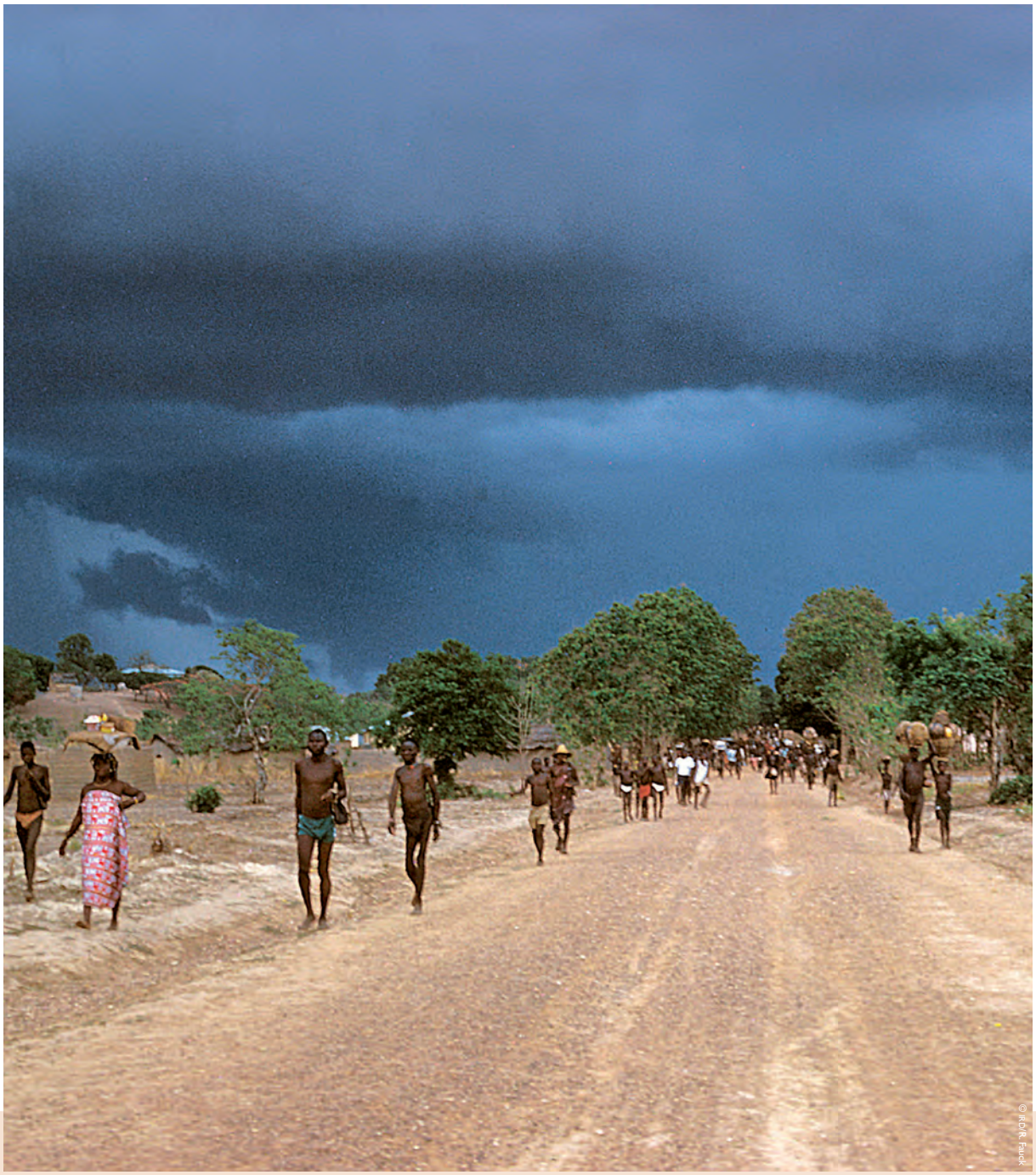
Researchers however took it a step further. In 2016, building on IRD's long-standing presence in Africa, they convinced telephone operator Orange to share their data. This enabled them to test the system in five countries: Burkina Faso, Niger, Mali, Cameroon and Morocco, with the launch of a real-time pilot in Cameroon in 2018. All that remains now is to perfect the business model to ensure Rain Cell's sustainability and operability.

PARTNERS

Universities of Ouagadougou, Abidjan, Yaoundé, Douala and Fez

2IE Ouagadougou, Burkina Faso

Hydrological-meteorological and civilian security services, urban communities in Niger, Cameroon, Mali and Burkina Faso



The monsoon, critical to water resources for Sahelian agriculture.

"Obtaining rainfall data in real time in African cities at high risk of flooding would help our services better anticipate risks; we are interested in the Rain Cell project. This innovative research gives access to weather information by making use of existing infrastructure, i.e. mobile telephone networks."

Ernest Ouedraogo, director general of the National Meteorological Agency of Burkina Faso

Heat wave warning in Africa

By the end of the century, the Sahel could be hit by extreme heat waves. Even though the local population is accustomed to high temperatures, they could be affected by these extreme events.

Soil cracked under the effect of drought, Burkina Faso.

In 2003, France discovered the potential lethality of heat waves. It introduced an alert and prevention plan which, during the next heat wave in 2006, paid off and limited the number of casualties. A few years later in 2013, researchers raised awareness of the impacts of climate change: residents of the Sahel region will face extreme heat events too and must be equipped with an appropriate warning system to avoid casualties during heat waves.

What is a heat wave in these already hot regions? And what danger thresholds should be taken into account for populations accustomed to high temperatures? To answer these questions, researchers undertook studies in Senegal and Burkina Faso, two countries where population monitoring activities are carried out. They began working with national meteorological agencies with a view to publishing a weekly heat wave forecast bulletin. This has been a routine procedure since 2016.

They subsequently decided to combine data on medical consultations and deaths from IRD's observatories with meteorological data, with a view to developing warning signals. This attractive concept was difficult to implement as this information was not collected in real time but every six months, which required adjusting the thermal threshold assessment techniques used in the countries of the Global North.

"Heat waves are frequent weather events in the Sahel and have a strong impact on human health. Climate projections point to an increase in the intensity and frequency of these events. To this end, prevention through the real-time dissemination of weather and climate information to users in order to mitigate the impact of heat waves is crucial, hence the essential role of the ACASIS project, which implements an early warning system using NICTs (SMS alerts, voice calls, website, mobile application)."

Pape Ngor Ndiaye, chief forecaster at ANACIM, Senegal's Meteorological Agency

Drawing water in a dried-up river, Burkina Faso.

••• Researchers lay the foundations for a heat wave warning system in Senegal and Burkina Faso •••

In addition, they conducted an in situ survey of thousands of people to better characterise their living conditions as well as their perception of and vulnerability to heat waves. Preliminary results suggested that people aged over 55 are more likely to suffer when high temperatures continue over long periods and the night-time temperature does not drop, while children under five react more rapidly to sudden rises in temperature. This data is crucial in the development of an effective and appropriate warning system within the next few years.

PARTNERS

Directorate of Meteorology of Senegal

Directorate of Meteorology of Burkina Faso

Cheikh Anta Diop University, Senegal
Ecological Monitoring Centre, Senegal

Gaston-Berger University, Senegal
University of Ouagadougou, Burkina Faso

Nouna Health Research Centre, Burkina Faso

Assessing seismic risks

Particularly devastating earthquakes can occur in Ecuador and Peru. In these countries, knowledge of the areas likely to be hit by earthquakes is a key aspect of public policies in terms of seismic risk prevention.

Monitoring seismic activity, Ecuador.

In 1906, Ecuador was struck by an 8.8 magnitude earthquake. This was the world's fifth most powerful earthquake ever recorded. Over the century that followed, the area was hit by a number of other major earthquakes, three of which had a magnitude of over 7. This frequency explains, among other things, the posting of IRD seismologists to the site. As the region lacked instrumentation, upon their arrival in 2008 they installed 10 measurement stations equipped with an accelerometer, a seismometer and a GPS beacon. The purpose of this instrumentation was to help them describe the tremors, but also the "silent" landslides which can occur on certain faults. Two years later, Ecuador completed the mechanism and now enjoys a modern monitoring network including 85 GPS beacons, 80 seismometers and 120 accelerometers. Measurement stations are used to produce seismic hazard maps.

By analysing the data collected, in 2014 researchers discovered a previously unknown tectonic plate, which they named "Inca" plate. They also calculated local stress forces and pinpointed the areas most likely to be hit by major earthquakes. The 7.8 magnitude earthquake which occurred in Ecuador in 2016, claiming nearly 700 lives, was located in one of the areas previously identified as dangerous. French and Ecuadorian researchers are now drawing up seismic hazard maps. This crucial information is now available to Ecuadorian policy-makers and institutions to simulate the impact of a seismic event and determine development priorities. Furthermore, these maps have also helped researchers conclude that the next major earthquake may occur in Peru, in the Lima region where more than 12 million people live.

PARTNERS

Quito National Polytechnic School, Ecuador

Oceanographic Institute of the Ecuadorian Navy

Guayaquil Coastal Polytechnic School, Ecuador

Geophysical Institute of Peru

"In Ecuador, earthquakes and volcanic eruptions have constantly affected the country's population and development. Knowledge of these events and their effects is key to managing risks, devising prevention policies and improving resilience. This knowledge is one of the facets of our institute, and IRD's contribution was central to the training of specialists and completion of joint research projects. The results achieved significantly enhanced knowledge of seismic and volcanic processes."

Alexandra Alvarado, director of the Geophysical Institute (2016-2018), Quito National Polytechnic School, Ecuador

After the earthquake, Ecuador.

Long-lasting eruptions

Ecuador has 80 volcanoes, 30 of which are potentially dangerous and likely to endanger the lives of millions of people as well as, more indirectly, the national economy.

Eruption of the Tungurahua volcano in 1999, Ecuador.

In 1999, two volcanoes regarded as "explosive" erupted in Ecuador. The first one was a few kilometres outside Quito, a city of two million residents whose airport is vital for the country's economy, but the second volcano, Tungurahua, caused most concern. It overlooked a small town with a population of 15,000 and was particularly dangerous. In fact, it is likely to produce pyroclastic flows, glowing ash clouds moving down the flanks of volcanoes at high velocity. Field teams initiated research in an attempt to determine the frequency and magnitude of eruptions, as well as the vulnerability of populations and surrounding facilities.

For good reason: in contrast to those of Hawaii or Mount Etna, Ecuador's volcanoes produce a highly viscous lava. Rich in silica, it flows a little like toothpaste squeezed out of a tube – by forming a lava dome which rises towards the sky and explodes under pressure from the gas trapped underneath. In 2006 in Tungurahua, a very powerful eruption generated pyroclastic flows, killing six people… The death toll remained low thanks to the local geophysical institute which involves volcanologists and authorities in charge of the safety of civilian populations. Local residents were warned in advance; the six casualties were people who returned to the red zone during the eruption and paid the ultimate price.

This example illustrates the need to adjust warning systems to the characteristics of volcanoes but also to the culture and psychology of local populations, to ensure people do not refuse to evacuate, and to avoid premature returns in the event of a crisis. The perception of risk is as important as the risk itself. Hence the relevance of the transdisciplinary approach, rooted in the field and over the long term.

PARTNERS

Geophysical Institute of the Quito National Polytechnic School, Ecuador

Consequences of the eruption of the Tungurahua volcano, Ecuador.

"Our cooperation with IRD on volcanology has proven to be very successful in determining the past behaviour of certain volcanoes (recurrence and power of eruptions, chemical properties of magma, associated hazards) and monitoring the activity of certain dangerous active volcanoes, such as Tungurahua, Reventador or Cotopaxi. In addition to publications and training, for example via the SVAN LMI, this collaboration is therefore a success with shared benefit."

Silvana Hidalgo, director of the Geophysical Institute, Quito National Polytechnic School, Ecuador

Mapping resources to manage priorities

While natural disasters affect countries of the Global North and South indiscriminately, they cause more damage in the South, due to the lack of appropriate emergency procedures. However, replicating disaster management systems from the North in the South does not make much sense, insofar as these countries seldom have resources similar to those of the North.

La Paz, a city exposed to landslides, Bolivia.

In the 1990s, researchers published an atlas featuring a map of seismic and volcanic risks in Quito, Ecuador. This founding and seminal work for Latin America failed however to arouse the interest of policy-makers, which is why the team decided to change their approach. A few years later, they addressed the notion of risk in terms of strategies. The idea was no longer to map out endangered areas but to analyse how the city worked with a view to determining priorities. The objective was to maximise the effectiveness of emergency measures in a context of limited resources. In conjunction with local institutions, scientists highlighted the economic importance of the historical heritage, the protection of which became a priority. Since then, during volcanic eruptions and ash falls, the roofs of historical buildings are cleared as a priority to prevent any risk of collapse.

Inspired by the example of Quito, in 2010 the city of Lima asked geographers to simulate the impact of a major earthquake on the capital. Once again in conjunction with policy-makers, the team analysed risks, but also the position of areas with vulnerable populations, the location and accessibility of hospitals, the operation of the road network, and access to water, electricity and food. This approach made it possible to identify problems and find solutions in advance, by widening certain roads or targeting critical points for action. This resource mapping methodology was used in 2012 and 2013 to analyse the situation of Port-au-Prince and La Paz, highlighting local characteristics such as the absence of major power companies in Haiti, which increases the number of contact points and changes how the crisis is dealt with. This approach, which examines the links between vital resources, could also be applied to the countries of the Global North.

PARTNERS

Municipio del Distrito Metropolitano de Quito, Ecuador

Instituto Nacional de Defensa Civil del Perú

Gobierno Autónomo Municipal de La Paz, Bolivia

Haiti Directorate for Civil Protection

••• The multidisciplinary approach helps create natural disaster management strategies •••

Cotopaxi volcano in eruption, Quito, Ecuador.

"Since 1988, several research programmes have been developed with the municipality of Quito, including the 'Information systems and risks of the Quito metropolitan district' programme (DMQ) from 2002 to 2004, the objective of which was to develop a method based on the understanding of vulnerability. This was a unique contribution to the traditional risk analysis notion, which proved to be a practical tool and helped focus on specific risk reduction actions. There is no doubt that the contribution made by IRD's cooperation had a positive impact on the planning work of the city of Quito. My own work was directly influenced by this research programme."

Nury Bermúdez, national risk management coordinator, UNDP, Ecuador, former Planning officer for the Quito Metropolitan District

Sounding out the hidden side of earthquakes

In subduction zones, 80% of the seismic energy is released at sea, sometimes near heavily populated coastlines such as the Pacific Rim. Hence the relevance of precisely measuring seismic activity in these vulnerable areas.

Immersion of a seismometer, Ecuador.

PARTNERS

Instituto Oceanográfico de la Armada, Ecuador

Instituto Geofísico de la Escuela Politécnica Nacional, Ecuador

Instituto Geofísico del Perú, Lima

Servicio Geológico Colombiano

Sonatrach, Algeria

Houari-Boumediene University of Science and Technology, Algiers

Great earthquakes do not happen just anywhere. They primarily occur in regions of the Circum-Pacific belt, known as "subduction" zones, such as Japan, Chile, Indonesia and Vanuatu. The latter zone was studied by seismologists from Orstom in the 1970s, when they were confronted with a trivial problem: in that part of the world, there are not enough land masses on which to install their measuring instruments.

They teamed up with researchers from the University of Texas, in Austin, who developed self-contained ocean-bottom seismometers. This was a substantial technical achievement as these instruments can record very large amounts of data. However, this data could not be transmitted through the water column and had to be stored on site until it was collected by the researchers… which required very high-performance batteries. In addition, as these instruments were installed at the bottom of the sea, they had to withstand pressure and had to be brought back to the surface to deliver their information. In many aspects, ocean-bottom seismometers were more similar to robots than their land-based equivalents.

After testing US prototypes, researchers began to develop their own instruments, the latest of which is currently being tested off the coast of Nice. It is equipped with lithium batteries and has a life span of at least three years. By comparison, previous generations, currently used in research, have a life span of six months. IRD owns 40 of those. Deployed in a network configuration, they shed light on the actual geometry of the Vanuatu subduction zone. In Ecuador, they were used to monitor the aftershocks of the great 2016 earthquake and enhance the understanding of the transfer of tectonic stress, notably towards the Colombian border where future earthquake rupture could potentially occur.

Young girl on a moped, Ouagadougou, Burkina Faso.

Using data to improve road safety

In Burkina Faso, as everywhere else in Africa, road crash injuries are an often overlooked public health issue. New tools for the GPS tracking and monitoring of road crash could help develop levers for action.

It is believed that road accidents could become the fifth leading cause of death in Africa by 2030. Yet data collected on accidents is scarce and unreliable, which impedes the development of prevention actions. This is why a team of researchers in Ouagadougou tested an accident surveillance system involving national police units, resulting in the mapping of accident "black spots".

This map shows that accidents often take place in densely populated districts and on city bypass and exit roads. 86% of those injured are two-wheeled vehicle drivers, primarily young men from working-class suburbs. This finding emphasised the inadequacy of road infrastructures in light of the growing number of two-wheeled vehicles, as well as the lack of public transportation, which forces young workers to travel long distances on motorcycles. Pedestrians, who account for 6% of injuries, are also road traffic victims. This fragility is exacerbated by difficulties in accessing healthcare, which were also measured by researchers as part of the monitoring of road crash victims in the Ouagadougou emergency department. Healthcare costs are very high and this prevents those injured from getting appropriate care.

Following the presentation of these results, more police forces were deployed at "accident black spots". In terms of improvement, old and narrow roads must be adapted to accommodate the growing use of two-wheeled vehicles. Last but not least, specific information on injuries is being used to raise the population's awareness of road hazards.

This data forms an essential part of the prevention of accidents and the improvement of road safety in Burkina Faso, as well as in other parts of Africa. Benin is currently testing the same system, with GPS tracking of accidents in Cotonou. The next step will be to study sub-regional roads between the main capitals of West Africa.

Traffic in Ouagadougou, Burkina Faso.

PARTNERS

Social Science Institute, Burkina Faso

Institute for Public Health Research, Benin

University of Montreal

Record levels of plastic pollution in fresh water

Floating waste, Ho Chi Minh City, Vietnam.

While the plastic pollution of oceans receives extensive media coverage, fresh water pollution is given less attention, even though this could well be a major health and environmental issue.

Microplastics being sorted in a laboratory, Ho Chi Minh City, Vietnam.

Plastic everywhere! In the trees, streets, fields and rivers of the Ho Chi Minh City region in Vietnam. The situation is so troubling that, when they arrived on site in 2015, a team hitherto specialising in environmental contamination by metals decided to refocus their research and dedicate themselves to plastic pollution: visible macroscopic plastic but also degraded, invisible plastic of less than 5 millimetres which combines with water or dust.

Researchers found that, while plastics are the subject of research and monitoring activities in the countries of the Global North and in the ocean environment, this was not at all the case in Global South countries, where water and waste treatment systems are most lacking.

In conjunction with teams working in France, they examined the water of the Saigon river in the heart of Ho Chi Minh City. The protocols designed for a river such as the Seine soon proved to be inadequate given the local concentrations of microplastics: the setting time of nets used to collect plastic contaminants was reduced from 30 minutes to one minute to prevent saturation problems. The results showed that the concentration of macroplastics in the water of the Saigon river was 700 times higher than that of a river running through a megalopolis in a developed country; and the concentration of microplastics was 1,000 times higher. One litre of drinking water can therefore contain more than 100 plastic fibres, with unknown effects on the environment and health. These fibres are also found in the atmosphere and can therefore end up in the lungs of the populations.

To cope with this emergency, in 2018 an exhibition in French, English and Vietnamese was organised by scientists to raise public awareness of the plastic issue in Vietnam. This hard-hitting approach stimulated discussions and may have contributed to raising awareness.

PARTNERS

Asian Water Research Centre (CARE), Ho Chi Minh University of Technology, Vietnam

Institute of Environmental Geoscience (IGE), Grenoble, France

Laboratory of Anthropology of Contemporary Worlds (LAMC), Free University of Brussels (ULB), Belgium

"Water, Environment, Urban Systems" Laboratory (LEESU), Paris-Créteil University, France

Tracesense, measuring traces of pollution

The long-term measurement of environmental pollution is a key yet difficult to achieve objective, for economic and technical reasons. Innovative measurement and detection tools must be developed to rapidly identify trace elements.

Humans do not have an exclusive role when it comes to pollution. Certain Bolivian ecosystems have the potential to naturally form methyl mercury, a particularly toxic organometallic neurotoxin. The concentrations of this toxin vary on a seasonal basis and above all over the course of a day. This "natural" pollution is difficult to study as the collection, chemical treatment and laboratory analysis of water samples are complex and costly procedures. Passive sensors, which could easily concentrate methyl mercury in water, must be immersed in the environment for several days to obtain a measurement. As a result, it is impossible to detect and study daily changes in methyl mercury concentrations.

This technical limitation led to the development of another measuring instrument. The idea, tested on a laboratory bench, is to use a nanostructured material to increase the absorption surface and accelerate the capture of the target molecule using a pulsed vibration system. With the help of an electronics engineer, a field prototype was created to capture the trace element, combined with temperature, light and position sensors connected to a smartphone application. With this device, methyl mercury can be captured in a few minutes, although measurement takes longer: once removed from the water, disposable nanostructured plates must be analysed in a laboratory to determine the level of concentration.

The cost price and the detection threshold of this technique are much lower than traditional approaches. These "Tracesense" sensors, patented in 2016 and currently undergoing testing, are very easy to use and could be deployed by non-specialists. In theory, with some adjustments they could also be used to detect other metals or endocrine disruptors.

Tracesense, pollution measurement device.

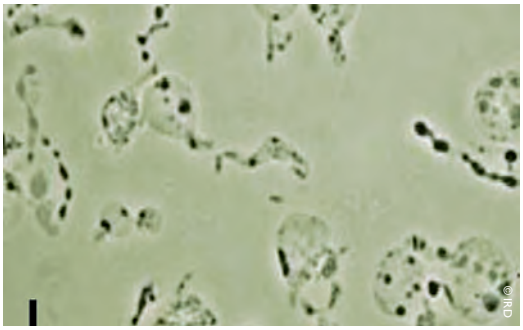
PARTNERS

Suez-Environnement, France

Mesotoga: bacteria found in polluted environments

How to eliminate pollution inflicted by humans on the environment? One option would be to activate naturally occurring biological mechanisms allowing certain microorganisms to break down and/or transform chemical contaminants so as to make them less toxic, or even completely harmless.

Stream contaminated with lead and tin, Bolivia.



Mesotoga, optical microscopy.

Surprisingly, highly contaminated environments, notably with heavy metals, organochlorines or hydrocarbons, can host very specific bacteria, *Mesotoga*. In the early 2000s, the presence of these bacteria in the environment was only known indirectly, through the use of molecular markers. As a result of studies conducted in 2011 on a Tunisian reactor treating industrial wastewater with high concentrations of heavy metals, a team of microbiologists finally managed to grow these bacteria (*Mesotoga* strain PhosAc3).

Two species belonging to this bacterial genus have been described to date, *Mesotoga prima* and *M. infera*. They belong to the order Thermotogales, anaerobic bacteria which had only been found in warm ecosystems such as hydrothermal springs or oil field water. Their presence in lower-temperature environments (30-45°C) therefore constitutes a puzzle in bacterial evolution that researchers are trying to solve. To enhance the growth of *Mesotoga*, researchers had the idea of cultivating *Mesotoga* with another bacterium capable of producing sulphides from sulfate. This operation was a success and enhanced the researchers' understanding of the metabolism of *Mesotoga*.

This bacterial combination, protected by two patents, could therefore be used to "bioremedy" environments contaminated with hydrocarbons, BTEX (benzene, toluene, ethylbenzene, xylene), organochlorines or heavy metals as a result of anthropogenic activities. From a more fundamental point of view, studying the genome of *Mesotoga* will shed light on the evolutionary transition which allowed microorganisms to switch from life at a low temperature to life at a high temperature or vice versa.

PARTNERS

National Institute of Applied Science and Technology, Tunisia

Centre of Biotechnology of Sfax, Tunisia

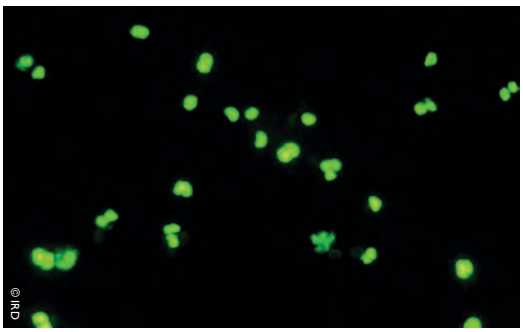
Catching cyanobacteria red-handed

The proliferation of microorganisms in marine or terrestrial aquatic environments can cause health problems, particularly when combined with the production of toxins. High-performance monitoring systems help reduce the impact of this phenomenon.

Certain cyanobacteria, such as *Microcystis,* are capable of changing water into a deadly poison. When they proliferate in fresh water, they sometimes produce a hepatotoxin, microcystin which, when ingested, can damage the liver or cause kidney tumours. Through drinking the water or via the rest of the food chain, they are therefore likely to affect human health as well as contaminate wildlife and domesticated animals. This is why, in a number of countries such as Canada and Australia, these microorganisms are constantly monitored. Their detection in water triggers health alerts or site closures… But are these measures always a necessity?

The proliferation of cyanobacteria does not necessarily mean that the water has become toxic. For reasons that are still unclear, the synthesis of microcystin is not systematic and false alarms are regularly triggered. Hence the relevance of a new approach based on molecular markers, published in 2017. Easier and faster than current procedures, it helps identify potentially toxic cyanobacteria and performs a visual count of those which are in the process of secreting toxins. Detection is achieved via molecular probes designed to characterise the identity and activity of microorganisms. These fluorescent probes are attached to RNA molecules: ribosomal RNAs, in order to specify the identity of the microorganism; and messenger RNAs to determine the activity associated with the biosynthesis of toxins.

This approach should contribute to improving monitoring systems and gaining a better understanding of the factors behind the synthesis of toxins. Since this seminal work, 25 activity probes have been designed to characterise all types of planktonic microorganisms as well as some of their noteworthy metabolic activities.



Cyanobacteria marked by molecular probe.

PARTNERS

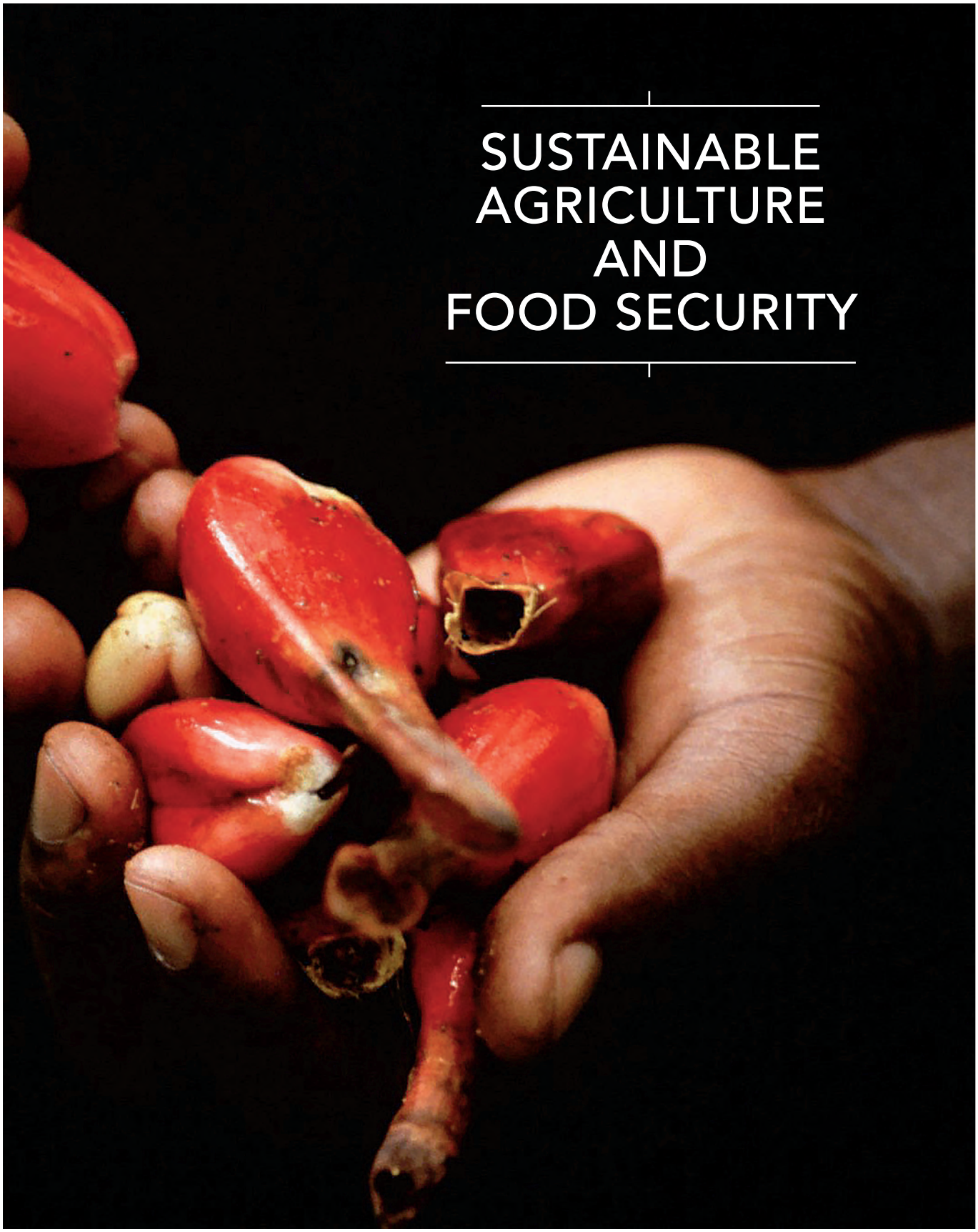
Loyalty Islands Province, New Caledonia

University of Rennes, France

Paris-Diderot University, France

PART 3

Developing sustainable agriculture and managing resources in keeping with global changes while preserving the environment are the challenges of sustainable development. The aim is to meet food security objectives looking ahead to 2050, to feed a world population which is expected to reach 9 or 10 billion and, in this respect, to improve water, soil and agrosystem management practices while controlling carbon flows, so as to manage all resources in a sustainable manner. Research on fish stocks and aquaculture resources should also help alleviate pressure on ocean resources.



SUSTAINABLE AGRICULTURE AND FOOD SECURITY

Sequestering carbon in soil

Soil serves as an interface between air, water and living beings. While its composition and structure determine its fertility, it also has the ability to sequester greenhouse gases. Since the 1992 Earth Summit, this ability has generated a lot of interest.

Decomposing organic matter.

Until the 1990s, soil scientists had two utmost priorities: soil fertility and the protection of these heterogeneous environments, where organic elements grow alongside mineral matter under sometimes intimate forms, notably in humus, an organic matter of plant, animal and microbial origin which, as it decomposes, changes soil properties.

To study this organic matter, in the 1970s soil scientists developed innovative techniques to understand its structure and composition, as well as quantify its distribution in tropical soils. This research resulted in maps positioning soils according to their organic matter content, as well as technological developments (infrared spectrometry) making it possible to increase the number of low-cost analyses. This research also led to the identification of farming practices which sequester more organic matter in soil to enhance land fertility, providing a wealth of information which aroused growing interest in the 1990s, when the world became aware of the importance of greenhouse gases. At the interface between the atmosphere and plants, soil is a potentially important compartment for the storage of greenhouse gases (CO_2, CH_4 and N_2O). Consequently, all previously acquired knowledge has been reviewed in light of carbon and nitrogen sequestration in soil.

"Organic matter in tropical soils is of paramount importance for soil fertility, all the more so as these soils are often highly altered and characterised by their low clay content and low reactivity (kaolinite). Research conducted by IRD on this issue has contributed to driving agricultural research in Burkina Faso and sub-Saharan Africa. It has been instrumental in theorising the biological functions of soil. The "Zai" technique is an excellent practical illustration of this."

Professor Edmond Hien, professor at the Joseph Ki-Zerbo University, Ouagadougou

Peatlands accumulate organic matter, filter water and provide forage, Bolivia.

••• Certain farming practices help enhance the potential to sequester carbon in soil •••

Researchers subsequently showed that the implementation of cultivation techniques such as conservation agriculture and agroforestry or the cessation of slash-and-burn farming could trap a significant amount of emissions over the next 20 to 30 years. This resulted in the "4 per 1,000" French initiative, the purpose of which is to increase carbon sequestration in soil by 0.4% each year, via appropriate agricultural practices.

PARTNERS

University of Ouagadougou, Burkina Faso

University of Antananarivo, Madagascar

University of São Paulo, USP/CENA, Brazil

LMI-IESOL, Burkina Faso - Senegal

Erosion in the shade of trees

Changes in agricultural practices have a strong impact on soil quality. Over the past decades, forest clearing for cultivation purposes has promoted water run-off on the surface of the land parcels, accelerating erosion and soil depletion.

Erosion gully, Mexico.

From 1946 to 1948, Algeria and Madagascar experienced significant soil erosion problems, including the formation of gullies, which was a new phenomenon. Following in the footsteps of the Americans, Orstom researchers undertook to study these processes in Africa, and later in Latin America and Asia. In the 1950s, they began by measuring the loss of matter on calibrated parcels. In 1973, these results were summarised to tailor the "universal soil loss equation" to African conditions and highlight some of its limitations. This equation, proposed by the Americans in 1959, is only universal in name, as it is only indicative of the impact of water erosion on the scale of the parcel, and in a US context.

In addition, these material loss measurements revealed the effective resistance of tropical soil and the relevance of maintaining plant cover rather than terracing. This was enough to revolutionise soil conservation, notably in Africa which saw a rapid transition from an approach based on terrace cultivation to erosion control using agro-ecological techniques, i.e. plant cover management, the use of crop residues, rotations, minimum tillage and fallows.

In the late 1970s, researchers attempted a more experimental approach: drawing inspiration from a US model, they built a large-scale rainfall simulator that they used from the tropical rainforest to the Sahel. As this was a very heavy device, they designed a smaller, easily transported version which has since been used on four continents. In the late 1990s, they also installed the device in water catchments to quantify erosion due to gullies and landslides, showing for example that the soil of a forest with no undergrowth degrades rapidly because raindrops expand as they fall on leaves and then hit the ground hard. Contrary to popular belief, tree plantations do not necessarily protect soils better than scarcer vegetation.

PARTNERS

Department of Agricultural Land Management, Laos

Soils and Fertilizers Research Institute, Vietnam

Department of National Parks, Wildlife and Plant Conservation, Thailand

Arid Regions Institute, Tunisia

Mohammed V University, Morocco

••• Orstom has long advocated for agro-ecological approaches to soil conservation in the tropical belt •••

Uprooted olive tree, Tunisia.

"As a national partner of IRD, I have witnessed the numerous impacts of multi-scale studies on erosion in Laos: they have helped raise the awareness of policy-makers while also resulting in direct recommendations to farmers on how to manage their land, emphasising the effects of inappropriate practices on erosion, land fertility and the quality of downstream water."

Oloth Sengtaheuanghoung, soil scientist, Department of Agricultural Land Management, Laos

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.

Cowpea nodules, Senegal.

Legumes (soybeans, peanuts, beans) produce seeds which contain up to 30% protein, which makes them nutritionally attractive. This is not their only benefit though, 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.

••• Symbiosis can be used to fertilise or remediate soil •••

In other contexts, this symbiosis has also been used to fertilise nutrient-poor soil, for example in Thailand where legume-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

"Research conducted in partnership with IRD, including work aimed at biofertilising farmers' fields with nitrogen-fixing bacteria, contributes to improving production yields while reducing the use of chemical fertilisers. It is particularly important for African countries, with a view to promoting resilient practices and mitigating the impact of climate change."

Diegane Diouf, professor at the Cheikh Anta Diop University of Dakar, Senegal

Preparing rice for transplantation, Thailand.

Macrofauna, macro-effect

Acting as an interface, soil provides numerous ecosystem services on which humanity depends: recycling of nutrients, primary production, carbon sequestration, resistance to erosion. Yet these functions could not be performed without soil-dwelling organisms.

Earthworm castings in a field, Togo.

In Madagascar in 2017, researchers showed that the addition of earthworms to soil could increase the yield of a rain-fed rice field by 40%. Hence the invertebrates' nickname of "soil engineers" used in the 1990s during the launch of a research programme on soil macrofauna.

At the time, the scientific community was just beginning to realise that invertebrates visible to the naked eye (earthworms, termites and larvae) play a leading role in the functioning of soil. They facilitate organic matter decomposition and nutrient recycling and availability to plants. By building underground networks, they also alter the physical properties (soil structure, water retention, erosion) and biological properties (modification of microbial activity) of soil. Furthermore, they can improve plant resistance to certain pathogens such as rice blast and certain parasitic nematodes.

••• Earthworms, insect larvae and termites have a major effect on soil properties •••

IRD has largely contributed to the highlighting and quantifying in tropical countries of these remarkable properties, notably via indicators making use of the macrofauna's activity to describe soil functions and understand the condition of an eco- or agro-system. These functional indicators have been the subject of extensive research and developments over the past few years, including the introduction of the Biofunctool® tool in 2018, which provides a set of field indicators to measure soil health.

Meanwhile IRD researchers, at the forefront of this issue, tested protocols to intensify certain macrofauna functions, thereby increasing the productivity and sustainability of small family farms.

PARTNERS

University of Antananarivo, Madagascar

Nagui Abrogoua University, Côte d'Ivoire

Xalapa Institute of Ecology, Mexico

Khon Kaen University, Thailand

"The study of soil macrofauna and its functions in agriculture and the environment is a scientific aspect which has only been addressed in Madagascar since the partnership between IRD (Eco&Sols UMR) and the Radioisotope laboratory was launched in 2004. Since then, it has been found that these organisms, more specifically earthworms, play a major role in maintaining the sustainability of Madagascar's agrosystems. The results of the studies carried out suggest that the direct introduction of earthworms, by inoculating parcels, or their indirect introduction, via the use of vermicomposting, contributes to the sustainability of Madagascar's agrosystems."

Professor Tantely Razafimbelo, Radioisotope Laboratory (LRI), Madagascar

Use of compost for agricultural work, Madagascar.

Correcting the pH of soil

Soil salinisation is one of the major obstacles to agricultural production in arid and semi-arid regions. This process has been largely exacerbated in recent decades due to the expansion of irrigated land without drainage, as well as climate change and rising sea levels.

Salty soil, Thailand.

PARTNERS

Assane Seck University of Ziguinchor, Senegal

National Research Institute of Rural Engineering, Water and Forests (INRGREF), Tunisia

Kasdi Merbah University, Ouargla, Algeria

Polders are scattered around Lake Chad which, one day, could feed a large part of the region's population. These polders are the ongoing results of old research conducted by researchers. While the soil surrounding Lake Chad is very fertile, it is also particularly difficult to cultivate, due to its high clay content. Water does not seep in easily. It stagnates and deposits mineral salts which make the land alkaline and less permeable. If precautions are not followed, this soil can quickly become infertile. Researchers solved this problem from 1950 to 1980 by adding gypsum and limestone to soil in order to change its pH, promote water drainage and boost yields.

••• By improving certain agricultural techniques, scientists converted land unsuitable for agriculture into arable land •••

In the 1970s, in West Africa this time, similar research was conducted on mangrove ecosystems with a view to making soil exposed to brackish water suitable for agriculture. The mangrove salinisation issue was even more complex, as salt was not the only challenge to be tackled to reclaim these milieus. Once it has been dried, mangrove land tends to oxygenate and to become acidic enough to kill plants. Scientist however found solutions on a case-by-case basis, by building small dams, using parcel lifting or pH modification techniques. In the 1980s-1990s, this experience led to a more experimental phase, followed by the modelling of soil acidification and salinisation phenomena. It became possible to provide farmers with suitable cultivation techniques prior to planting or sowing.

Mangrove rice field, Guinea.

"Orstom's work served as a basis for stimulating research on the reclamation of salty and acidic rice-growing land in the mangroves and *tannes* of the Basse Casamance region, an issue which has become even more critical in light of climate change, the fight against desertification, biodiversity conservation and the decrease in agricultural and crop production in West Africa. Research currently conducted by the Assane Seck University of Ziguinchor is driven by the desire to build and update scientific knowledge while developing certain ecosystem services related to the mangrove, such as solar salt, a recent ground-breaking initiative which is currently under review."

Lamine Fall, teacher-researcher, Assane Seck University of Ziguinchor, Senegal

Small dams, major effects

From simple tanks to large dams, storing water is a necessity in arid regions: the construction of small dams has gradually developed in recent decades.

Onion cultivation using rainwater stored in a small dam, Burkina Faso.

Livestock by a reservoir, Burkina Faso.

In the 1980s, the Sahel was hit by severe drought, prompting scientists to explore the agronomic potential of mud flats, i.e. the wetlands that African populations were forced to flee because of onchocerciasis. As this disease was now under control since the parasite that caused it was eliminated, new development opportunities were opening up to populations. Researchers tested new small and medium-sized stormwater management infrastructures: permeable rock dams in Burkina Faso, partially subsurface dams in Mali, and small dams in Côte d'Ivoire and Senegal. This research inspired NGOs which, in turn, started installing small reservoirs.

The interest was such that, in 1996, research was initiated on these small reservoirs in the Sahel (Burkina Faso and north of Côte d'Ivoire), Latin America (Mexico and Brazil), North Africa (Morocco and Tunisia) and the Middle East (Lebanon), as part of the "Small Dams" multidisciplinary project. Hydrologists, agronomists and fisheries experts improved the techniques, while geographers, ecologists, sociologists and economists began to gauge their effects, as hundreds of thousands of small dams have been built since the 1980s.

"Research was conducted on hillside dams in Tunisia to support an ambitious land use planning project implemented by the Ministry of Agriculture. It resulted in the creation of an observatory used as a reference for current water and soil conservation projects. Exchanges between scientists from the Mediterranean region, sub-Saharan Africa and Latin America have also underlined the fundamental role of these infrastructures in the sustainable development of arid areas."

Professor Akiça Bahri, National Institute of Agronomy of Tunisia, former head of IWMI for West Africa and former coordinator of the African Water Facility with the African Development Bank

Hillside dam in Tunisia.

••• Research focuses on hydraulic developments for the reclamation of mud flats •••

While their economic performance has been regularly criticised as being sub-optimal, research emphasises the value of these small dams and demonstrates that they are an effective tool for mitigating the effects of global changes. Numerous and widely dispersed, they provide a variety of services (domestic use, irrigation, livestock watering, fishing, groundwater recharge, etc.) in close proximity to rural populations. They are good sediment traps, thereby significantly extending the operational life of major structures further downstream. They also provide wetlands which contribute to maintaining aquatic and terrestrial biodiversity. Small dams are currently instrumental in land use planning in the most vulnerable regions of the tropical belt.

PARTNERS

West Africa: International Water Management Institute (IWMI)

Brazil: Federal University of Pernambuco (UFPE)

Mexico: National Research Institute in Forestry, Agriculture and Fisheries (INIFAP)

Mediterranean: Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD), National Research Institute for Rural Engineering, Water and Forestry of Tunisia (INGREF)

Water in African soil

According to Unicef, more than 2,000 children, mostly African, die each day because they do not have access to drinking water, a problem international investment has thus far failed to solve.

Groundwater exploration using magnetic resonance.

Thirty percent of Africans do not have access to drinking water in sub-Saharan Africa, despite the construction of tens of thousands of wells and boreholes in recent decades. Forty percent of the boreholes drilled fail to discover water or, when they do, it is not enough to meet the demand. This raised the question of the approach used to determine the location of boreholes.

In Africa, 40% of the subsoil consists of ancient, hard rocks. Deemed to be non-porous, they are assumed to let water flow when they are fractured. These areas are generally searched for on the surface using various techniques, including the analysis of aerial images or in situ soil resistivity measurements.

In 2012, to assess this approach the GRIBA project was deployed in three countries where the subsoil consists of ancient rocks: Benin, Burkina Faso and Uganda. After analysing the results of many boreholes drilled over the past decades, and testing a number of new sites, it appeared that the main source of drinking water does not lie in fractures but in underground areas where rocks are altered and reduced to a sand-like state. This was a major breakthrough: groundwater should not only be sought in fracture zones.

In 2015, researchers took it a step further by developing a method used to characterise these invisible, deep-seated sand alteration areas from the surface. It required two instruments: one standard tool used to measure electrical resistivity in two dimensions and detect sand alteration areas; and the other, RMP, developed by IRD and used to determine the volume of water available and estimate the potential withdrawal volume. This enabled the setting of sustainable abstraction thresholds, and Benin is acquiring the equipment needed to test this approach on a larger scale.

PARTNERS

University of Abomey-Calavi, Benin

University of Ouagadougou, Burkina Faso

Makerere University, Uganda

General Directorate for Water, Benin

Ministry of Water and the Environment, Uganda

"This research, conducted in partnership with IRD, helped train junior and senior Benin researchers in the implementation of this new groundwater prospecting approach in bedrock areas. In addition, the population and the authorities are now aware of groundwater levels in the communities surveyed. At the end of the day, policy-makers have become aware of how effective this new approach is, and have incorporated it into tender specifications for drinking water supply in Benin."

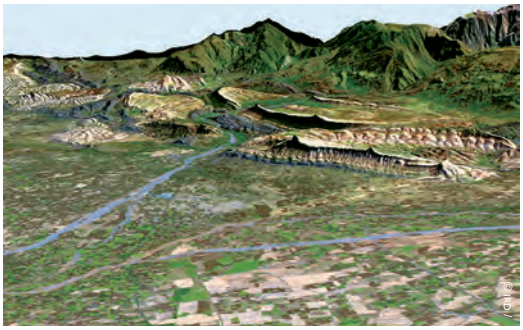
Professor Nicaise Yalo, University of Abomey-Calavi, Benin

Borehole equipped with a pump, Benin.

Measuring water

Humans are putting mounting pressure on water resources. They use water for drinking, washing and, above all, irrigation purposes. Eighty percent of the water abstracted is intended for agriculture, which poses a significant challenge in regions where freshwater is increasingly scarce.

Rural landscape in Morocco.



Modelling of a valley in Morocco.

Farmers use water to irrigate their fields, but the amount withdrawn is not clearly known, even to water management agencies, a fact which is not without consequences for the environment or the populations. The absence of quantification makes it difficult to estimate the pressure on the water table and avoid excessive withdrawals. In an attempt to remedy this situation, in the early 2000s a scientific programme was established in a semi-arid region of Morocco to determine the amount of water needed for every crop, as well as the amount used by farmers for irrigation purposes. When is irrigation necessary and how much water should be applied?

Researchers started working in the field to measure evapotranspiration and the water balance as accurately as possible for various types of crop and under various weather conditions. They came up with values which they used to model the water consumption of Moroccan crops based on the weather and high spatial resolution satellite data to monitor plant growth over time and space. They were therefore able to determine the quantity of water used in agriculture for vast territories.

They developed an initial version of the SAMIR model, a platform intended for water management bodies to better gauge the quantities withdrawn for the agricultural sector. However, the routine use of SAMIR was impeded by the high cost of high-resolution satellite images and their insufficient frequency. These two obstacles were removed with the launch, in 2015 and 2017, of the *Sentinel 2* satellites of the Copernicus European programme, which provide free, very high resolution images of every spot on Earth every five days. The SatIrr model was later created to respond more specifically to the need to manage each irrigated parcel. This is accessible online for free, advising farmers on the amounts of water required. Tailored to the Mediterranean region at present, it will soon be configured for damper climates, such as that of southern India.

PARTNERS

Cadi Ayyad University of Marrakech

Haouz Agricultural Development Office, Morocco

Tensift Hydraulic Basin Agency, Morocco

National Institute of Agronomy of Tunisia

Underground passage entrance, Skoura oasis, Morocco.

Khettaras: living vestiges

The hot and dry climate of the Mediterranean Rim forced local populations to come up with solutions to find water, notably by modifying their environment. Drainage tunnels – or *khettaras* – are amongst the techniques implemented over the centuries and currently being restored.

They were thought to have dried up, but in the aftermath of the drought that devastated Morocco until the early 2000s, the return of water was accompanied by the reopening, in pre-Saharan oases, of large drainage tunnels dug by humans over the centuries. In 2005, a research team looked at the rehabilitation, in the Tafilalet region, of a maze of underground tunnels of 5 to 10 kilometres each, at a depth of 2 to 18 metres. Their purpose was to drain water from the water table and bring it to the oases.

While such structures exist and are still being used in Iran and Algeria, they were believed to be completely abandoned in Morocco. Not quite the case as, in at least five locations (Figuig, Boudnib, Tafilalet, Todgha, Skoura), researchers found tunnels in the process of being rehabilitated by rural populations and described the functioning of these structures, locally known as *khettaras*.

It appears that people living in oases are now involved in the maintenance of *khettaras* and in agriculture, particularly young people who have returned to rural areas because of rampant unemployment in the cities. This is a risky undertaking in light of climate uncertainty, its clear purpose being to revive collective action and regain control over access to water with a view to a potential shortage in the coming years.

This research resulted in the publication of scientific articles as well as the construction of two models presenting the operation of these hydraulic structures. One is on display at Marseille's Mucem, while the other is in the Mohammed VI Museum of Water Civilisation in Marrakech, Morocco. This has raised the profile of these ancestral techniques which, unlike modern approaches, make use of the water from water tables without ever leading to excessive withdrawals.

Khettara in the Tafilalet valley, Morocco.

PARTNERS

Cadi Ayyad University of Marrakech

Ibn Zohr University of Agadir

Hassan II Institute of Agronomy and Veterinary Medicine, Rabat

ORMVAO, Ouarzazate

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.

Agroforest village, Indonesia.

In 1980, a team of tropical 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 had been 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 support rice crops, before producing fruit, rubber and firewood. Other agroforests on the island account for 80% to 90% of the animal biodiversity, including a rhinoceros which was thought to be extinct.

Studies conducted later in Brazil and 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

"Research conducted in partnership with our IRD colleagues on community agroforest systems in Morocco directly contributed to qualifying traditional knowledge to improve the conservation of these agroforests and socio-cultural areas. Managing these agroforests as a common good *(Agdal)* helps develop expertise as well as a model for accessing resources, which guarantees the sustainable and sound management of forage and timber resources: valuable lessons can be learned to improve our public policies around these issues."

Mohamed Alifriqui, Ecology and Environment Laboratory, Cadi Ayyad University, Marrakech, Morocco

Damar agroforest, Sumatra, Indonesia.

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

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 the practices of the Global South.

PARTNERS

Centre for International Forest Research (CIFOR), Indonesia

World Agroforestry Centre (ICRAF), Kenya

Cadi Ayyad University, Morocco

Instituto Nacional de Pesquisas da Amazônia (INPA), Brazil

Institute of Agricultural Research for Development (IRAD), Cameroon

Land: a scientific tool for development

Village scene, Rhumsiki, far north region of Cameroon.

After African countries gained independence, African agriculture was in need of modernisation. Development operations were financed with no preliminary studies, creating a need for scientific knowledge relating to African agricultural issues.

Field labour, Niger.

In the 1950s and until the early 1960s, large-scale agricultural surveys were initiated in a number of African countries (Guinea, Côte d'Ivoire, Cameroon) to provide overall statistics on the scale of vast regions. Consequently, this data concealed spatial differentiations, in addition to being static and minimising the role of food crop production.

This led to the adoption of a radically different approach in the 1960s: using monographs to describe the components of local agrarian situations which were to provide indicators tailored to every form of African agriculture. The core document was a set of land maps, defined as an "appropriate part of a territory, developed and used by the people who live therein and from which they derive their livelihood".

From the 1960s to the 1980s, generations of young geographers conducted land surveys which accurately reflected local agrarian organisations. In contrast to previous assumptions, these surveys were as elaborate as in Europe, with original features such as the pivotal role of certain trees in farming systems.

In the 1990s, developers realised that the land-based approach could provide insight into farming innovations, such as the integration of crop growers into migrant reception centres and parcel improvements following the adoption of new agricultural outputs. The purpose of the "land management" policy was to involve village communities in the development process, notably the preservation of natural resources and land management.

As they involved prolonged immersion in village life, land surveys raised the researchers' awareness of the pertinence of the farmers' knowledge of agriculture. This rehabilitation of local knowledge, which is more relevant than ever, is the foundation of endogenous rural development, free from external influence.

PARTNERS

Human Sciences Institute (EPHE, 6th Section), Paris, France

Paris I-Sorbonne University, France

Paris X-Nanterre University, France

The Amazon forest hiding behind felled trees

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

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.

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 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 and the distribution of useful species such as the Brazil nut, cacao and 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.

Cassava tubers and cuttings, Río Negro, Brazil.

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

Optimising agricultural knowledge

The droughts of 1972-1973 in the Sahel revealed the importance of land degradation and its consequences for the people. Recognition of this importance on an international scale was a gradual process.

Line of stones against erosion, Gabon.

Irrigation channel, Niger.

The old pipe gives the sweetest smoke, it is said, and one can draw inspiration from ancestral practices to develop tomorrow's agricultural techniques. This was the gist of the large-scale fallow programmes implemented in the 1990s by IRD in those Sahelian countries affected by desertification: Côte d'Ivoire, Niger, Senegal, Mali and Burkina Faso. The idea was to identify traditional agricultural practices and optimise them to respond to the needs of growing populations.

In Burkina Faso, researchers paid close attention to "zai", a technique used by farmers to spectacularly revegetate dry land. It consists of criss-crossing the soil with small gullies and only planting at the intersection of these lines, making it possible to till the land in a targeted manner, by bringing water and organic matter to exactly where the plant is growing. Researchers optimised this practice by adding bacteria or fungi capable of breaking down the organic matter and therefore accelerating the release of nutrients beneficial to the plant.

An alternative approach was to use termites as biological fertiliser by making them break down crop residues. The resulting powder was used, for example, to grow tomato plants in Burkina Faso. Furthermore, researchers developed assisted natural regeneration techniques to promote the growth of new shrubs on agricultural land, and prevent the ageing of tree populations, which offer havens for biodiversity while providing natural protection against water and wind erosion. These various forms of knowledge were recognised by the French scientific committee on desertification, and included the "Great Green Wall" project initiated in 2008.

PARTNERS

Cheikh Anta Diop University, Senegal

Senegalese Institute of Agricultural Research

Environment and Agricultural Research Institute, Burkina Faso

From IPCC to operational status

Climate change is a reality, the effects of which are already being strongly felt. As such, "weather-sensitive" companies and stakeholders in the agricultural sector and the wine industry are particularly affected, due to their high level of economic vulnerability.

Scientific knowledge in terms of climate change is summarised in reports issued by the IPCC, the prestigious Intergovernmental Panel on Climate Change… but also in very concrete tools valuable to society. At least, that was the idea of a climatologist who, in 2010, convinced IRD to help him create a French-Argentine venture named Ecoclimasol. The purpose of the company was to create platforms via which small producers could better prepare for climatic hazards, by accessing more targeted agro-climatic forecasts obtained using digital models, sensors and local weather stations.

In its early years of operation, those interested in the company were not farmers so much as insurance companies, who used the system to detect fraud. The platform was also used to determine the validity of compensation claims in case of extreme climate events. After this initial success, the team developed two other interfaces, one for farmers and the other for wine growers. Affordable and easy to use, they provided real-time forecasts for the next few days or for the season, thanks to artificial intelligence capable of compiling data from different information channels. They helped users avoid unnecessary expenditure and pollution, notably because they could avoid applying fertilisers or plant crop protection products just before a rainy period.

At the same time, Ecoclimasol developed a platform in Argentina to make all climate forecasts transparent and understandable. Research continues to this day with the identification of the most vulnerable areas and advice on how to adapt to climate change, making it possible to better protect people and design future infrastructure such as bridges, roads and sanitation systems.

Climavista Agro platform, Ecoclimasol.

PARTNERS

International Centre for Higher Agronomic Research - Mediterranean Agronomic Institute of Montpellier (CIHEAM-IAMM), Montpellier, France

Pierre-Simon-Laplace Institute (IPSL), Paris-Saclay University, France

First mapping of rice yellow mottle virus

Rice yellow mottle virus affects wild and cultivated rice varieties. Specific to Africa, it can generate yield losses of up to 100%. It therefore poses a threat to the continent's food security.

Rice variety sensitive to the rice yellow mottle virus.

Manual transplantation of young rice plants grown in a nursery, Tanzania.

Rice yellow mottle virus is a scourge which – for once – spreads slowly. In order to be contaminated, a rice plant must come into contact with a plant affected by the virus or interact with beetles capable of transmitting the virus. Certain farming practices such as transplantation can also accelerate the spread, which still remains rather slow. Consequently, the virus has had plenty of time to evolve and differentiate into several strains of variable virulence. In the late 1990s, two teams of researchers initiated research into this disease. The first team attempted to select rice plants resistant to rice yellow mottle virus, while the other focused on the virus, more specifically its genetic diversity.

To this end, the second team analysed the RNA of viruses collected throughout Africa on different dates and showed that rice yellow mottle virus first appeared in East Africa, and evolved as it spread. As a result, every virus strain has its own distribution area. The characteristics of these strains were tested in laboratories. In 2018, this study led to the publication of a map outlining the distribution area and virulence of the various virus strains, as well as a guide for the appropriate deployment of the most resistant rice varieties, for example by avoiding regions with the highest risks of the virus breaking this resistance and attacking these varieties: in Burkina Faso, Togo, Benin, Niger and Nigeria, researchers discovered a particularly virulent virus strain, against which no known resistance gene is durably resistant. Moreover, this mapping work revealed anomalies in the circulation of certain strains, which seem to disperse more quickly than others and expand their distribution area.

PARTNERS

AfricaRice Centre, Bouaké, Côte d'Ivoire

Faculty of Agricultural Sciences and the Environment (FSAE), University of Tillabéri, Niger

Cassava and its bacteria legacy

There is a bright future for cassava. The fourth main source of calories in tropical countries, this plant with edible roots can withstand drought and, against the backdrop of global warming, could become tomorrow's staple food.

In 1985, a bacterium devastated all the cassava fields in Congo-Brazzaville, causing large-scale famine. Observed a few years earlier in Côte d'Ivoire, it was believed to have fallen down from the sky. No, *Xanthomonas phaseoli* pv. manihotis, or *Xpm* as it is commonly known, is from this earth, as demonstrated by researchers when they detected its existence in Latin America, the home region of cassava and probably that of the bacterium, where it also decimates plantations and spreads with cuttings. To grow cassava, farmers transplant stem cuttings. If the initial plant is infected, the risk of an epidemic situation is significant.

To try and reverse this trend, researchers created cassava nurseries in forest areas fairly isolated from one another. However, they also focused on the molecular mechanisms which determine the virulence of the microorganism. In the early 2000s, they sequenced the bacterial genome. One of the 5,000 genes discovered caught their attention as its inactivation completely prevents the bacterium from multiplying. This opened up new disease control options. Meanwhile, in 2018 they developed a high-performance molecular diagnosis tool to detect infected plants and prevent the spread of contaminated cuttings.

Researchers also explored the genetic diversity of the microorganism to shed light on its ability to break the resistance mechanisms of cassava. To do so, they collected diseased seedlings in various African and Latin American countries, but also in herbaria, finding a cassava leaf which had been infected in 1821 in Argentina. This long-term research will improve knowledge of the pathogen's historical and contemporary distribution area, with a view to ultimately increasing the understanding of its evolutionary history and predicting future epidemics.

Bags of cassava semolina, Brazil.

PARTNERS

Félix-Houphouët-Boigny University, Côte d'Ivoire

University of Sciences, Techniques and Technologies of Bamako, Mali

Environment and Agricultural Research Institute, Burkina Faso

Universidad de los Andes, Universidad Nacional de Colombia, International Center for Tropical Agriculture, Colombia

Unwitting pests

While maize and sorghum are the most produced cereals in Africa, their yield is low because of adverse weather conditions, lack of soil fertility, diseases but also butterfly larvae.

Larva of *Busseola fusca* insect, a maize and sorghum pest.

In Africa, the larvae of certain butterflies bore into the stalk of cereals such as maize or sorghum, causing average yield losses of 20% to 40%. To deal with this problem, farmers learned how to eliminate surrounding uncultivated land which, according to agronomists, formed a reservoir for these pests. This idea was refuted by other scientists as part of a programme deployed in the early 2000s in East Africa, primarily in Kenya, Uganda and Tanzania.

As larvae seemed to differentiate themselves through a variety of cycles and behaviours, researchers examined them more closely and found dozens of species behind the few pests identified for close to a century. This finding, confirmed by genetic studies, raised questions about what drives only some species to become insect pests. Research revealed that most larvae are in fact highly specialised. Among the numerous species found in uncultivated land, only a few generalist species or species feeding on grasses related to cereals are capable of raiding crops.

This uncultivated land is also home to many natural enemies of larvae, in particular wasps. Therefore, proximity to uncultivated land, far from being a problem, seems to be a solution to limit the impact of pest larvae by strengthening biological control.

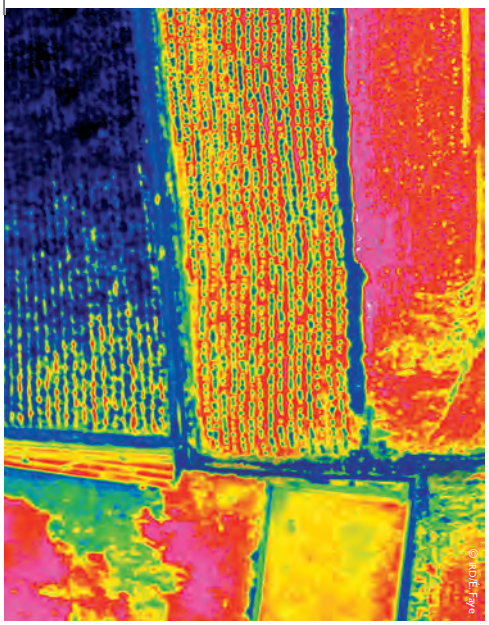
A recent biological control assessment carried out in Kenya, Mozambique and Zambia showed that it helped limit yield losses while lifting nearly 140,000 farmers out of poverty. Another promising solution to strengthen biological control would be the simultaneous cultivation of several types of cereal, to limit the proliferation of specialist insects.

PARTNERS

School of Biological Science, University of Nairobi, Kenya

Faculty of Agronomy and Forest Engineering, Mozambique

Faculty of Sciences and Biodiversity Monitoring Center, University of Kisangani, Democratic Republic of the Congo



Thermal landscape based on images from a drone.

Fields under thermal surveillance

Drones can visualise changes in temperature in a crop with centimetric precision.

In the Ecuadorian Andes, an invasive insect, the Guatemalan potato moth, has been wreaking havoc in potato fields for years, ruining up to 100% of crops. IRD began to explore this scourge in the early 2000s, showing that the development cycle of this species, like that of most insects, was closely correlated with temperature. This finding prompted researchers to look at the effect of the thermal heterogeneity of the environment on the behaviour of these pests. They became interested in measuring this heterogeneity, not on the scale of the planet, continent, region or field but on the scale of the insect, i.e. the centimetre.

This is why, in 2012, researchers equipped a drone with a thermal camera and precisely configured its flight route and altitude using an autopilot and GPS coordinates. This innovation allowed them to record changes in temperature on the surface of plant leaves. They showed that, within a 1.5 metre radius, insects can find a range of higher or lower temperatures within a 20°C range in relation to air temperature, thereby allowing them to adapt to ambient temperature fluctuations. This surprise discovery put the possible impact of climate change in perspective, at least for these pests.

This research led to the development of a digital tool kit, making it easier to monitor the health of fields via drones equipped with a thermal camera. The temperature of leaves damaged by pests changes, which enables their detection and paves the way for targeted action. In addition, an ongoing analysis of changes in temperature based on the position of plants could help design field architectures that are less conducive to moth invasions.

Drone flying over a field, Ecuador.

PARTNERS

Pontifical Catholic University of Ecuador (PUCE)

Raising policy-makers' awareness of bio-invasions

Catching rats, Cotonou, Benin.

Eighty percent of the global trade in goods is by sea, with consequences for ecosystems and people as shipping is particularly conducive to the dissemination of invasive species.

Port of Cotonou, Benin.

In the late 18th and early 19th century, the rapid growth of steam navigation had an unexpected impact in the form of a plague pandemic. Within 10 years, the black rats transported in the holds of ships carried the disease to all the major ports of the world. This historical example is one of the consequences of a biological invasion. There are other possible effects, notably on biodiversity, agriculture and the economy.

Despite the signing of international conventions aimed at preventing the spread of invasive species, the countries of the Global South are often ill-prepared for the risks and challenges posed by these bio-invasions. In sub-Saharan Africa, not all invasive species are known, and inventory initiatives are few and far between. Aware of the situation, researchers launched a number of initiatives in conjunction with several universities in Senegal, Niger and Benin. In 2016, a team of scientists from these three countries was established, laying the foundations for the implementation of a wider network in 2018: an international research group – Global South (GDRI-Sud) aimed at supporting research and training in invasive species in West Africa, and raising awareness of the challenges they pose among African teachers, public authorities and socio-economic stakeholders.

For example, researchers are currently establishing a partnership with the port of Cotonou to test various innovative approaches intended to better control invasive species, including the rodents likely to be introduced via merchant ships. In this port alone, one tenth of the amount of rice passing through storage warehouses is lost because of exotic mice and rats. And this is just a very small part of the actual cost of bio-invasions, as the cost associated with their consequences in terms of health, agriculture and ecosystem services remains completely unknown. As an order of magnitude, the USA allocates USD 128 billion a year to the monitoring and control of invasive species, i.e. 1% of its GDP.

PARTNERS

Cheikh Anta Diop University, Gaston-Berger University, Senegal

Senegalese Institute of Agricultural Research

Abdou Moumouni University, Directorate General of Plant Protection, Agrhymet Regional Centre, Niger

Polytechnic School and University of Abomey-Calavi, Autonomous Port of Cotonou, Benin

Dikhil palm grove, Djibouti.

Sexing to develop date palms

There are very few date palm genetic improvement programmes. Yet there is a great need for disease resistant and abiotic stress resistant plants, which are key to safeguarding and developing palm groves.

The date palm is excessively shy, taking seven to ten years before unveiling its first flowers, and therefore its gender. This dioecious species is either male or female, like the fig tree and the kiwi. This feature is not convenient for farmers: when they plant a seed they have a 50-50 chance of growing a male plant for seven years, which is a pollinator but is unable to produce dates.

This is why, in North Africa, in countries where palm groves are a tradition, farmers have overwhelmingly opted for clonal multiplication. Female plant cuttings are endlessly replanted, causing a significant loss of genetic diversity in the date palms of these regions. This is detrimental to the organoleptic properties of dates and limits the adaptability of crops to diseases or climate change.

Hence the date palm selection programmes that have been developed since 2007, notably through a federated network of African countries. In 2011, a Qatari team published the first date palm genome. With this sequencing, IRD researchers identified three genetic markers, making it possible for the first time to distinguish between males and females in 100% of cases.

This discovery, patented in 2012, has revolutionised practices. In Morocco, it is used to plant male plants in traditional palm groves to overcome the pollinator shortage. In Djibouti, it is used to select female plants and set up new palm groves in the desert.

Young date palm plants, ADIM NGO, Djibouti.

PARTNERS

University of Tunis

Djibouti Study and Research Centre (CERD)

Turning green waste into gold

Sugar, wine, olive oil and coffee production processes generate agro-industrial waste, representing significant volumes which are often discharged into rivers, thus becoming sources of environmental pollution.

Raimbault columns.

Traditional oil press, Morocco.

For every litre of olive oil obtained, 95 kilograms of green waste are thrown away (alpechin, pomace, prunings and leaves). For every cup of coffee, kilograms of pulp, grounds, prunings and leaves are wasted. In most agricultural sectors, more than 90% of plant biomass is tossed aside, causing major pollution problems. Researchers are trying to limit this enormous waste by recovering green waste.

To this end, they use an invention patented by IRD in 1975: the Raimbault column, a vertical glass tube whereby a controlled amount of gas can pass through a natural organic substrate or compound. This laboratory tool was improved to create bioreactors capable of growing filamentous fungi on agro-industrial waste and mass producing spores which will be used to seed more green waste.

In 2006 in the sugar sector, IRD researchers and their partners identified a fungus which secretes an enzyme capable of breaking down lignin and converting sugarcane bagasse into pulp. Another study conducted in Mexico showed that a fungus could be used to convert this bagasse into cattle food. Other fungi can be used to remove tannins or caffeine from coffee pulp, which can then serve as a source in the production of high added value molecules, such as antioxidants or enzymes.

In the olive oil industry, after extracting olive oil, the solid and liquid waste can be used to produce vermicompost, or even earthworms, while agro-industrial residues pre-digested by mould can become a source of production for antibiotics or biopesticides. The future looks bright for bioconversion technologies, with almost limitless possibilities.

PARTNERS

University of Tunis El Manar

Hassan II Institute of Agronomy and Veterinary Medicine and Ibn Zohr University, Morocco

Cheikh Anta Diop University, Senegal

Federal University of Parana, Brazil

"The long-standing solid-state fermentation technique is about to become relevant again. While traditional fermentation techniques have been mastered in many parts of the world, they have enjoyed a resurgence around the world over the past 20 years, with a view to understanding their principles and developing new applications."

Gustavo Viniegra-Gonzalez, professor of Biotechnology, Universidad Autonoma Metropolitana, Mexico

Sugar cane mill, Cape Verde.

••• Agro-industrial waste can be recovered instead of being dumped •••

Moving towards sustainable aquaculture

For the past 15 years, aquaculture no longer just aims at producing large quantities of fish; it also seeks to be more environmentally friendly.

Fish farm combining panga with duckweed and gourami, Indonesia.

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 in 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 panga 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 panga, 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

Clown loach, Indonesia.

Controlling reproduction

In recent decades, aquaculture production has increased from 5 million tonnes in 1980 to nearly 74 million in 2014. This growth is attributable to the fish farming boom.

In 2014, aquaculture reached a historic high, with the sector providing more than half of the fish for human consumption. It is estimated that this proportion could continue to increase and exceed 60% by 2030. This rise in aquaculture has been primarily felt in tropical areas and emerging Asian countries, where research conducted by IRD and its partners helped control the breeding cycle of 10 African, Amazonian and Asian species, notably in Vietnam where, in the 1990s, researchers managed to control the reproduction of panga, who belong to the catfish family.

At the time, this fish was already being farmed by the Vietnamese, but juveniles were harvested from the Mekong, which caused ecological and political problems, particularly with Cambodia. By examining the reproduction cycle of panga, researchers developed a hormonal induction protocol enabling the artificial reproduction of fish in order to obtain hatchery-reared fry. As a result, annual production soared from 50,000 to more than one million tonnes in approximately 15 years. Similar research was conducted in West Africa on lagoon tilapia, African sea catfish or vundu catfish, and on barred sorubim in the Amazon Basin. For the Amazonian *pirarucu*, a technique was developed to distinguish between male and female spawners.

Research was also conducted on species intended for the ornamental fish market such as the clown loach, a species endemic to the rivers of Indonesia's Sumatra and Borneo islands, where more than 50 million wild juveniles are harvested every year and exported all over the world. For this species, controlling reproduction in captivity in Indonesia corresponds with a twofold objective: economic and environmental. The idea is to alleviate fishing pressure on natural populations while also providing fry for the markets on a more regular basis.

Arapaima gigas, or *pirarucu* specimen bred in captivity, Amazon, Peru.

PARTNERS

Ocean Research Centre, Abidjan, Côte d'Ivoire

University of Cantho, Vietnam

Agency for Marine Affairs and Fisheries Research and Development (AMAFRAD), Jakarta, Indonesia

University of Santa-Cruz, Bolivia

Instituto de Investigaciones de la Amazonía Peruana (IIAP), Iquitos, Peru

Cirad, France

Tropical tuna under surveillance

The development of fishing practices using artificial floating objects could endanger tuna populations and sensitive marine species caught by accident.

Seine fishing, Seychelles.

Any object floating on the surface of the ocean is likely to attract tropical tuna. In the early 1990s, this encouraged fishermen to deploy artificial floating objects ("fish aggregating device" or FAD) to aggregate fish and facilitate their harvest using large nets known as seines, which encircle schools of fish. While this has contributed to improving vessel performance, it has raised concerns about the sustainability of tuna resources and the environmental impact of this practice.

••• Data has been collected since the late 1960s to monitor changes in tuna populations •••

Thousands of FADs are currently adrift on the ocean surface, some of which are crude and consist of bamboo rafts ballasted with a net. Their journey sometimes ends in vulnerable areas such as coral reefs, where they cause substantial damage, which prompted researchers to test new biodegradable models, in conjunction with the industry. Other FADs are equipped with measuring instruments, including GPS and even sounders to remotely inform fishermen of the presence of tuna under the FAD. If this technological upgrading were not regulated by Regional Fisheries Management Organisations (RFMO), it could have serious implications for the sustainability of abundant target populations and species affected by collateral damage.

Research confirmed that FADs tend to aggregate young (juvenile) yellow-fin tuna and big-eye tuna, who have a lifespan of approximately 15 years, and this could have adverse consequences for these two

"Insufficient knowledge of the number of FADs deployed by fishing vessels each year leads to significant uncertainties when evaluating stocks. As a result, FADs are a major and topical research area for countries of the Global South, to whom scientists must provide guidance to effectively respond to sustainable development issues."

Justin Amande, Ocean Research Centre, Abidjan

Drifting FADs on the dockside, Seychelles.

populations. Lack of knowledge about the natural mortality rate of juveniles makes it difficult however to get a clear picture of the actual impact of this fishing method. FAD fishing also causes the highest number of by-catches of non-target and sensitive species such as sharks, rays and green swordtail fish. Certain individuals are kept on board and others thrown overboard, in most cases dead.

Since the French started fishing for tropical tuna in the late 1960s, IRD's observatory of exploited tropical pelagic ecosystems has been entrusted to collect and verify the commercial data of French vessels operating in tropical waters, in conjunction with the fishing industry and partners from the Global South. Fishing data is based on the collection of logbooks kept by fishermen, indicating the dates and locations of fishing operations, catch by species and the fishing method used (FAD or free school). This information is corrected and validated by landed catch samples, as well as the frequent presence of scientific observers on board fishing vessels, thereby supplementing said information with observations on by-catches and incidental catches. Electronic observation can sometimes complement human observation. This data is used by scientists within Regional Fisheries Management Organisations to evaluate the stocks of tropical tuna and certain species caught incidentally, and to measure the environmental impact of this form of fishing. They are however still struggling to fully quantify the effect of FADs. To be continued…

PARTNERS

Ocean Research centres, Abidjan and Dakar

Seychelles Fishing Authority

Ministry of Fisheries Resources, Madagascar

Regional Fisheries Management organisations (RFMO)

Moving towards more sustainable baits

At global level, pelagic longline fishing has the same economic impact as seine fishing, which is used for tuna. It tends to target large tuna and swordfish, but can cause collateral damage, notably in sea turtles, sharks and seabirds.

Longline by-catch.

Artificial bait.

Pelagic longline fishing vessels leave a line behind, sometimes dozens of kilometres long, capable of carrying up to 3,600 hooks, which remain adrift for hours. These hooks are baited with mackerel, sardine or squid to attract large pelagic fish such as tuna or swordfish… However, sharks and sometimes protected species such as turtles, certain seabirds and marine mammals are also caught, depending on the fishing ground. And this is not the only disadvantage, as longline fishing uses 350,000 tonnes of natural bait each year, which could just as easily be consumed by humans. A terrible waste, all the more so as only 15% of this bait manages to catch target fish, with the rest being thrown back into the sea. The bait is also being purchased at an ever-increasing price, and must be kept frozen on land and at sea, which represents significant costs for shipowners and fishermen.

To reduce the environmental and economic costs of natural bait in longline fisheries, research programmes were initiated in 2008. The idea was to replace natural bait with artificial and reusable versions. Various fish-shaped lures were tested on Reunion Island for three years. An environmentally friendly artificial bait (APARE) was developed in 2011, tested and patented by IRD and, to this day, avoids catching protected species. In practice, this reusable soft and punctured shell made of biodegradable polymer can be filled with pulp made from fishery waste. Artificial bait could contribute to reducing production costs while recovering fishery by-products. A number of changes are to be made to the initial prototypes developed. Researchers are currently attempting to implement various improvements, in partnership with industrial companies, and are hoping for a 2025 market launch.

PARTNERS

Rural Federal University of Pernambuco, Recife, Brazil

Seychelles Fishing Authority, Port Victoria, Seychelles

CAP RUN/ARDA, Reunion Island

Oceanographic campaign, Peru.

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?

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 15 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 and 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 a hundred or so Peruvian scientists in 15 years. Knowledge was updated, thereby basing conceptual and numerical models on validated processes.

Tools were also developed to improve the prediction of El Niño events, view the location of water bodies, track ship and bird movements by GPS and 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.

Peruvian seiners in a fishing zone.

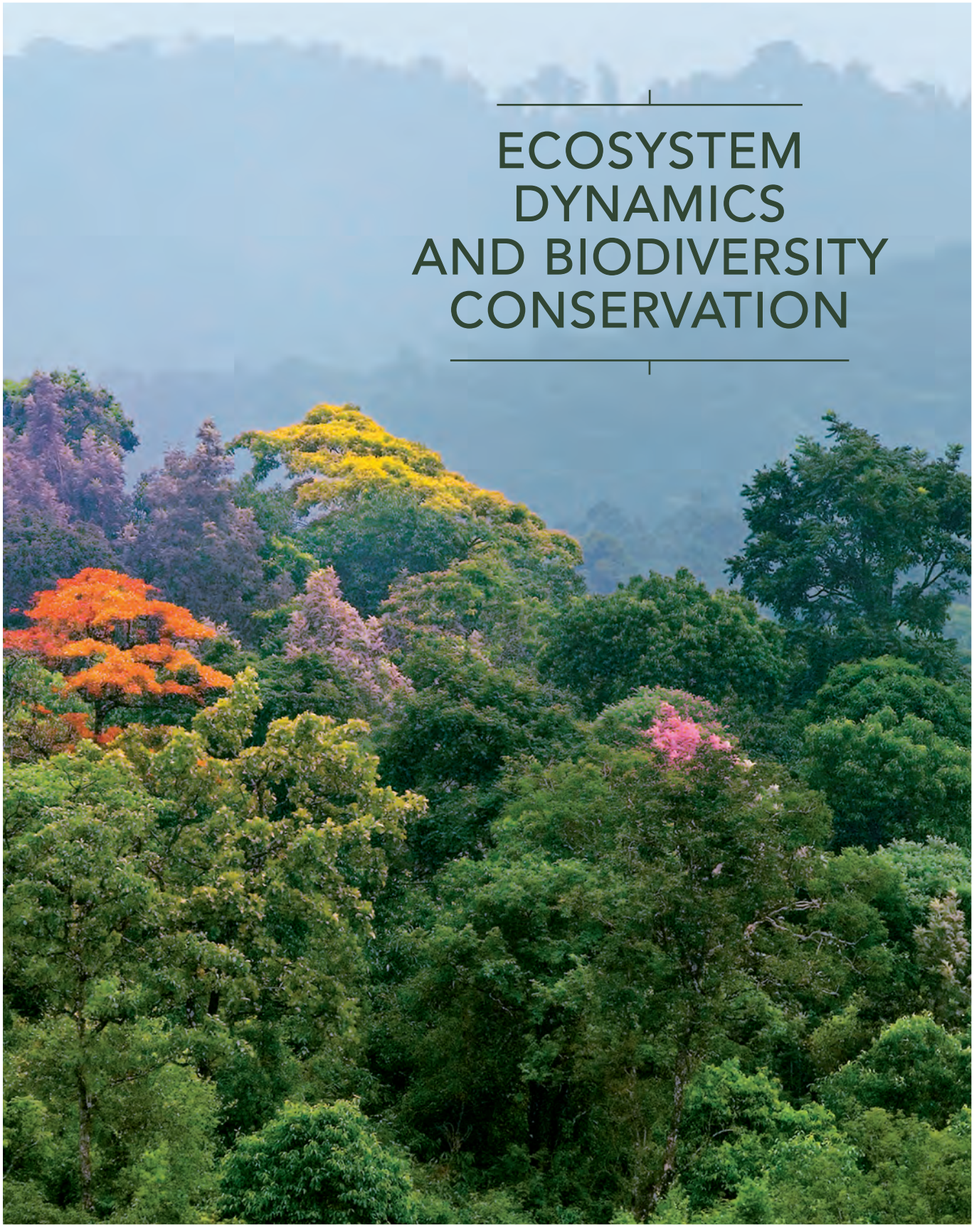
PARTNERS

Instituto del Mar del Perú (IMARPE)

PART 4

In light of climate change and growing environmental pressure, a better understanding of ecosystem dynamics and biodiversity conservation is today's key scientific issue. From the water cycle to soil dynamics, from old and current climate mechanisms to the identification and protection of biodiversity, the purpose of IRD's multidisciplinary research is to develop the global and sustainable management of ecosystems while integrating the adaptation and resilience capabilities of humans and the environment.

ECOSYSTEM DYNAMICS AND BIODIVERSITY CONSERVATION



Crackdown on El Niño

El Niño is a major driver of climate variability in the tropical belt. It alters rainfall and the productivity of certain oceanic regions and influences the formation of cyclones, with considerable societal implications. Consequently, understanding this phenomenon is a top scientific priority.

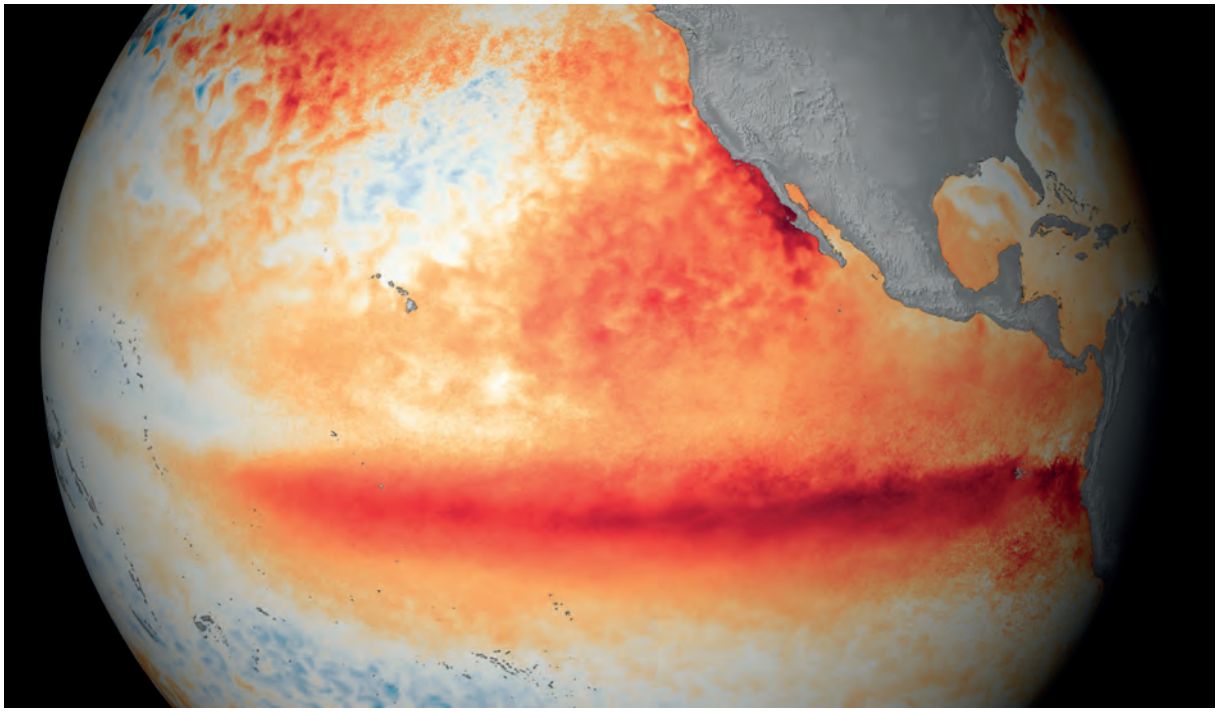
Northern Peru, destruction caused by El Niño.

In the 1980s, meteorologists were unequivocal: the weather was impossible to predict more than one or two weeks in advance. Ten years later, they were proved wrong by climatologists who managed to predict certain weather anomalies several months in advance. Getting to this point required the observation and understanding of a phenomenon about which practically nothing was known: El Niño. IRD played a significant part in this international success story, collecting numerous observations thanks to merchant vessels, oceanographic campaigns, and contributing to the installation of "TAO", a network of instrumented buoys distributed across the surface of the Pacific since the 1990s.

These observations gradually revealed the secrets of El Niño, a major climate phenomenon linked to interactions between the ocean and the atmosphere. In the Pacific, the winds usually blow from east to west, causing the upwelling of deep, cold water, rich in nutrients,

"The El Niño phenomenon has significant effects in Peru, as a result of which it raises numerous scientific issues regarding its dynamic, mechanisms and, more importantly, its predictability in the eastern Pacific. El Niño generates extreme events, with devastating consequences for people and infrastructures, which notably affect farming activities and fisheries in Peru. As a researcher working in this field, I had the good fortune to work with international experts in Peru, with the support of IRD, and to make the most of IRD's student expatriation and training model which, in addition to producing scientific publications, enables the application of newly gained knowledge to all activities…"

Ken Takahashi, head of the National Meteorological and Hydrological Service, Peru



False-colour satellite image of an El Niño episode. © NOAA

near South American shores, and warmer water conducive to heavy rainfall on the other side of the Pacific. This balance is frequently upset, resulting in El Niño events accompanied by droughts in Australia, unusually warm and low-productivity waters in Peru, or tropical cyclones in French Polynesia.

IRD researchers contributed to demonstrating the predominant role of the Central Pacific region in the creation of the "snowball effect" resulting in the development of an El Niño episode. This research, published in the late 1990s, shed light on the ocean-atmosphere interactions responsible for the development of El Niño. IRD is still working on the multiple dimensions of this climate phenomenon, more specifically on the two categories of El Niño, distinguishing between extreme events with devastating impact and other, more frequent events confined to the Central Pacific region. IRD was also instrumental in showing that the most extreme El Niño episodes could become far more frequent by the end of the 21st century. In addition, the Institute acts a driving force in the ongoing remodelling of the global Pacific ocean observing system.

PARTNERS

National Meteorological and Hydrological Service, Peru

NOAA, USA (development of the TAO network)

Commonwealth Scientific and Research Organisation, Australia

TOGA, then CLIVAR programme

Exploring tropical oceans: the Pirata programme

In the 1960s, tropical oceans were poorly understood. The creation of multiple observation systems including ships, drifting buoys and fixed buoys greatly contributed to raising awareness of these oceans, which are key to the climate system.

Buoy from the Tao-Pirata network, tropical Atlantic.

In the 1960s, Orstom launched measurement campaigns in Nouméa, lasting more than two decades, the purpose of which was to describe, for the first time, the dynamic and thermal structure of the western Equatorial Pacific. They discovered the existence of previously undetected Equatorial currents, undercurrents and counter-currents. These observations, combined with those of the US scientists in the eastern Equatorial Pacific, provided a complete understanding of the El Niño phenomenon on the scale of the entire Equatorial Pacific Ocean.

In 1974, to improve predictions of the cyclones which regularly affect the Caribbean, the GATE international programme was created, bringing together oceanographers and meteorologists for the first time. In Dakar and the Caribbean, researchers tried to understand how the heat accumulated in this area was transferred to the atmosphere. Subsequently, the FOCAL/SEQUAL French-American programme (1982-1984) focused on the structural variability of the tropical Atlantic Ocean, likely to be affected by the El Niño phenomenon in the Pacific. FOCAL and SEQUAL were followed by TOGA (1985-1995), a large-scale international programme of operational ocean observations, to which Orstom contributed most of its observation capabilities in the Pacific and Atlantic oceans.

••• Pirata's projections can help African farmers better anticipate the planting period •••

Building on lessons learned from these programmes, in the late 1990s the USA, France and Brazil set up a network, called Pirata, of meteo-oceanic buoys in the tropical Atlantic. These buoys transmitted numerous marine and atmospheric parameters in real time, such as water temperature and salinity at various depths, wind speed

PARTNERS

NOAA, USA

University of Cape Town, South Africa

University of Abomey-Calavi, Benin

GEOMAR, Germany

INPE, DHN, UFPE, Brazil

"Orstom, now known as IRD, developed oceanographic research centres in the tropical belt, including in Abidjan, Dakar, Tahiti and Nouméa. When these centres were created, tropical oceanography was something of a curiosity. It has now become a key component of the climate issue, which includes phenomena such as El Niño and global warming."

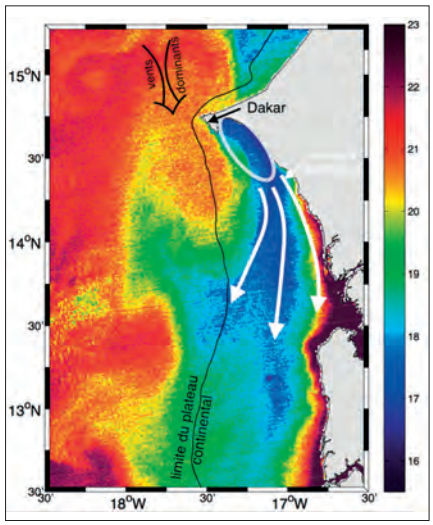
George Philander, professor at Princeton University, member of the National Academy of Sciences, USA

Buoy deployment, Gulf of Guinea.

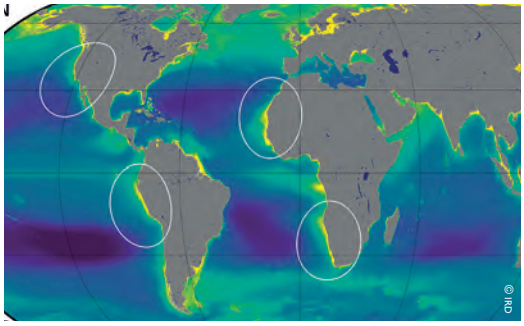
and direction, etc. These observations contributed to improving the forecasting of events such as cyclones, but were also used for seasonal forecasts: they were instrumental in determining that the cooling of waters in the Gulf of Guinea comes a few weeks before the onset of the African monsoon, a valuable piece of information which can help farmers optimise their planting period. The originality and value of the Pirata network's observations lie in its ability to process all the global and local space-time dimensions of the observed phenomena, by involving the countries of the Global South, which is IRD's specific mission.

Modelling upwelling

Upwelling is a process in which cold water, rich in nutrients and small fish, rises towards the surface. Some countries of the Global South have based their economy on this godsend, for better or for worse… As these areas are temperamental and sensitive to climate variability.



LOCEAN IPSL Senegalese upwelling model.



Average surface chlorophyll. The four major upwelling systems are circled.

Upwelling zones are as rich in fish as they are versatile and fragile: in the Humboldt current system, off the coasts of Peru and Chile, water productivity drops with every El Niño episode. Off the coast of Namibia, overfishing led to the proliferation of jellyfish, preventing fishable species from returning to their habitat. Consequently, the proper understanding of the physical, geochemical and biological dynamics of upwelling is a research topic of primary importance for many countries of the Global South. Upwelling dynamics are however complex and difficult to study for many Southern countries.

••• IRD provides the countries of the Global South with models simulating upwelling dynamics •••

While some models simulate how these processes work, they are fairly difficult to operate and require a high level of theoretical skills, as well as supercomputers with computational power not always

"I received a doctorate from the University of Cape Town (South Africa) as part of IRD's structures. I also had the opportunity to visit several research institutes in Brest and interact with experts in physical oceanography and ocean modelling. This specific training was important to me, as I developed skills which helped me find a job. In addition, it was important for marine science in the region to gain a better understanding of ocean circulation in the South-west Indian Ocean. Better management practices can now be implemented in the region thanks to this improved understanding of ocean circulation, combined with the dynamic of marine ecosystems."

Dr Issufo Halo, physical oceanographer, Cape Peninsula University of Technology, Cape Town, South Africa

Upwelling along Senegal's coastline.

available in the countries of the Global South. Hence the idea of adapting the models to this reality by creating tools to make them more easily accessible and capable of running on standard computers. This is how IRD and its partners have adapted the Roms ocean modelling system (renamed Croco) over the past two decades, to simulate ocean currents.

Croco uses grids interlocked with each other to achieve a fairly fine spatial resolution at lower computing costs. It is also combined with systems which simulate geochemical and biological cycles, respectively modelling the supply of nutrients (Pisces) and the life cycle of fish (Ichtyop). It therefore consists of two separate modules which adjust to requirements. It is used by nearly 1,500 researchers and engineers worldwide, particularly in West Africa, Madagascar and South-East Asia, to independently monitor and understand upwelling developments, among other things.

PARTNERS

University of Cape Town, South Africa

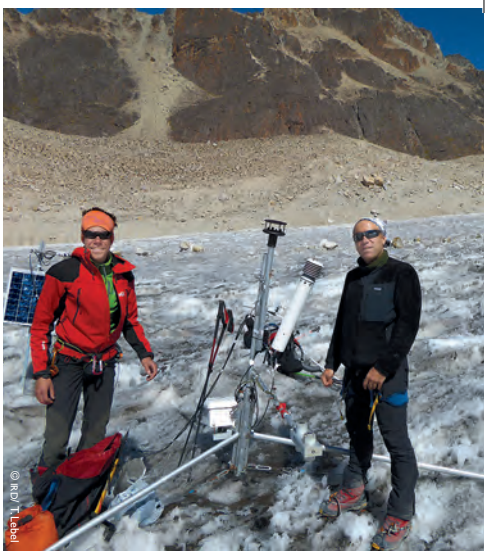
Instituto del Mar del Perú (IMARPE), Peru

Cheikh Anta Diop University, Senegal

CNRS, France

University of California Los Angeles (UCLA), USA

Critical zone observatories



Mission on the Zongo glacier, Bolivia.

With the emergence of the global shift issue, the observation of natural environments is developing in keeping with a national and international strategy.

Flow measurement on Rio Marañon, Peru.

In the early 1970s, the great West African drought raised concerns among the scientific community regarding the stability of the environment and climate in the tropical belt. In the years that followed, this concern became a research priority. Observatories were designed to determine long-term trends in the different physical and biogeochemical variables which control the "critical zone", i.e. the thin layer between the lower atmosphere and the subsoil, which accounts for 99% of terrestrial life.

••• Over the past 30 years, national observation services have monitored the impact of global shifts in the tropical belt and the Mediterranean Basin •••

The sites selected to host these observatories are representative of the major tropical systems. The best structured sites were designated as "National Observation Services" by IRD and CNRS. They were designed to reflect the specific features of the environments they monitor. A number of observatories were created over the years: AMMA-Catch in Niger, Benin and Mali, which documents West Africa; Hybam in Brazil and Andean countries, to observe the Amazon Basin; Glacioclim in Bolivia and Ecuador, which monitors changes in tropical glaciers; Pirata in the tropical Atlantic; and Omère in Morocco and Tunisia, dedicated to the Mediterranean region.

These observatories are critical to understanding the mechanics and impact of global shifts. Field data collected provides input so that the models can be validated and upgraded. It is also used to test and calibrate new measurement techniques such as radar, infrared or microwave sensors, or proton magnetic resonance (PMR), making it possible to qualify groundwater. In situ data from the observatories is also valuable when calibrating satellite data, such as recently with the GRACE satellite which uses gravitational field fluctuations to infer continental water storage variations over very large areas.

PARTNERS

Universities, meteorological services and hydrological and water resource services in Central and West Africa, Andean and South-East Asian countries

AMMA, impending rain on IRD's measurement site, Niger.

"The Hybam and Glacioclim observatories provide the scientific community of tropical Andean countries with a robust tool for addressing the needs of decision-makers in light of global shifts, by effectively documenting changes in the region's hydroclimatic regimes."

Juan Carlo Espinoza, Geophysical Institute of Peru, Lima

From local hydrology to global climate

In the 1980s, the emergence of global circulation models provided scientists with the tool they needed to anticipate possible global climate changes. The creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 marked the advent of a new scientific front located at the interface between public development and environmental management policies.

Arrival of the monsoon.

In 1990, in Niger's Niamey region, IRD researchers worked with scientists from Météo France, CNRS and NASA as part of the Hapex-Sahel project. They installed elaborate instruments which, for two years, recorded air and water flows on very small scales; in short, everything making it possible to describe and understand exchanges between the earth and the atmosphere, within a study area of approximately 10,000 square kilometres. This was a perfect surface area to feed data into early climate simulation models. This was a totally new objective for Orstom as, historically, Orstom's hydrology activities were firmly anchored in local development issues. Researchers, engineers and technicians were sent out into the field to quantify variations in rainfall or flood patterns with a view to effectively designing hydraulic dams and sanitation systems. The primary aim was to acquire data relevant to the application. Young researchers from the Institute progressively promoted a more comprehensive view of hydrology as a key component of the climate system, without however turning away from their mission, which was to help secure access to water resources for the populations of the countries where they operated

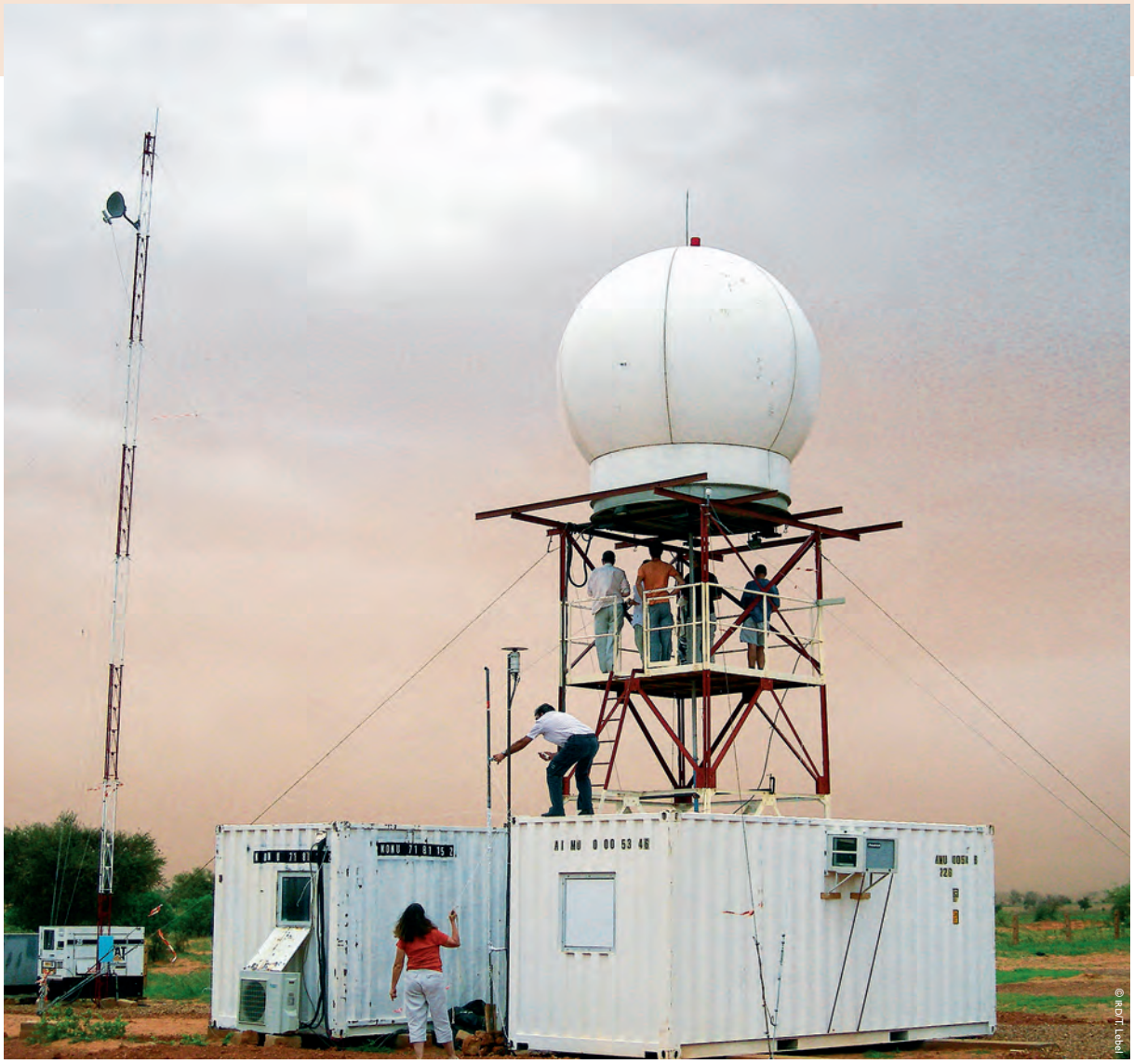
Hapex-Sahel was a turning point in this process: the first measurement campaign organised to understand climate mechanisms in the tropical belt, resulting 15 years later in the AMMA campaigns, where 600 scientists took a close look at the functioning of the African monsoon to improve its representation in climate models while anticipating its future developments in the context of global change.

PARTNERS

Universities, directorates of Meteorology, Regional West African research centres

"The Agrhymet Centre began working with IRD forty years ago. The Hapex-Sahel and AMMA projects marked a turning point, making it possible to jointly build a comprehensive view of how climate change would affect the hydrological cycle and water resources in the Sahel."

Abdou Ali, head of the Information and Research Department, Agrhymet Regional Centre, Niger

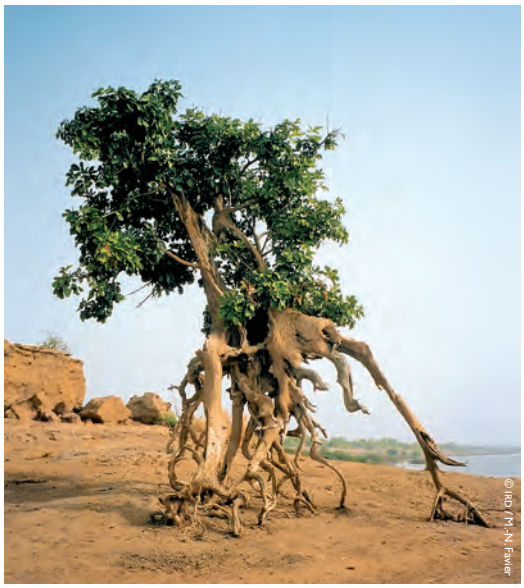


MIT radar on the Niamey site, Niger.

••• From Hapex-Sahel to AMMA: moving towards a comprehensive view of the water cycle consistent with the emergence of the climate change issue •••

The paradoxes of the Sahel

From the 1960s to the 1980s, Orstom ran environmental monitoring programmes in a number of African countries. The data collected facilitated the understanding of climate change and water dynamics in the Sahel.



Tree uprooted by floods.

From 1968 to 1993, the Sahel was hit by severe drought. And yet, river flows kept increasing from the 1980s, even though it did not rain more. This peculiarity did not happen by itself: in some instrumented parts of Niger, the groundwater levels even started rising. Hydrologists were able to explain this dual paradox in retrospect by studying the environmental data gathered since the 1960s on equipped basins.

••• The water cycle in the Sahel changed over a 30-year period, with prolonged droughts affecting agriculture as well as livestock farming •••

It appears that increased run-off had resulted from the extreme drought of 1983-1984, which destroyed whatever remained of an already damaged vegetation. This absence of a vegetative cover, notably trees, increased water run-off and reduced its infiltration into the soil. So why did the groundwater level start to rise in certain locations? Because in certain Sahel regions, water does not flow into the sea. It builds up in large ponds, where it eventually seeps into the subsoil, feeding into the water table.

There were more surprises in store for researchers, as the revegetation of the Sahel which began in the 1990s was not accompanied by reduced

"IRD, through research on long-term observation sites such as AMMA-CATCH, has shown that water, a scarce resource which limits socio-economic development, flows in abundance in the Sahel in spite of climate change. The dual hydrological paradox observed thus offers a development opportunity."

Professor Ibrahim Bouzou Moussa, Abdou Moumouni University, advisor to the Minister of Higher Education, Research and Innovation, Niamey, Niger

Annual flood, Niger.

run-off levels as expected. IRD solved this new riddle by showing that, in the regions in question, 30% to 50% of soils are degraded and incapable of absorbing water. Without a proactive remediation policy, they would remain "impermeable". The consequence was the modification of the overall water balance of the Sahel, with further risks of flooding and the need to adapt hydraulic structures and sanitary infrastructures to this new reality; but also to investigate new irrigation opportunities.

PARTNERS

Cheikh Anta Diop University, Senegal

Gaston-Berger University, Senegal

Amadou Mahtar Mbow University, Senegal

University of Zinder, Niger

University of Ouagadougou, Burkina Faso

University of Bamako, Mali

Flooding caused by downpours

Since the 1950s, the number of deaths caused by floods in Africa has increased fivefold. The Sahel is particularly affected. This phenomenon is due to several factors: population growth, extreme vulnerability of communities, ill-conceived developments, but also changing climate and rainfall patterns.

Flooding, Niger.

Even desert countries can be threatened by floods: in 2012 and 2017, the River Niger overflowed, causing hundreds of fatalities and tens of thousands of victims. This phenomenon has become chronic, which raises the question of its origin. Is the heaviest stormwater run-off witnessed in the Sahel since the late 1980s really the only explanation for the occurrence of these disasters?

••• Since the 1990s, extreme rainfall in the Sahel has been increasingly frequent and intense •••

To find out more, IRD researchers studied rainfall patterns in the Sahel and analysed daily precipitation data recorded from 1950 to 2015 in the Sahel. They found a tendency from the 1990s for rainfall intensity, not frequency, to increase, particularly for the most extreme events.

Taking it a step further, researchers broke down the data recorded since 1990 by the AMMA-CATCH observatory in Niger. To their great surprise, they showed that peak intensity within these rainfall events has tended to increase by 2% to 3% every decade since the early 2000s. Up until then, this trend had only been observed in the

"Recurrent floods, devastating overflows or production losses are challenges awaiting Sahel countries in light of climate change. Hence the importance of having quality observations over long periods, without which these events cannot be anticipated. This type of study must have a knock-on effect within our national hydrology services, that must take this rainfall intensification phenomenon into account in their flood risk communication and structural design calculations."

Ibrahim Maïnassara, hydraulic engineer, in charge of collecting rainfall data, Niger

Squall line upon arrival of the monsoon.

USA. In Niger, rainfall is also undergoing more intense phases, making run-off and flooding more likely.

This intensification suggests a change in rainfall patterns in the Sahel. In fact, the Sahelian climate could be changing rather than just fluctuating between successively dry and wet period, which means policies designed to protect people and property against floods should be reassessed. This could also increase the precariousness of populations as they face less frequent but heavier rains.

PARTNERS

Abdou Moumouni University, Niamey, Niger

Cheikh Anta Diop University, Dakar, Senegal

Gaston-Berger University, Saint-Louis, Senegal

Agrhymet Regional Centre, Niamey, Niger

Directorate of Meteorology of Benin

Directorate of Meteorology of Burkina Faso

Directorate of Meteorology of Senegal

ECOSYSTEM DYNAMICS AND BIODIVERSITY CONSERVATION

Small catchments, great results

In the 1950s, France decided to develop its colonies by building expensive transport infrastructures and hydraulic installations, the design of which is problematic due to the limited amount of data available. As a result, this data must be complemented.

Water level measurement system, Benin.

In the aftermath of the Second World War, France was being rebuilt… and decided to build dams, bridges and water supply systems in its colonies. These were significant projects that had to be suitably dimensioned to withstand local rainfall, run-off and river flow variations. A fledgling Orstom was entrusted with collecting data necessary for the launch of these projects.

From North Africa to Equatorial Africa to South America, Orstom officers monitored nearly 300 water catchments, most with a surface area of less than 100 square kilometres, selected for their homogeneity or representativeness. At first, these water catchments were lightly equipped with rain gauges and run-off measurement devices, and were monitored for three to five years, or longer in exceptional circumstances. The objective was to determine a water balance and estimate annual run-off variability, as well as the scale and frequency of overflows.

In the 1990s, the measurements began to be used to configure and provide input for models. Researchers monitored fewer water

"From 1989 to 1993, Orstom successfully worked in collaboration with the Institute of Hydraulic Research (IPH) of Porto Alegre (Brazil). Hydrological and sedimentological monitoring stations were installed in field crops and were the subject of numerous scientific publications. These systems, which are still in operation thirty years later, have helped train dozens of hydrometry students in the field, thereby promoting the observation and acquisition of quality data. This action made a significant contribution to the advancement of hydrological research and the training of human resources in our country."

Professor Nilza Maria dos Reis Castro, who holds a doctorate from the University of Strasbourg
Institute of Hydraulic Research, Federal University of Rio Grande do Sul, Porto Alegre, Brazil

Gauging of a small stream in the Andes, Ecuador.

••• Monitoring a multitude of small water catchments helped describe the water cycle and provided further insight into risks in the tropical belt. But there is more to it than that •••

catchments, but in more detail, to gain a better understanding of water movements. From then on, researchers have applied this experience to more specific contexts exposed to global change, including climate change: rural territories (North Africa, West Africa, Latin America), mountain areas (Andes, Himalayas) or urban areas (West and Central Africa, Mexico).

PARTNERS

HydroSciences, Montpellier

UMR LISAH (Inra-IRD-Montpellier Supagro)

Institute of Environmental Geoscience (IGE), France

Centre for Spatial Studies of the Biosphere (Cesbio), France

Institute for Ecology and Environmental Sciences (iEES), France

Gauging rivers from space

For the purposes of agriculture, research or power generation, knowledge of river flows is vital. However, this information is not always available, notably in the many water catchments where rivers are no longer regularly monitored.

Satellite image of the Amazon.

Sentinel-5 satellite, Copernicus programme.

Worldwide information on river flows has steadily declined over the past 40 years, returning to its level of the early 20th century. Why? Because of a chronic lack of infrastructure in certain countries of the Global South and a culture of secrecy in politically sensitive regions. Yet, in the era of climate change and global modelling, this data has never been more important. This has prompted researchers to come up with a technique to remotely gauge river flows, using hitherto untapped satellite data.

The military and scientists have been using satellites since the 1970s-1980s to observe sea level variations and detect any thermal or gravitational anomalies. These satellites send waves to Earth and these waves are reflected by water. The round-trip time of the wave is used to determine the water altitude, its "altimetry". While this technique was effective for large bodies of water, it was difficult to use for rivers, because of disruption caused by vegetation and houses.

••• A cutting-edge technique helps determine the river water level from satellite data •••

On the assumption that these satellites spent one third of their time above the continents, in the early 2000s researchers recovered raw data from the ENVISAT and T/P satellites and developed new algorithms to determine the height of rivers to within 30 cm. From 2002 to 2010, an IRD team calibrated the methodology on the Amazon Basin and showed that even tiny rivers can be monitored from space. This research resulted in a qualitative leap in 2016, with the launch of the Copernicus satellites which reduce the risk of error by a factor of three. The water levels calculated are now universally accessible on the Hydroweb website.

PARTNERS

National Water Agency (ANA), Brazil. Geological Survey of Brazil (CPRM). Amazonas State University (UEA), Brazil

International Commission of the Congo-Oubangui-Sangha Basin (CICOS), Democratic Republic of the Congo

Niger River Basin Authority, Niger

National Centre for Space Studies (Cnes), France

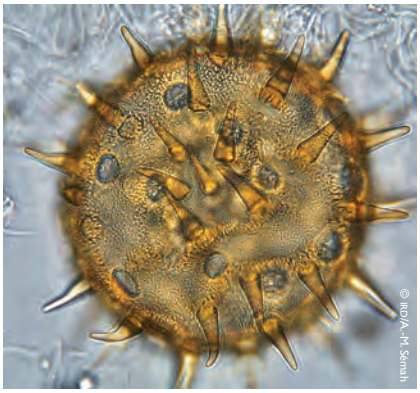
The Amazon River.

"Our partnership with IRD helped train students in technologies which will be essential to future hydrological monitoring operations. Now, thanks to IRD, CPRM has a trained Master's or PhD level space hydrology team. These engineers and technicians therefore contribute to the hydrological monitoring of remote regions by satellite, while using this new source of information to supplement the data produced by Brazil's Hydrological Monitoring Network. In return, our expertise in field measurements and river campaigns, combined with our network of stations, play a major role in the development of these new technologies, by helping validate and calibrate satellite data."

Daniel Médeiros Moreira, CPRM (Serviço Geologico do Brasil)

Exploring South America's past climate

What will the future climate be like? The answer to this question requires a better understanding of past climate variations, on the scale of the planet as well as the region. There is however little research into the paleoclimates of certain parts of the world.



Pollen, a good climate indicator, optical microscopy.

Mission on Rio Napo, Ecuador.

"You brought coal all the way here?" In the late 1970s, a team of researchers were surprised by the cooking techniques used during an expedition to the Amazon. The cook's negative reply led to a major breakthrough: there is charcoal in the Amazon, a remnant of the great fires which devastated the forest in the past. The carbon-14 dating of this charcoal showed that it was formed 6,000 years ago. This prompted a series of research projects aimed at finding out about South America's past climate, which was previously unknown.

In the 1980s, Orstom researchers began to focus on lakes, more specifically lake sediments. These sediments keep a trace of past climates: the pollen, crustaceans and microorganisms deposited there over time are indicators of past vegetation or temperature, while the oxygen-18 concentration provides information on the level of rainfall. Researchers collected core samples from dozens of lakes in Bolivia, Peru and Brazil. By doing so, they managed for the first time to piece together South American climate variations over the past 40,000 years.

This unprecedented wealth of data revealed the climatic heterogeneity of the South American continent and confirmed certain assumptions. For example, 6,000 years ago when the Sahara was green, the Amazon Basin experienced a dry period due to a change in monsoon patterns, giving rise to the aforementioned fires. More recently, the data accumulated was used to test and calibrate models simulating past and future climate variations.

PARTNERS

Universidad Mayor de San Andrés, La Paz, Bolivia

Cayetano Heredia University, Peru

University of Sao Paulo, Fluminense Federal University, Federal University of Ceara, University of Brasilia, Brazil

Drying up of Lake Chad.

A sea of fresh water

Orstom has been engaged in the multidisciplinary observation of Lake Chad since the late 1950s. This long-term endeavour now makes it possible to assess the various development scenarios for the lake.

Lake Chad is a water expanse with no access to the sea, subject to evaporation, which however is not saline. In the 1950s, this peculiarity prompted hydrologists, soil scientists and biologists to undertake research on the lake which, at the time, extended over 20,000 square kilometres. They analysed the system's hydrological mechanics and showed that, at depth, salt seeps into the aquifer, forming saline water tables which underpin the fresh water layer. This research stopped abruptly in the 1970s because of the war, and only resumed in the late 1990s. By that time, the lake had shrunk considerably. A satellite image taken in 2001 estimates its surface area at 3,000 square kilometres. Nevertheless, scientists were unsure how to interpret this variation in terms of functioning or future evolution. A number of studies were undertaken. Remote detection and field work made it possible to determine past variations of Lake Chad, showing that 8,000 years ago, during a particularly hot climatic period, the lake's surface area was 350,000 square kilometres. Therefore, the fluctuations of Lake Chad are not new.

Meanwhile, hydrologists made the most of new technologies to clarify current water stratification in the aquifer. Water on the surface is fresh yet rich in bacteria and non-potable, whereas deeper water layers are salty but potable. Improving knowledge of water body structures can help optimise the quality of freshwater boreholes.

In 2010 however, field research was halted once again due to security issues, before resuming by recovering data accumulated since the 1990s, which forms a baseline for supporting Lake Chad's development and planning programmes. It is notably used to document the various water transfer scenarios from the Congo basin to the Lake Chad basin, which are largely based on data collected by Orstom and IRD over several decades.

Hydrology measurement, Lake Chad.

PARTNERS

University of N'Djamena, Chad

University of N'Gaoundéré, Cameroon

Abdou Moumouni University, Niamey, Niger

Ministry of Hydraulics and regional directorates, Niger

University of Maiduguri, Nigeria

Soils in all their forms

Hydrological modelling currently forms the basis for the forecasting of floods and low flows. It allows for the correct dimensioning of civil engineering structures: dams, bridges, pipes and irrigation systems.

Water erosion, Niger.

Quantifying water run-off in the water catchments of the tropical belt was one of Orstom's traditional tasks. It was meant to facilitate the development of roads or sanitation systems in countries where there was still a great deal to be done, a colossal task that, in the late 1970s, researchers set out to put to statistical use. The objective was to create a model to estimate the level of 10-year floods, based only on a limited number of parameters such as the shape of the water catchment, the type of soil and, vegetation and the rainfall pattern. This original idea was a failure, as the nature of soil appeared to be entirely unrelated to the run-off level measured on the surface. Researchers struggled to understand this paradox.

••• Soil surface characteristics provide information on the soil's ability to support water run-off •••

The turning point occurred after 1980, when researchers understood that soil, as envisioned by soil scientists, is indicative of its history and formation, but its surface properties are not. Said properties vary depending on the agricultural use, plant cover and weather conditions. This led researchers to switch from the notion of soil-based hydrological units to that of units based on "soil surface characteristics".

These characteristics can be measured using large portable watering cans: rainfall simulators. This field equipment helps predict the level of water run-off in a given place, and draw up a new kind of map identifying soil surface characteristics. This data provided a more realistic representation of water transfers, while allowing IRD to develop models more in tune with reality. This progress significantly improved forecast accuracy in terms of floods, low water periods and even the quality of water.

PARTNERS

University of Niamey, Niger

Arid Regions Institute, Tunisia

Department of Agricultural Land Management, Laos

Soils and Fertilizers Research Institute, Vietnam

Run-off study in Mexico.

"Research in the dynamics of the layered surfaces of fine and sandy crop-growing soils in the Sahel revealed that these soils tend to undergo widespread crusting which causes substantial run-off. More importantly, this research highlighted the fact that this phenomenon is essentially due to their strong susceptibility to the formation and extension of the erosion crust, the type of soil surface which causes most run-off, that even long-term fallow periods cannot seem to significantly counter."

Jean-Marie Ambouta Karimou, professor at the Abdou Moumouni University of Niamey, Niger

Sand, dust and wind

In arid and semi-arid environments, the land is vulnerable, densely populated and exposed to the wind. In these regions, wind erosion must be taken into account to the same extent as water erosion to anticipate soil changes for agriculture.

Wind-borne dust measurement, Niger.

Laboratory container for measuring wind-borne dust, Niger.

In the 1930s, massive dust storms devastated crops in the "Dust Bowl", a vast territory straddling Texas, Kansas and Oklahoma, forcing thousands of farmers to leave their land. US researchers found that these disasters were linked to the extension of agricultural land, which contributes to the wind erosion of soil that has become too fragile. Their research led to very accurate soil erosion models, yet difficult to transpose to other continents.

• • • The need to analyse and model wind erosion in the Sahel • • •

This is why, in the 1990s, IRD and CNRS researchers decided to examine wind erosion in the Sahel, a cultivated, densely populated region where dust can fertilise the Amazon forest. They began by describing the process on various scales, from the grain of sand carried over a few metres to dust carried across the region. From 2006 to 2010, as part of the AMMA campaign, they installed a device in Niger to measure dust flows, including a six-metre high tower and an underground laboratory. The idea was to determine the number, size distribution and composition of wind-borne particles. They also installed three dust monitoring stations in the Sahelian strip, which are still operational, in Niger, Mali and Senegal.

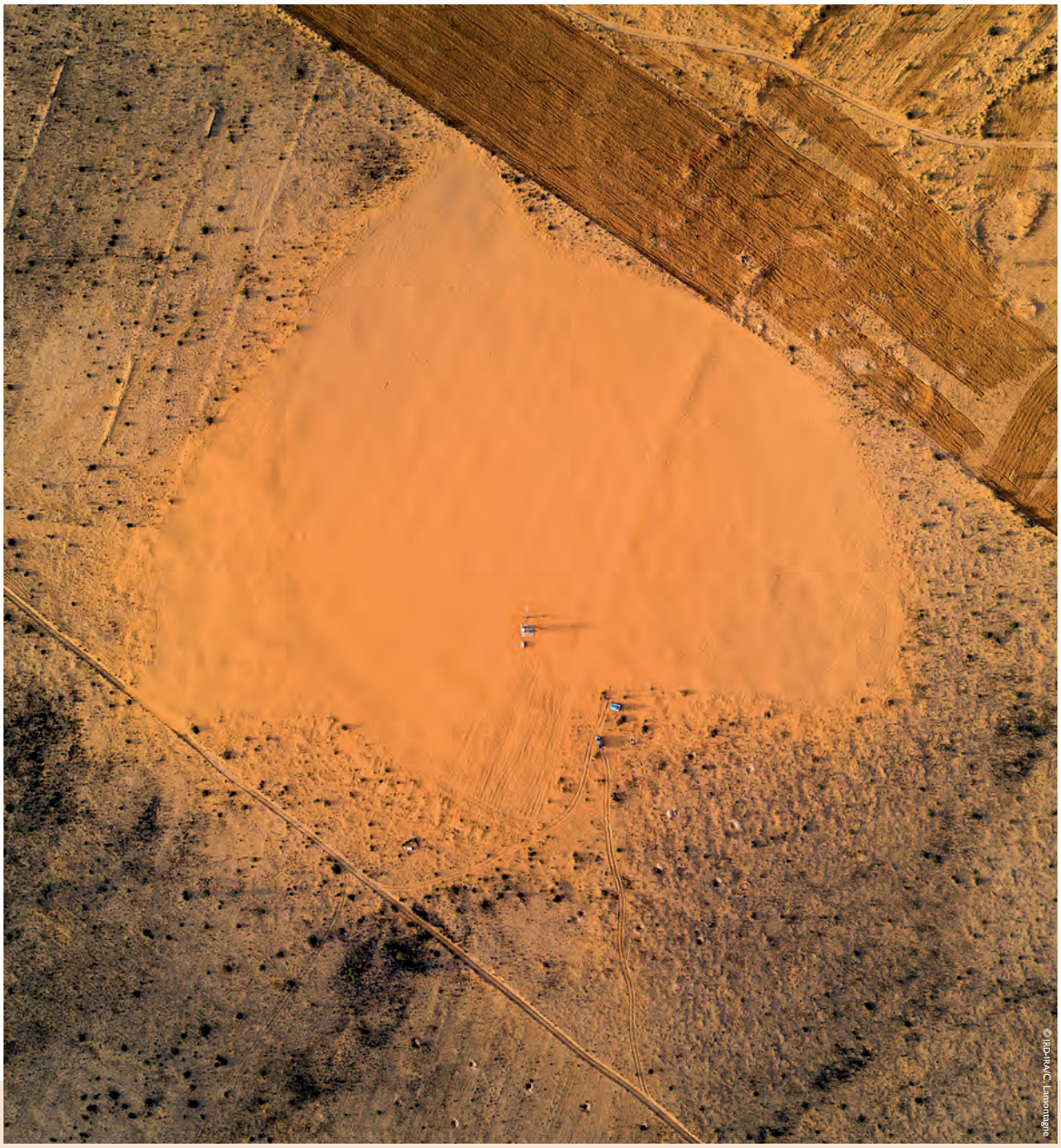
They demonstrated that the most intense wind erosion period in the Sahel was not during the dry season, as expected, but at the start of the rainy season, from May to June. This erosion was accentuated by land cultivation and the systematic collection of agricultural residues, resulting in an almost complete lack of vegetation at this time of year. This research aims at modelling the progressive loss of fertility of Sahelian soils.

PARTNERS

Abdou Moumouni University, Niamey Niger

Arid Regions Institute of Médenine, Tunisia

LISA UMR (Interuniversity Laboratory of Atmospheric Systems), iEES-Paris UMR, ISPA Inra Bordeaux UMR



Wind erosion measurement, Tunisia.

"The scope or value of research on wind erosion in Niger, initiated or developed thanks to IRD, can be found on three levels: 1) fundamental, to understand the processes involved in this threat in the context of the Sahel and Niger; 2) academic, through the training of an increasing number of students in this field and the improvement in "land management and conservation" modules via the results of in situ measurements; and 3) practical, via the strategic dune stabilisation or land restoration priorities."

Amadou Abdourhamane Touré, UAM / FAST / Department of Geology, Niamey, Niger

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, as they were unable to attain objective field surveys. 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.

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

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 there. 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 on it. This methodology, combined with field surveys, made it possible to draw up a catalogue of around 20 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

Aerial view of the French Guiana forest.

"From the beginning, ONF, in its capacity as forestry manager, assumed its responsibility, in particular in terms of the need for a better understanding of how to manage the surrounding ecosystem. To supplement their internal skills, ONF quickly developed partnerships with research organisations, including Cirad and IRD. These partnerships are continuing to this day, within the framework of projects such as Habitats or Dynfordiv, driven by the continuous improvement of the principles and rules governing the management of the French Guianan tropical rainforest."

Olivier Brunaux, Regional Directorate of French Guiana, head of the Cayenne Territorial Unit

Pastures and humans drip-fed by glaciers

Biodiversity study, Bolivia.

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

This "state of grace" will come to an end once the glaciers are gone. The absence of water during the dry season could 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

Universidad Mayor de San Andrés, Bolivia

Anchovy fishing, hauling of trawl gear, Peru.

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.

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 seabirds. 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 person, an IRD researcher, had an idea. Why not gather all worldwide data on the monitoring of seabird 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 seabirds 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 seabirds is affected due to lack of food. This effect was analysed in detail during another meeting.

By comparing data from 7 marine ecosystems in the Arctic, Antarctic, Pacific and Atlantic, covering 14 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.

Seabirds tracking the hauling of trawl gear, Peru.

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

Discovery of "super coral" in New Caledonia

Ocean acidification and warming could have drastic consequences on coral reefs. In New Caledonia however, some corals are resisting under totally unexpected conditions.

Studying coral bleaching, New Caledonia.

In 2016, collaboration with an Australian team prompted IRD researchers working in New Caledonia to inventory all corals located near mangroves. In Bouraké, they found a surprising coral reef which thrived under extreme temperature, pH and oxygenation conditions. These environmental conditions seemed similar to those expected by the end of the century which, based on experiments conducted in aquariums, could spell doom for corals. Consequently, these projections are moderated by the discovery of the New Caledonian site.

••• Some corals can survive under totally unexpected physical-chemical conditions •••

Researchers have been examining this unique site since 2016, considered to be a natural laboratory for studying the ability of coral reefs to adapt to environmental changes. They discovered that 50-odd coral species have adapted to this more acidic, warmer and oxygen-poor environment. Surprisingly, elsewhere in the world these very species are the first to die from severe heat.

"The coral reef ecosystem forms a fundamental and vital part of New Caledonia's natural and cultural heritage; it nurtures people in every sense of the word, while actively participating in the construction of codes of conduct for society and building its identity."

Didier Poidyaliwane, government official in charge of customary matters, ecology, sustainable development, relations with the Customary Senate, customary councils and customary lands, New Caledonia

Coral bleaching, New Caledonia.

During the 2016 heatwave, only 20% of corals from the "laboratory site" in Bouraké suffered from bleaching, compared with 100% for the rest of New Caledonia. This unexpected resilience may be due to symbiosis with a specific, heat-resistant single-celled alga, but also to factors which remain to be discovered but are probably linked to the proximity to mangroves. To find out more, researchers monitored the environment, attempted various experiments and analysed the genetic material of the algae.

The presence of corals living in these environmental conditions, similar to and even worse than those expected by 2100, sparks hope that some corals might survive global warming, and even that some of the damaged areas might be salvaged or repopulated.

PARTNERS

University of New Caledonia

Aquarium des lagons, New Caledonia

University of Technology, Sydney, Australia

University of Milan-Bicocca, Italy

PART 5

To effectively contribute to development, knowledge arising from research must be disseminated, shared and adopted by as many people as possible. On the basis of this principle, which is one of its key focuses, IRD has a long-standing commitment to implementing a wide range of tools and schemes intended to share research knowledge and data. It therefore contributes to building the capacity of scientific communities in the Global South while enabling citizens to become active stakeholders in the development process.

OPEN SCIENCE AND SHARED KNOWLEDGE

Supporting teams of scientists

In the 1990s, IRD became aware of a bitter reality: despite investment and collaborative efforts, many countries of the Global South fail to develop quality research. And their economic difficulties are not the only reason for this failure.

JEAI in hydrogeophysics, Benin.

Although IRD is a research organisation, its purpose is not only to produce new knowledge. Its multiple aims include development aid for countries of the Global South, and deploying their own research systems is a way to help achieve this goal. For decades, this took the form of support and training operations for students of the Global South. However, this strategy turned out to be ineffective as, once trained, young researchers were often very isolated and received little financial support, eventually losing some of their skills or changing career path.

••• IRD provides grants to fund research teams or help with their scientific progress •••

This forced IRD to change its strategy in 1994: rather than training individuals, the Institute decided to support research teams entirely made up of nationals from partner countries. With the "AIRE Development" programme which was extended until 2005, 35 foreign teams received financial support over six years and established valuable contacts with the eight French research organisations involved in the programme. This enhanced the sustainability of research groups while also raising their profile so that they could secure additional international funding… thereby achieving greater self-reliance.

Meanwhile, the AIRE Development programme revealed the existence of motivated teams that were too scientifically inexperienced to apply for funding under the programme. In 2000, IRD created the "young associated team" (JEAI) programme especially for them, a three-year grant allowing a team to work hand in glove with IRD

PARTNERS

Universities, research organisations, ministries for higher education and research in Global South countries

"The 'AIRE development' programme was based on four pillars: wide range of research topics, scientific excellence, research coordination and the training of trainers. Within an African environment marked by dwindling funds for higher education and research brought about by structural adjustment plans, IRD has become a major player in scientific cooperation thanks to this initiative."

Maurice Tchuenté, initially research lecturer in Computer Science, then university chancellor, then Cameroon's Minister for Higher Education and Research. He is currently a member of IRD's scientific council

The JEAI team in Cameroon.

to acquire skills and experience. In keeping with these schemes, the Institute also set up "international joint laboratories" (LMI), operational structures housed on the premises of partners from the Global South, based on a targeted research topic and a sustainable scientific platform (laboratory, major equipment, computing resources, documentation centre, etc.). Last but not least, IRD helped create new training programmes and implement research and education assessment systems.

Mosquitoes, viruses and globalisation

The emergence of viral diseases transmitted by mosquitoes in urban areas of the northern hemisphere is indicative of the need for strong cooperation between researchers of the Global North and South. The Montpellier *Vectopôle* allows researchers and students from all over the world to conduct innovative research together in the area of biology and the control of insect vectors.

Tsetse fly (*Glossina* sp.), vector for sleeping sickness in Africa, marked with fluorescent powder.

Dengue fever, Zika virus disease, chikungunya: 10 years ago, these diseases were unknown to the general public. Now that our cities have been taken over by tiger mosquitoes, these viruses with exotic names that were believed to be confined to tropical regions have moved towards temperate areas. Not so much because of climate change, but rather because of globalisation which, in step with the carriage of passengers and goods, has allowed diseases and the eggs of African and Asian disease-carrying mosquitoes to spread. As a result, these diseases and vectors, long forgotten in the northern hemisphere but known and studied in the Global South by IRD researchers and their partners, now pose a global health threat. The mobilisation of researchers from the Global North and South, learning from each other's experience and expertise, is an innovative solution for the sustainable management of this now global vector risk.

Research and training needs are commensurate with the challenge ahead. This is why IRD and the Occitanie region invested more than EUR 2.5 million in the construction of the *Vectopôle*, a unique platform in Europe, consisting of 350 square metres of contained laboratories, where researchers can safely work on biting insects, whether or not they have been infected with a virus, bacteria or parasite. They

"The Pasteur Institute of Bangui, in close cooperation with the IRD team, undertakes research projects on arbovirus and malaria vectors, some of which require access to IRD's *Vectopôle* platform. For the three theses (2012 to 2019) in medical entomology completed within the IPB, some of the research was conducted as part of this platform."

Dr Carine Ngoagouni, Pasteur Institute of Bangui, Central African Republic

Joint Vectopôle laboratory in Montpellier, maximum containment (l3) for studying vector-pathogen interactions.

••• A platform for research and training •••

investigate the behaviour of insects, their ability to transmit various infectious agents and changes in insecticide resistance.

Operational since 2015, the *Vectopôle* has become the cornerstone of a network of Montpellier insectaries where research extends to animal disease vectors and crop pests. The consortium called *Vectopôle Sud* coordinates research involving major human, animal and environmental health issues, which affect the environments of the Global North as well as South. This holistic health approach will create links between different sources of knowledge which up until now were too thematically and geographically compartmentalised.

Vectopôle Sud consortium website: http://www.vectopole-sud.fr/

PARTNERS

Institute of Research in Health Sciences (IRSS), Bobo-Dioulasso, Burkina Faso

Pasteur Institute of Bangui, Bangui, Central African Republic

Pierre Richet Institute (IPR), Bouaké, Côte d'Ivoire

Franceville International Centre for Medical Research, Gabon

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

University of California Davis, USA

Supporting the creation of clinical research centres in Africa

In Africa, the emergence of research centres designed and run in conjunction with partners, open to researchers from the Global North as well as South, represents a new model for scientific cooperation and development.

Patient follow-up, CERFIG, Guinea.

Centre for infectiology research and training (CERFIG), Guinea.

PARTNERS

CRCF: Fann National University Hospital, Cheikh Anta Diop University, Senegalese Ministry of Higher Education, Research and Innovation, (National AIDS programme, PNLS), Senegal, IRD, IMEA, ANRS

CERFIG: Gamal Abdel Nasser University of Conakry, Guinea's National Institute of Public Health, IRD, Inserm, University of Montpellier

IRCB: Centre for Integrated Malaria Control (CLIP), Faculty of Health Sciences of the University of Abomey-Calavi (FSS/UAC), IRD, Inserm

In the early 2000s, a major clinical study was initiated in Senegal to demonstrate that triple antiretroviral therapy could be implemented in Africa for people living with HIV. This required a platform bringing together, under the same roof, all that was needed for patient care and quality research. This was how, after years of cooperation between IRD and its partners and with support from the EU and ANRS, the Fann Regional Centre for Research and Training in clinical management (CRCF) was established in 2005. Located within Dakar's University Hospital, this is also an open platform used to train researchers from the Global South and North.

Similarly, during the Ebola virus epidemic (2013-2016) in Guinea, the need to monitor survivors resulted in the opening of a facility centralising resources and skills: the Guinea Centre for Infectiology Research and Training (CERFIG), managed by partners since November 2017, organises multidisciplinary studies on emerging diseases in humans and animals.

Meanwhile, in Benin, the need to perform several multi-centre trials for the treatment and prevention of malaria and to develop a malaria vaccine intended for pregnant women was the reason behind the creation of the Benin Clinical Research Institute (IRCB). Initially focused on specific diseases, such as CRCF and CERFIG, this new platform was extended to all communicable and non-communicable diseases, with a view to organising and participating in multi-centre trials in the Francophone sub-region.

Sampling larvae in Benin.

Training health supervisors

Malaria, dengue and chikungunya epidemics make it necessary to monitor the insects carrying these diseases over long periods. This task is notably carried out by medical entomologists.

A finding emerged in the late 1990s: although vector-borne diseases were still present, if not on the rise, the number of medical entomologists was declining. Without them, how can vectors be tracked in the field? These professionals are the only ones capable of determining whether or not insects carry diseases. This crucial skill was unfortunately lacking due to the absence of dedicated academic courses, notably in France.

This led to the creation, in 2006, of an international Master's degree course in Medical and Veterinary Entomology (MIE) at the University of Abomey-Calavi, in Benin, in partnership with the University of Montpellier. In 2015, this course was moved to Côte d'Ivoire, in Bouaké's Alassane Ouattara University.

The first year of the course is held in both France and Côte d'Ivoire, while the second year is in Côte d'Ivoire (three months) and Burkina Faso (one month), after which students undergo a research training period in France or abroad. The MIE's geographical position is not insignificant, as it allows students to actually immerse themselves in the transmission areas of major vector-borne diseases while having access to state-of-the-art laboratories in this domain.

Since its inception, the MIE has trained 116 students from 26 different countries, some of which are non-Francophone (Ghana, Bolivia, Cape Verde and Equatorial Guinea). Forty-five theses have been defended or are underway. Career prospects are very good for these young people, who are subsequently recruited by universities and research institutions, but also by national control programmes, NGOs and private companies involved in vector control. The MIE has also developed distance learning courses and helped train a network of entomologists in France and Africa.

MIE course, Cotonou, Benin.

PARTNERS

Alassane Ouattara University, Bouaké, Côte d'Ivoire

Pierre Richet Institute, Bouaké, Côte d'Ivoire

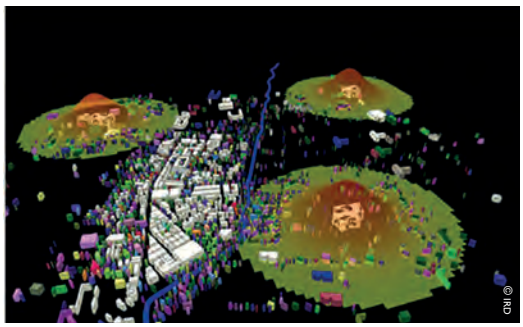
Institute of Research in Health Sciences, Bobo-Dioulasso, Burkina Faso

Inter-regional centre for research-development on livestock in sub-humid zones, Bobo-Dioulasso, Burkina Faso

University of Montpellier, France

"Boundless" modelling

New approaches to computer modelling and simulation help assess, through virtual experiments, the consequences of political decisions, natural disasters and health measures. However, they often continue to be seen as a matter for computer experts, who are sometimes well out of touch with the situation on the ground.



Modelling of the Red River flood in Hanoi.

In 2006 in Vietnam, a team worked on the simulation of a bird flu epidemic. The objective was to visualise the spread of the H5N1 virus through villages and understand the impact of political decisions on the progress of the epidemic. The team found that the observed spread of bird flu epidemics can only be simulated if the virus is capable of surviving in water, not just among wild bird populations. The veracity of this condition was confirmed by laboratory studies, demonstrating the relevance of an approach that the team later applied to the management of emergency relief within the context of natural disasters.

This change of paradigm and application encouraged researchers to find a form of generalisation shared by the different types of event studied. This is why they decided to create multi-purpose software capable of modelling a potentially infinite range of dynamic phenomena via the programming of IT objects referred to as "agents", in areas as diverse as epidemiology, land use changes, the management of shared resources and urban mobility.

In 2010, they brought GAMA on line (http://gama-plaform.org), a free software program for the modelling and simulation of spatialised phenomena. It uses a unique and intuitive language, GAML, specifically designed by the team to be easily operated by non-experts. Researchers intended to make modelling accessible to a wider audience and put this model-based approach within everyone's reach, in particular by providing visualisation tools enabling the in-depth analysis of the phenomena simulated, in the form of animated maps, realistic 3D representations and serious games, where artificial agents are replaced with actual individuals capable of interacting with the simulation. GAMA is currently used by approximately 2,000 modellers worldwide.

PARTNERS

Vietnam National University, Hanoi, Vietnam

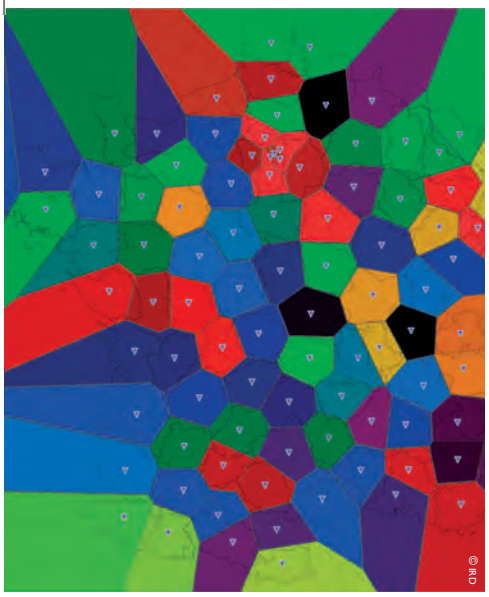
University of Can Tho, Vietnam

University of Wageningen, Netherlands

Paris-Sud University, France

University of Toulouse 1, France

University of Rouen, France



Geometry calculations in SavGIS.

OPEN SCIENCE AND SHARED KNOWLEDGE

Home-made GIS

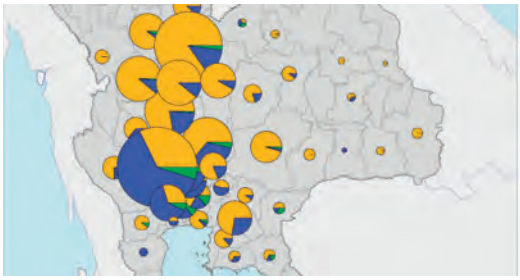
In the early 1980s, geographic information systems (GIS) had not yet taken off to become what they are today, and off-the-shelf software products were non-existent. Orstom developed a platform capable of managing and representing geo-referenced data.

Two million lines of code: this is the size of a unique geographic information system (GIS), designed and developed within the Institute. It all began in the 1980s at the Bondy Research Centre where, in a dedicated department, cartographers came up with a visual translation of the data provided by researchers. This gave rise to the idea of creating software capable of rapidly managing and processing geographic information. At the time, this was an innovative and daring approach. Developers were recruited, computers equipped with graphics devices were purchased and, in 1986, the application was already being used to draw up a digital land register in Martinique.

It was subsequently enhanced and used to build an *Atlas of the City of Quito*. A dedicated database was created, compiling all the geo-referenced information on the city, in terms of demographics, transport networks, high-precision geology and topography, etc. It continues to be used to this day, and is updated by the municipality of Quito.

SavGIS software development continued, making it possible to draw up geological, urban and archaeological site maps. Managing and cross-referencing millions of bytes of data, in the 1990s it gained the ability to integrate aerial and satellite images, used for example to analyse the architecture and environment of refugee camps in Kenya. It also eventually offered the possibility of building spatialised models, thereby simulating a number of epidemics in South-East Asia and Africa, and analysing health risks in Thailand and Laos.

SavGIS is free and accessible on the Internet (www.savgis.org). It has already been downloaded more than 10,000 times, in particular by Internet users from Africa. This French-language software provides numerous downloadable base maps and geo-referenced data sets.



Health risk modelling: bird flu outbreaks in poultry farms, 2004-2008, Thailand.

PARTNERS

Municipality of the metropolitan district of Quito, Ecuador

Pan-American Institute of Geography and History

Franceville International Centre for Medical Research, Gabon

Asian Institute of Technology, Thailand

Center for Vectors and Vector-Borne Diseases, Mahidol University, Thailand

Pasteur Institute of Cambodia, Phnom Penh, Cambodia

Public data on West African fisheries

IRD has published data gathered in West Africa's estuarine, lagoon and continental ecosystems.

Mangrove oyster fishing, Sine Saloum, Senegal.

Fisheries sampling vessel, Senegal.

To keep track of changes in ecosystems, collecting field data is a necessity, preferably over long periods. However, this type of information is lacking in some parts of the world such as West Africa.

Hence, in 2000, IRD researchers drew from their records to compile all the information on fish communities in the lagoons, estuaries and continental water bodies of this region. Their effort led to the creation, in 2006, of the Information system on fish communities and small-scale fisheries of the estuarine, lagoon or continental ecosystems of West Africa (PPEAO – http://ppeao.ird.fr).

This was a public database gathering all the raw information obtained from 1978 to 2013 as part of various research projects. Some of the data is the result of experimental fisheries conducted by researchers (more than 5,300 fishing operations), while other data comes from surveys conducted among small-scale fishermen (more than 110,000 landing surveys).

This database was used to track changes in fish communities, notably in Senegal in the estuaries of Casamance and Sine Saloum, where water salinity increased in the second half of the 20th century. It also made it possible to study the effects of the establishment of marine protected areas in Senegal, Guinea-Bissau and Mauritania. Species occurrences harvested as part of experimental fisheries were donated to the Global Biodiversity Information Facility in 2016 (GBIF – www.gbif.fr).

PARTNERS

Centre for Oceanographic Research of Dakar-Thiaroye, Senegal

Abidjan Ocean Research Centre, Côte d'Ivoire

Boussoura National Centre for Fisheries Science, Guinea

Seine fishing, Senegal.

Mapping out regulations

The maritime and coastal areas of the Global South are characterised by the diversity and sectoral specialisation of environmental rules. The result is a lack of clarity, even a lack of knowledge of applicable law. Addressing this problem is becoming urgent.

In 2010, as they sailed the Saloum Bay in Senegal, IRD and IUCN researchers became aware of the complex regulatory maze governing the maritime areas of the Global South and, more importantly, its lack of clarity as fishing, oil drilling and nature protection rules overlapped within the same area. In 2013, this led to the production of various regulatory atlases for the maritime areas of Mauritania, Senegal, Guinea and Cape Verde.

The idea was to present the different regulatory layers on the same interactive map, in order to display the different rules applicable to a given location with just a few clicks. This research revealed inconsistencies, notably in Mauritania where two decrees, one issued by the Ministry of Defence and the other from fisheries authorities, were incompatible. This was also the starting point for the drafting of the first environmental law textbooks in these countries. In Senegal, the atlas – and the regulatory errors detected – is a guiding document for the ongoing national reform.

This approach has been replicated since then as another atlas was created in 2017 for Cape Verde. A fifth atlas is being developed in Brazil, in keeping with the Paddle European project and as part of an interdisciplinary process. The idea is no longer to simply map out regulations but to supplement them with data from the fields of ecology or physics. In Brazil, this has helped pinpoint areas very rich in fish, which may warrant a marine protected area classification.

Inshore fishing canoes, Senegal.

PARTNERS

Cheikh Anta Diop University, Dakar

Instituto Nacional de Desenvolvimento das Pescas, Cabo Verde

Universidade Presbiteriana Mackenzie, Sao Paulo, Brazil

Rice as a common good

In the early 2000s for the first time, an international team sequenced the DNA of a model plant, *Arabidopsis*, widely 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, the 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 and 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 and 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 Genome and Development Laboratory (LGDP), CNRS-UPVD UMR University of Perpignan, France

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

"IRD's analysis of the rice genome contributed to a better understanding of the diversity of cultivars in the African cultivated rice species, while promoting AfricaRice's development of NERICA varieties resulting from cross-breeding between the two cultivated rice species."

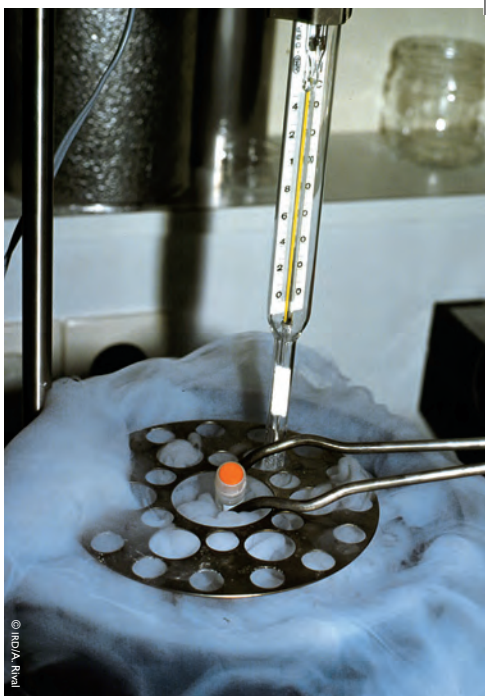
Moussa Sié, formerly head of the Africa-wide Rice Breeding Task Force's Africa Rice Center (AfricaRice), Bouaké, Côte d'Ivoire

Rice panicle.

••• IRD, CNRS and Génoscope sequenced rice chromosome 12 •••

OPEN SCIENCE AND SHARED KNOWLEDGE

Custodians of agricultural diversity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Cryopreservation of seeds.

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.


© IRD / M.-N.Favier

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.

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

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 preserved perfectly in cold storage rooms but must be regenerated every 20 to 30 years.

"The programmes implemented by IRD and its partners in the Global South contributed to safeguarding the genetic diversity of numerous species while defining the methods used to collect and utilise genetic resources. They were also dedicated to informing, training and raising the awareness of scientists, farmers and policy-makers of the importance of using genetic resources to contribute to improving agricultural productivity in light of global changes."

Ndjido Kané, Senegalese Institute of Agricultural Research

Coffee plant flowers, Côte d'Ivoire.

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 and biotechnologies (micropropagation, meristem culture) were developed, as was the liquid nitrogen storage technique (cryopreservation).

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 in 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

The French Guiana forest in a herbarium

There is no book or collection providing an exhaustive list of all plants found in French Guiana. This shortcoming made it necessary to create a herbarium in 1965, which has since become an international reference in terms of tropical botany.

Façade of the French Guiana Herbarium.

In French Guiana in the 1960s, botanists working on tree architecture came up against a practical obstacle: in the absence of publications on French Guiana's flora, they were struggling to determine harvested species. The only documents available dated back to 1775 and listed 1,241 species, a very low number in light of French Guiana's biodiversity.

In 1965, they decided to put together a formal collection and created the *Herbier de Guyane*. Under the umbrella of Orstom, harvesting campaigns were initiated and, over the next decades, some 200,000 specimens representing 5,000 species were assembled. They all come from the Guiana Shield, with 80% of samples from the French Guiana department and the rest from Guiana and Suriname. This explains the international reputation of the *Herbier*, which involves a consortium of 150 specialists from all over the world. All these experts successively published the various volumes of the French Guiana flora, each corresponding with a plant family. To date, one third of the Herbarium's plant families have been the subject of a monograph.

••• In French Guiana, the creation of a herbarium advances knowledge •••

This platform, which brings together experts, plant collections and database under the same roof, has now become a must for all research relating to French Guiana's plant world. Three hundred researchers use this facility every year, as do schoolchildren and private citizens. This major reference tool is the only one which currently provides a pragmatic approach to French Guiana's plant diversity. This lively platform monitors changes in classification and provides all researchers involved in projects with a floral dimension with an essential working tool. It grows a little each year and keeps track of the plants' past distribution areas. The database of the *Herbier de Guyane* is available on line: http://publish.plantnet-project.org/project/caypub

PARTNERS

University of French Guiana

Museu Goeldi, Brazil

IEPA, Brazil

EMBRAPA, Brazil

French Guiana Amazonian Park

French Guiana Regional Nature Park

CNRS, Inra, Cirad, France

"The *Herbier de Guyane* is a must for all researchers with an interest in neotropical biodiversity. It hosts one of the largest collections of plants from the Guiana Shield region, which remains one of the least explored regions north-east of the Amazon. The collections of the *Herbier de Guyane* have been very useful, not only for studies of French Guiana's flora but also in helping us find out more about Brazil's biodiversity."

Paulo H. Labiak Evangelista,
Federal University of Paraná, Brazil

Preparation of specimens in a forest.

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, with 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.

The software 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 program 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 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.

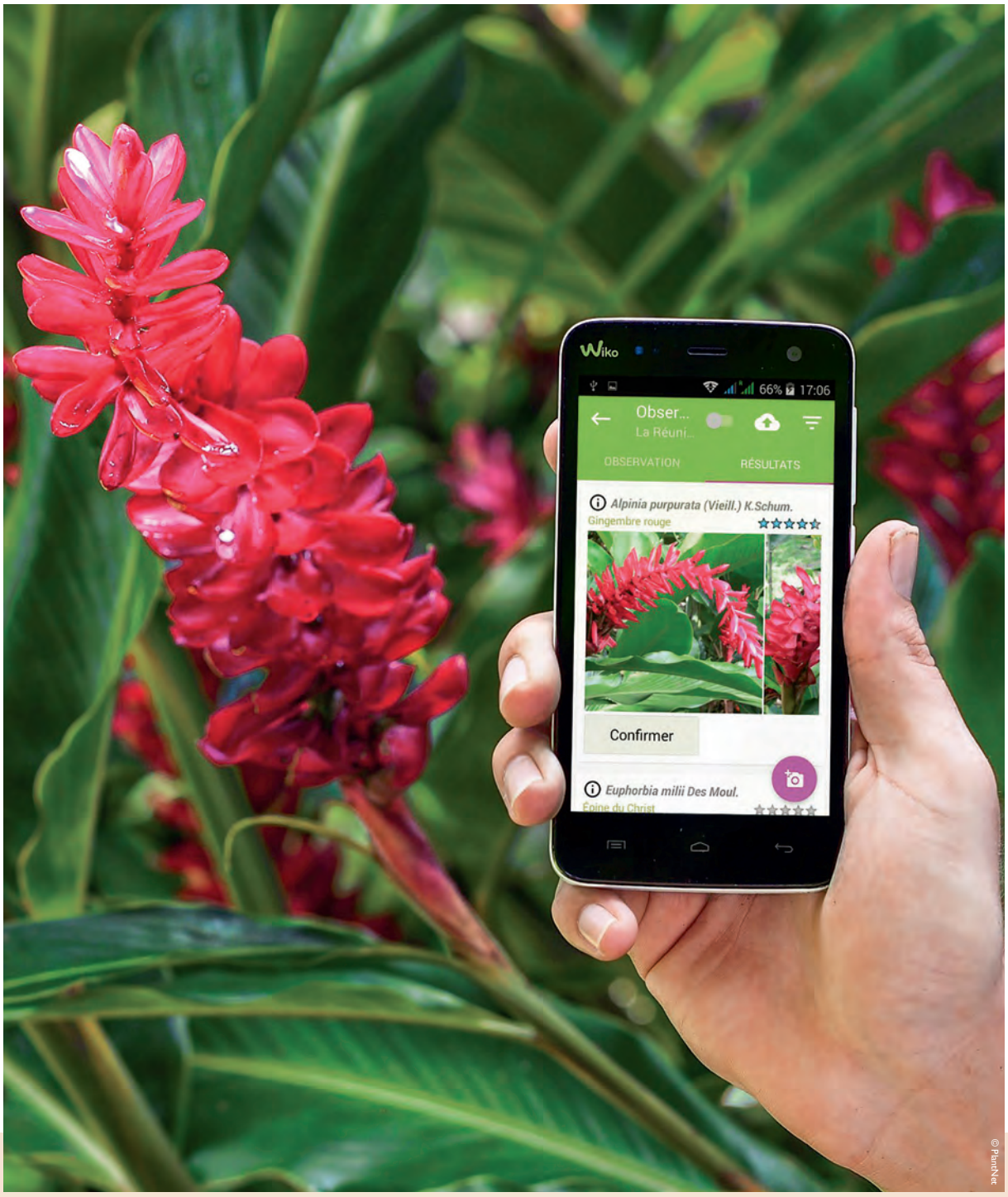
PARTNERS

Inra, Cirad, Inria, France

Tela Botanica, France

Numerous partnerships in Latin America, Africa and the Indian Ocean

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



Pl@ntNet application on a smartphone.

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.

Plants collected for therapeutic steam bath, 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 the oral knowledge which forged their identity. These societies were undergoing rapid developments, which were not

"The project aimed at identifying plant uses was well accepted by the population, as it was perceived not only as an attempt to directly showcase medicinal flora, but also as a form of cultural preservation, seeing as very few people are now familiar with this part of the Yanesha culture, and young people are less and less interested in it."

Augusto Francis Lores, representative of the San Pedro de Pichanaz community, Azulis area, Peru, and in charge of the project for the Yanesha section

Huaraz medicinal plant market, Peru.

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

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 ensures 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

Participative archaeology in the Marquesas Islands

The image associated with the Marquesas Islands, their population and culture was undermined during the colonial period. Their remoteness from decision-making centres in Tahiti and small population and strong prejudice have limited the awareness of the archipelago's history.

Participatory archaeology, Marquesas Islands.

You do not always need money to be innovative or a pioneer. In the Marquesas Islands, lack of resources turned potentially very limited research into a community-based and participatory process. It all began in the 1980s with initial research conducted as part of voluntary technical assistance in the Marquesas Islands, an isolated archipelago 1,500 kilometres from Tahiti. Islanders revealed the existence of a rock shelter they believed to be ancient, and participated in the original excavations.

Occupation was dated at 200 BC, an estimate which was later revised to AD 800. Nonetheless, this initial experience aroused the curiosity of the Marquesans who, in the 1990s, asked for and obtained the posting of a researcher dedicated to the archipelago's archaeology, with a view to studying a site the population wished to use as part of the brand new Marquesan cultural festival. With the help of a local cultural association and the municipality, a valley on the island of Hiva'Oa was explored, revealing the scale of past settlements: this site became a symbol of Polynesia.

In the Marquesas Islands, before Western vessels arrived bringing diseases with them, the population was close to 100,000. In 1920, there were only about 2,000 Marquesans left, and most villages were abandoned, before being forgotten altogether. The rediscovery of these valleys and their ancient occupation was consistent with a powerful cultural revival. For the purposes of the festival, excavated remnants were partially restored and regained their initial function. This is how participatory archaeology naturally developed in the Marquesas Islands well ahead of time. Thanks to festivals organised every two to four years on various islands of the Archipelago, seven sites have been partially restored, three of which have been selected for the recognition of the Marquesas Islands as a World Heritage Site. Each of them contributes to the cultural, economic and tourism development of the Marquesas Islands.

PARTNERS

University of French Polynesia

Municipalities of the Marquesas archipelago

Cultural and handicraft associations of the Marquesas Islands

Cultural Federation of Motu Haka o te Henua Enana

Museum of Tahiti and Her Islands

••• In the archipelago, archaeology has become a vector for development •••

Carved stone, Fatu Iva, Marquesas Islands.

"I've been lucky, I've been around a bit. I've travelled. And I've understood. We visited Hawaii sites with the children of a traditional Hawaiian school. They have sites, but they also have fake ones. It made me think: we have actual sites back home!"

Yvonne Katupa, Hatiheu, Nuku Hiva, 19 April 2018, interviewed by Zoé Lamazou

Discovering a new civilisation

The upper Amazon has long been regarded as a region where human history was negligible. Archaeologists believed that the Amazon environment was not conducive to the development of an actual civilisation.

Containers, La Florida, Ecuador.

In 1998, Ecuador and Peru put an end to their border dispute and opened access to a territory in the Upper Amazon over which they had been fighting for years. Archaeologists worked there for the first time from 2000 to 2007, revealing some 400 archaeological sites, evidence of an unknown civilisation. They called it Mayo-Chinchipe-Marañón, after the three rivers which mark the boundaries of this 2,000 square kilometre area. The sites featured many remnants of dwellings, with stone and ceramic artefacts. Datings suggested that this civilisation was 5,300 years old, and survived for at least 3,000 years.

••• It is believed that cacao was not domesticated in Mexico but in the Upper Amazon •••

Archaeologists conducted thorough excavations on the most imposing site, Santa Ana-La Florida, discovered in March 2003, digging out remnants of stone architecture, polished stone containers and pottery very different from that of other Amazonian cultures. They unearthed the oldest residues of a cocoa drink in history. They also found remnants of burnt cacao in a household bin, a sign that beans may also have been used for cooking. Therefore, while cacao was brought back from Mexico by the Conquistadors in the 16th century, the plant may have been domesticated much earlier in another American region, in the Upper Amazon, where there are numerous varieties of wild cacao

"The positive impact of archaeological research in the upper Amazon, with its societal dimension, contributes to reasserting the identity of populations through their local cultural heritage…"

Quirino Olivera Nunez, chair of the Peruvian Association of Archaeology and Social Development of the Amazon

Mortar shaped like a cacao pod, Ecuador.

trees. This finding confirmed an old story, thereby adding economic value to the excellent reputation of the cacao produced in this region. It was directly beneficial to local producers and populations.

Furthermore, the remnants of the Mayo-Chinchipe-Marañón community featured shells from the Pacific. This civilisation was therefore in contact with coastal populations and people living in the Andes, and probably also with those of the Amazon River. There is no doubt that much remains to be discovered, as more than two thirds of the Amazon is still archaeologically unexplored.

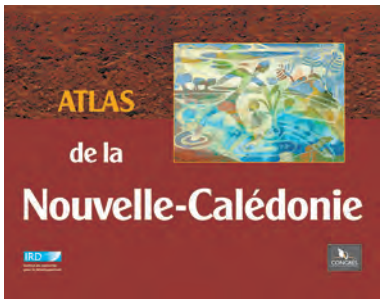
PARTNERS

Instituto Nacional de Patrimonio Cultural, Ecuador

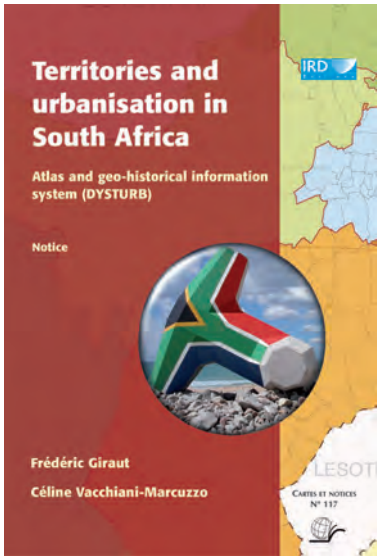
University of Calgary, Canada

Anthology of atlases

Spatialising figures to make them legible and accessible at first glance is the purpose of atlases, publications used to extend the dissemination of knowledge beyond a circle of initiates.



Cover of the *Atlas de la Nouvelle-Calédonie*.



Cover of a CD-ROM atlas on South Africa.

Making knowledge visible is the purpose of the atlases produced by IRD from the 1970s for Côte d'Ivoire and French overseas departments and territories. These publications have always combined and crystallised the knowledge of as many as a hundred contributors, experts in geology, economics, botany, agriculture, history or demography, generally under the responsibility of geographer-researchers. The knowledge gained in all these fields was collected with the dual aim of inventorying and enhancing the consistency of information, and was ultimately presented in the form of maps and records.

Meanwhile, another type of atlas was regularly published from 1967 to 1987. Referred to as "Land Atlasas", they focused on the agrarian structures of sub-Saharan countries, each describing the situation in a specific country, thereby facilitating benchmarking between countries.

••• Various atlases have been produced and published by IRD at the request of Southern States or overseas territories, but also to explore specific scientific fields •••

Generally created at the request of States or territories, traditional large-format atlases have been published on New Caledonia (1981 and 2013), French Guiana (1979 and 2001), Polynesia (1993), Cameroon (1995 and 2000), etc. They provide countries or territories with a sovereignty tool, even a strong symbol of unity. This explains their usually large print runs and broad dissemination among institutions. Certain publications are also dedicated to cities of the Global South, like the Quito, La Paz, Ouagadougou and Hà Nôi atlases, or to economic sectors, like the *Atlas of small-scale fisheries in Peru,* released in 2017, or various atlases of tuna-like species in the Atlantic and Indian oceans. Some of the themes developed have resulted in further studies to assist in the economic or political decision-making process (land reform, fisheries regulations, land use planning, etc.).

PARTNERS

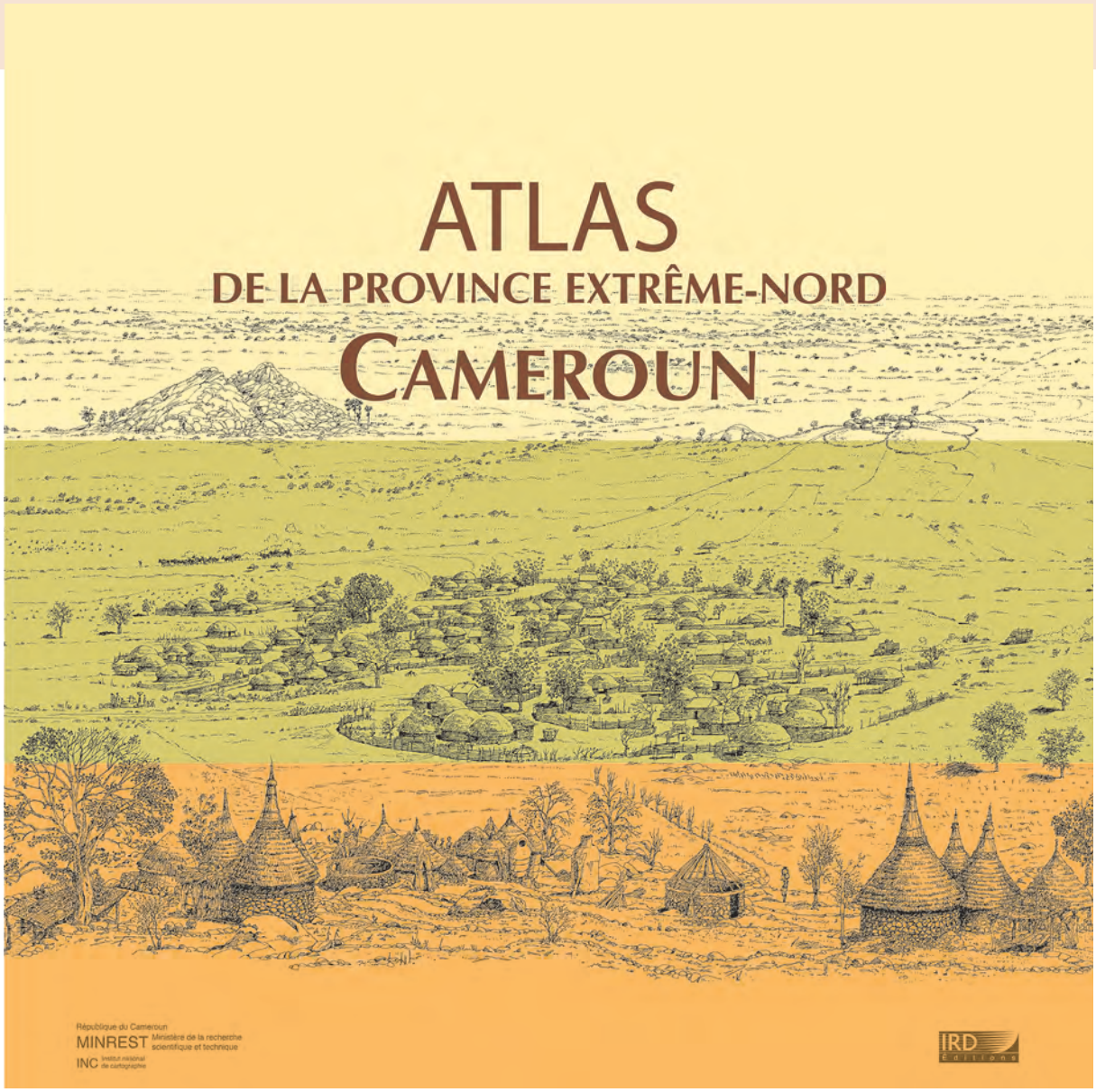
New Caledonia Assembly

French Guiana Region

Cameroon Ministry of Scientific and Technical Research

"The *Atlas de la Nouvelle-Calédonie* published by Orstom in 1981 continues to be a reference to this day, due to the wealth of knowledge and pertinent analyses it contains. Nevertheless, the need to update information and set meaningful benchmarks for the understanding of contemporary New Caledonia prompted the New Caledonia Assembly to produce a new atlas, in close partnership with IRD."

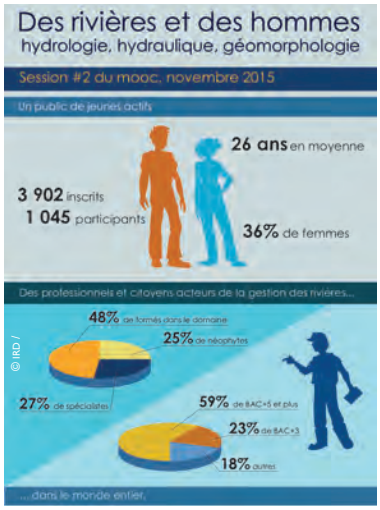
Excerpt from the foreword of the *Atlas de la Nouvelle-Calédonie* (2013), Roch Wamytan, president of the New Caledonia Assembly



Cover of the *Atlas de la province extrême-nord Cameroun*.

Virtual education

Access to quality education is the fourth of the 17 sustainable development goals. It is an essential precondition for reducing inequalities.



MOOCs (Massive Open Online Courses) are often run by experts in a given field. They were initially created in the USA, before they grew to become a global phenomenon by the end of 2012. That year, researchers involved in the Network of Excellence in Engineering Sciences of the French-speaking Community (Rescif, www.rescif.net) decided to take the plunge and create a MOOC on the topic of "Rivers and Humans". The idea was to showcase theoretical and applied knowledge in terms of hydrology and geomorphology, based on five-week sessions.

Launched in 2014 and renewed in the autumn of each year, this MOOC is the first online course created in conjunction with experts from the Global North and South. Ten researchers present theoretical concepts based on actual case studies, notably in Mexico, Benin, Vietnam and Ecuador. The knowledge taught can be transposed to most countries of the world, hence the popularity of this MOOC, which has been used by about 10,000 people from 85 countries. The participants are students, technicians, but also private citizens wishing to have a better understanding of the meaning of their everyday actions.

This MOOC, which teaches unusual, even non-existing subjects in certain contexts of the Global South, is available in French, English, Vietnamese and Spanish. It is notably used in Vietnam by research lecturers to provide education combining online with in-person learning methods. Other MOOCs have since been created in conjunction with IRD, including "Climate Change Causes and Issues" in 2015, "Malaria" in 2016, "Medical Entomology" in 2017 and "Sustainable Development Goals" in 2018, which was voted best academic MOOC of the year.

PARTNERS

Polytechnic Institute of the National University of Vietnam

Quito National Polytechnic School, Ecuador

Grenoble-IME, France

École Normale Supérieure of Lyon, France

Université Lumière Lyon 2, France

Catholic University of Louvain, Belgium

Interview conducted as part of the ePOP initiative, New Caledonia.

Science as a tool for citizens

Science is not just a matter for researchers. It is also a way of perceiving and considering the world, like the arts or literature. This is the vision behind the development of innovative actions aimed at young people.

Science is a culture, a way of looking at the world. It is in this spirit that, in 1999, IRD launched the "Youth Clubs for Research and Development" in France and in partner countries. These long-term projects involving close cooperation between a teacher and a researcher, led groups of pupils to conduct a scientific study, from the definition of the topic to the presentation of results one or two years later.

There were 15 to 30 clubs operational worldwide each year, essentially within upper and lower secondary schools. The topics addressed varied greatly, depending on local issues. Young people covered themes such as insect pests, access to transport, migration, climate change, etc. Whenever possible, the results were presented to local decision-makers so that pupils could become aware of the civic-minded dimension of the knowledge gained.

In 2004, IRD was entrusted by the Ministry of Foreign Affairs with the coordination of scientific culture projects in Africa. This experience helped start a dialogue and establish a lasting relationship with African associations. Actions such as travelling exhibitions, conferences, scientific theatre or workshops were developed.

Subsequently, projects aimed at students were implemented, e.g. ePOP, a collaborative initiative whereby young Pacific Islanders were invited to collect questions on their mobile phones from the local population regarding the effects of environmental changes and pass them on to scientists. Large gatherings of these young people were also regularly organised, for example in Morocco in 2016 during the COP22 in Marrakech, where 150 or so young people discussed and reflected on the issue of "Closely Monitored Climate".

Youth club in Niger as part of the "Closely Monitored Climate" scheme.

PARTNERS

French Institute

France Média Monde

Agency for French Education Abroad (AEFE)

Associations, NGOs and schools

Knowledge and images accessible to everyone

At a time when science is becoming more open and freely accessible, IRD's *Horizon Pleins Textes* database is something of a precursor, having made IRD researchers' publications available online, free of charge, in the mid-1990s.

Nowadays, 99,000 scientific documents are stored in IRD's institutional archives, a hybrid digital and paper collection of which 66,000 open-access PDF documents were downloaded nearly three million times in 2018, essentially in French-speaking Africa countries, led by Côte d'Ivoire, Algeria and Cameroon.

This wide-ranging digital corpus, to which nearly 3,000 new documents are added every year, is multidisciplinary (tropical soil science, hydrology, oceanography, human and social sciences, health, botany, etc.) and ensures international exposure for the partnered research conducted by IRD and its partners in the Global South over the past 75 years.

In 2018, this documentary collection was awarded the "Collection of Excellence" certification by the French Ministry of Higher Education and Research, thus recognising its value with regard to both heritage and science.

Searchable from a multilingual promotional website (French, Spanish and English) or directly via general purpose search engines, the Horizon database meets the requirements of the National Plan for Open Science and is also harvested by major scientific information infrastructures such as Open Aire and Base, which disseminate the results of partnered research for development throughout the world.

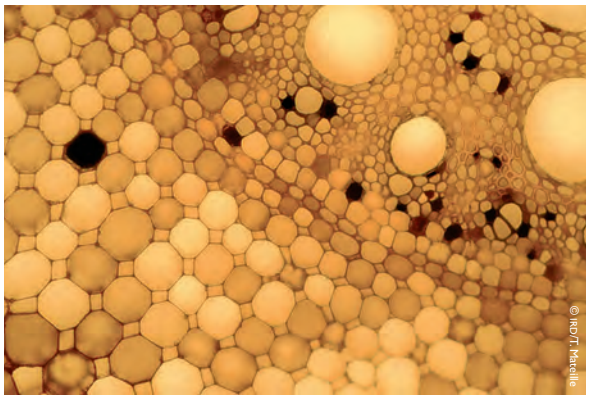
Furthermore, IRD has an extensive library of images built up over several decades of research in the Global South. A unique iconographic fund featuring more than 50,000 photographs of Africa, Asia, Latin America, Oceania and overseas territories, the Indigo photo library stores and disseminates photographs taken and captioned by IRD researchers. These pictures taken on the ground or in laboratories cover a broad spectrum of disciplines: Earth and life sciences, health sciences, human and social sciences. They are accessible to everyone: journalists, publishers, researchers, teachers, students and private citizens.

HORIZON PLEINS TEXTES

http://www.documentation.ird.fr

INDIGO PHOTO LIBRARY

http://www.indigo.ird.fr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Replaying and changing the scene
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epidemiologist and physician, Ceped UMR

A sugar paste to combat hunger
Text written based on press articles
and documents

Preventing the effects of malnutrition
Serge Trèche,
nutritionist, Nutripass UMR, retired

Combating deficiencies
Jacques Berger,
nutritionist, Nutripass UMR

Preventing obesity in the Maghreb
Pierre Traissac,
epidemiologist, Nutripass UMR

Part 2 – Hazards, risks and vulnerabilities

Niakhar: sentinel area since 1962
Valérie Delaunay,
demographer, LPED UMR

Genealogy of *Plasmodium*
François Renaud,
biologist, Mivegec UMR
Éric Delaporte,
infectologist, TransVIHMI UMI

The mosquito net revolution
Pierre Carnevale,
medical entomologist, malariologist, retired
Vincent Robert,
medical entomologist, Mivegec UMR
Frédéric Darriet,
medical entomologist, Mivegec UMR

Preventing malaria intermittently
Cheikh Sokhna,
biologist, malariologist, Vitrome UMR

Protecting pregnant women from malaria
Michel Cot,
epidemiologist and physician, Merit UMR

Reconstructing the history of HIV
Martine Peeters,
virologist, TransVIHMI UMI

The battle against Ebola
Éric Leroy,
virologist, Mivegec UMR

Ebola: a predetermined ending?
Éric Leroy,
virologist, Mivegec UMR

Humanising biosecurity measures
Alice Desclaux,
anthropologist, TransHIVMI UMI

The OCP programme, or how to eradicate "river blindness"
Bernard Philippon,
medical entomologist, retired
Vincent Robert,
medical entomologist, Mivegec UMR
Jean-Marc Hougard,
medical entomologist, Mivegec UMR

The effect of insecticides on the environment
Didier Paugy,
hydrobiologist, retired

Testing before treating
Michel Boussinesq,
parasitologist and physician, TransHIVMI UMI

Lights out for the tsetse fly?
Philippe Solano,
entomologist/parasitologist, Intertryp UMR

Pioneers in the Zika virus
Dorothée Missé,
virologist, Mivegec UMR

Developing mosquito factories
Louis-Clément Gouagna,
medical entomologist, Mivegec UMR

Vaccinating dogs to save humans
Jean-Loup Lemesre,
immunobiologist, Intertryp UMR

Detecting drug-resistant tuberculosis
Anne-Laure Bañuls,
microbiologist, Mivegec UMR

Climate-related epidemics
Christophe Menkes,
climatologist, Entropie UMR
Morgan Mangeas,
mathematician, Espace-Dev UMR
Benjamin Sultan,
climatologist, Espace-Dev UMR

Closely monitored glaciers
Thomas Condom,
hydroglaciologist, IGE UMR

Watching out for our water
Marielle Gosset,
hydrometeorologist, UMR GET

Heat wave warning in Africa
Serge Janicot,
climatologist, Locéan UMR

Assessing seismic risks
Jean-Mathieu Nocquet,
geodesist, geophysicist, Géoazur UMR

Long-lasting eruptions
Jean-Luc Le Pennec,
volcanologist, Magma and volcanoes UMR

Mapping resources to manage priorities
Sébastien Hardy,
geographer, Prodig UMR

Sounding out the hidden side of earthquakes
Philippe Charvis,
geophysicist, Géoazur UMR
Yann Hello,
marine geophysicist, Géoazur UMR

Using data to improve road safety
Emmanuel Bonnet,
health geographer, Résiliences UMI

Record levels of plastic pollution in fresh water
Émilie Strady,
water geochemist, MIO UMR

Tracesense, measuring traces of pollution
David Point,
environmental chemist, GET UMR

Mesotoga: bacteria found in polluted environments
Bernard Ollivier,
microbiologist, MIO UMR

Catching cyanobacteria red-handed
Isabelle Biegala,
microbiologist, MIO UMR

Part 3 – Sustainable agriculture and food security

Sequestering carbon in soil
Christian Feller,
soil scientist, Eco&Sols UMR, retired
Collectif MOS,
Eco&Sols UMR

Erosion in the shade of trees
Christian Valentin,
soil scientist, iEES-Paris UMR, retired

Plant symbiosis
Éric Giraud,
microbiologist, LSTM UMR

Macrofauna, macro-effect
Éric Blanchart,
soil ecologist, Eco&Sols UMR

Correcting the pH of soil
Jean-Pierre Montoroi,
expert in agropedology, iESS-Paris UMR

Small dams, major effects
Philippe Cecchi,
ecologist, Marbec UMR
Jean Albergel,
hydrologist, Lisah UMR

Water in African soil
Jean-Michel Vouillamoz,
Hydrogeologist, IGE UMR

Measuring water
Vincent Simonneaux,
research engineer in remote detection and hydrology, Cesbio UMR
Salah Er-Raki,
hydro-climatologist, Cadi Ayyad University
Gilles Boulet,
hydrologist and modeller, Cesbio UMR

Khettaras: living vestiges
Thierry Ruf,
geographer, Gred UMR

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

Land: a scientific tool for development
Jean-Baptiste Boutrais,
rural geographer, Paloc UMR, retired

The Amazon forest hiding behind felled trees
Laure Emperaire,
ethnobotanist, Paloc UMR

Optimising agricultural knowledge
Robin Duponnois,
ecologist, LSTM UMR

From IPCC to operational status
Jean-Philippe Boulanger,
climatologist, Locéan UMR

First mapping of rice yellow mottle virus
Eugénie Hébrard,
plant virologist, IPME UMR

Cassava and bacteria legacy
Valérie Verdier,
plant pathologist, IPME UMR
Boris Szurek,
plant pathologist, IPME UMR

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Bruno Le Rü,
entomologist, EGCE UMR
Paul-André Calatayud,
entomologist, EGCE UMR

Fields under thermal surveillance
Olivier Dangles,
ecologist, Cefe UMR

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Gauthier Dorbigny,
biologist, CBGP UMR

Sexing to develop date palms
Frédérique Aberlenc,
biologist, Diade UMR

Turning green waste into gold
Sevastianos Roussos,
microbiologist, IMBE UMR, retired

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

Controlling reproduction
Marc Legendre,
fish physiologist, Isem UMR

Tropical tuna under surveillance
Daniel Gaertner,
fisheries biologist, Marbec UMR
Pierre Chavance,
marine biologist, Marbec UMR, retired
Pascal Bach,
fisheries ecologist, Marbec UMR

Moving towards more sustainable baits
Pascal Bach,
fisheries ecologist, Marbec UMR

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

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Jérôme Vialard,
oceanographer, Locéan UMR

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Jacques Merle,
physical oceanographer, Locéan UMR, retired
Bruno Voituriez,
physical oceanographer, retired
Bernard Bourles,
physical oceanographer, Legos UMR

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Pierrick Penven,
physical oceanographer, Lops UMR

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Thierry Lebel,
hydro-climatologist, IGE UMR

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Thierry Lebel,
hydro-climatologist, IGE UMR

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hydro-climatologist, HydroSciences UMR
Luc Descroix,
hydrologist, Paloc UMR

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hydro-climatologist, LTHE

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Pierre Chevallier,
hydrologist, HydroSciences UMR, retired

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Stéphane Calmant,
geophysicist, Legos UMR

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Bruno Turcq,
paleoclimatologist, Locéan UMR

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Guillaume Favreau,
Hydrogeologist, IGE UMR

Soils in all their forms
Christian Valentin,
soil scientist, iEES-Paris UMR, retired

Sand, dust and wind
Jean-Louis Rajot,
soil scientist, iEES-Paris UMR

Cataloguing the French Guiana forest
Raphaël Pélissier,
ecologist, Amap UMR

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

The proportion of birds
Philippe Cury,
marine ecologist, Marbec UMR

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Ricardo Rodolfo-Metalpa,
biologist, Entropie UMR

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Hervé de Tricornot,
expert in research policies, retired

Mosquitoes, viruses and globalisation
Frédéric Simard,
medical entomologist, Mivegec

Supporting the creation of clinical research centres in Africa
Éric Delaporte,
infectiologist, TransHIVMI UMI
Michel Cot,
epidemiologist and physician, Merit UMR
Jean-François Etard,
epidemiologist and physician, TransHIVMI UMI
Bernard Taverne,
anthropologist, TransHIVMI UMI

Training health supervisors
Jean-Marc Hougard,
medical entomologist, Mivegec UMR
Florence Fournet,
medical entomologist, Mivegec UMR

"Boundless" modelling
Alexis Drogoul,
computer scientist, Ummisco UMI

Home-made GIS
Marc Souris,
mathematician, researcher in information science, UVE UMR

Public data on West African fisheries
Monique Simier,
biostatistician, Marbec UMR

Mapping out regulations
Marie Bonnin,
environmental lawyer, Lemar UMR

Rice as a common good
Alain Ghesquière,
geneticist, Diade UMR

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Serge Hamon,
plant breeder, Diade UMR
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population genomicist, Diade UMR

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botanist, Amap UMR

A botanist in my smartphone
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At the cutting edge of ethnopharmacology
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ethnopharmacologist, Pharma-Dev UMR
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ethnopharmacologist, EIO UMR, retired

Participative archaeology in the Marquesas Islands
Pierre Ottino-Garanger,
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Discovering a new civilisation
Francisco Valdez,
archaeologist, anthropologist, Paloc UMR

Anthology of atlases
Benoît Antheaume,
rural geographer, Prodig UMR, retired

Virtual education
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hydrogeomorphologist, IGE UMR

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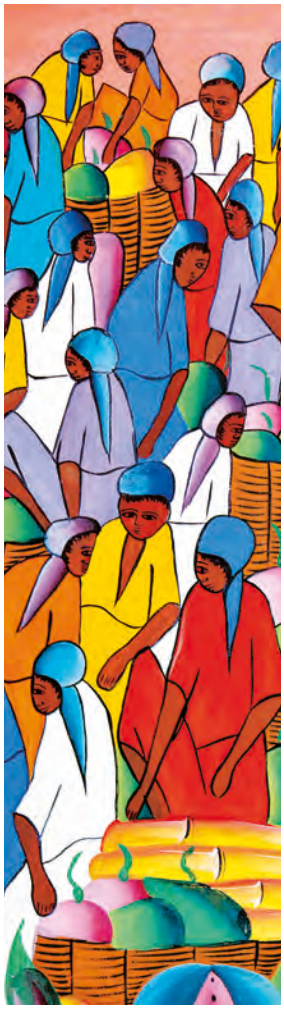

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