Plant Genetic Conservation

Plant diversity sustains all animal life, and the genetic diversity within plants underpins global food security. This text provides a practical and theoretical introduction to the strategies and actions to adopt for conserving plant genetic variation, as well as explaining how humans can exploit this diversity for sustainable development. Notably readable, it initially offers current knowledge on the policy context of plant genetic resources. The authors then discuss strategies from *in situ* and *ex situ* conservation to crop breeding, exploring how plant genetic resources can be used to improve food security in the face of increasing agro-biodiversity loss, human population growth and climate change. Each chapter draws on examples from the literature or the authors' research and includes further reading references. Containing other useful features such as a glossary, it is invaluable for professionals and undergraduate and graduate students in plant sciences, ecology, conservation, genetics and natural resource management.

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Drawing by Glen Baxter celebrating the challenges of plant genetic resource conservation.
Baxter, G. (1974). Fruits of the World in Danger. Gotham Book Mart, New York. Used by permission of the author, who retains the copyright.

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FOREWORD

The year 2020 will hopefully be seen as the year the world awoke from its slumber and started to realize the extent of the global crisis facing biodiversity. Both *The State of the World's Biodiversity for Food and Agriculture* report, the first global assessment of biodiversity for food and agriculture worldwide, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)'s *Global Assessment Report on Biodiversity and Ecosystem Services* present alarming pictures of unprecedented biodiversity loss and future scenarios of accelerated rates of loss if we fail to act at this point in time. We have clearly reached a point where business as usual is not a viable option if we are to have a long-term future as a species.

The State of the World report warns that, despite the growing evidence of biodiversity's key role in food security and nutrition, the diversity of production systems worldwide is in decline. Of the thousands of plant species cultivated for food, fewer than 200 contribute substantially to global food output, and only 9 account for 66% of total crop production.

The IPBES assessment highlights that local varieties of domesticated plants, as well as wild relatives of our crops, are disappearing globally and that this loss of genetic diversity poses a serious risk to global food security and undermines the resilience of many agricultural systems to threats such as pests, pathogens and climate variability. Fewer and fewer crop species and varieties are being cultivated, raised, traded and maintained around the world, despite many efforts, mostly local and uncoordinated. The IPBES global assessment reports that the drastic loss of agro-biodiversity is the result of land use change, traditional knowledge loss, market preferences and globalized trade, and that too many hotspots of plant genetic resources have been lost, remain under threat or do not receive the formal protection they urgently require.

What can the global community do in the face of such an onslaught? The Sustainable Development Goals (SDGs) and the UN Convention on Biological Diversity (CBD) post-2020 biodiversity framework can provide us with a renewed opportunity to commit and mobilize, provide real political will and leadership, and coalesce action around the conservation and use of plant genetic resources for sustainable agriculture, food systems and sustainable and healthy diets. Mainstreaming plant genetic resources to this end is central if we are to achieve the SDGs by 2030.

We also need to find more creative ways in which to use plant genetic resources in agriculture, food systems and supply chains as well as to explore innovative approaches that incentivize a greater demand and desirability for a more diverse use of plant genetic resources, driven by consumers. Only when we are actively using plant genetic resources for sustainable farming and food systems that deliver diverse, nutritious foods, can we hope to effectively safeguard this green gold for future generations and reverse current alarming rates of biodiversity loss.

Plant Genetic Conservation is a long awaited, much-needed textbook, which I welcome very warmly. It provides up-to-date, state-of-the-art information and knowledge essential to safeguard our global heritage and wealth of plant genetic resources, including a historical perspective, the scientific underpinnings of applied taxonomy, genetics, diversity assessment and measurement needed for effective conservation planning, strategies and actions. Further the text presents a comprehensive overview of germplasm collection, conservation and evaluation, and its importance for plant breeding and general utility.

This book will make an enormous contribution to ensuring plant genetic resources are available for

future food production and climate scenarios and the global nutrient needs. I am convinced it will be widely used by universities to build vital capacity and skills for the task ahead, as well as by decision-makers and practitioners working in the field to more effectively conserve the breadth of plant genetic diversity. It is a clear contribution to the IPBES report, which recommends '*ensuring the adaptive capacity of food production incorporates measures that conserve the diversity of genes, varieties, cultivars, landraces and species which also contribute to diversified, healthy and culturally-relevant nutrition*'.

Juan Lucas Restrepo
Director General – Bioversity International
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PREFACE

Purpose of the Book

We live in critical times for the world's biological diversity. Plants, as the foundation of the food chain, are essential for sustaining all animal life and the habitats in which animals can thrive, and underpin many ecosystem services. They also supply humans directly with the bulk of our food, construction materials, fibres, medicines, dyes and many other products. Plants are an essential and precious resource for humankind. The International Union for Conservation of Nature (IUCN) estimates that out of the total 16 000 plant species found in India, people use at least 5 000. Yet it is universally agreed that, largely as a result of recent human activity, there is a catastrophic loss of biological diversity occurring at present, and we are living through the sixth global biodiversity extinction with species and, equally importantly, genes and alleles, being lost in perpetuity. It has been estimated that approximately 20% of plant species will be lost in the near future, and although more difficult to estimate, up to 35% of plant genetic diversity is likely to be lost over the same time period. The signing of the Convention on Biological Diversity at the 'Earth Summit' in Rio de Janeiro in 1992, together with the establishment of the International Treaty for Plant Genetic Resources for Food and Agriculture in 2001, the Food and Agriculture Organization (FAO) Global Plan of Action for Conservation and Use of PGR in 1996, the Strategic Plan for Biodiversity 2011–2020, including Aichi Biodiversity Targets in 2010, the CBD Global Strategy for Plant Conservation 2011 – 2020 in 2010, the UN Sustainable Development Goals in 2015, and more recently the first State of the World Report on Biodiversity for Food and Agriculture and IPBES report each drew attention to the need to conserve the world's natural resources, the need to link biodiversity conservation to sustainable exploitation and human development, and the requirement to ensure equitable sharing of the benefits arising from the exploitation of biological diversity. The exploitation of plant genetic resources is of fundamental importance to the survival of humankind; therefore, the need to focus on conserving plant diversity and sustainable exploitation is critical to all our futures.

Yet thus far plans made, or targets established, are consistently failing. At the time of writing, the UN estimates there are 7.7 billion humans on Earth, 78% living in developing countries, and it is predicted there will be 9.6 billion by 2050, 86% of them in developing countries (primarily Africa). FAO estimates that to feed the human population in 2050 will require food supplies to increase by 70% globally and at least 100% in developing countries, while the Intergovernmental Panel on Climate Change (IPCC) estimates that climate change may reduce agricultural production by 2% each decade by 2050. It can logically be argued that the planet is beyond its carrying capacity for its human population. In this state, we are over-exploiting the planet, and our unsustainable actions are directly causing an exponential loss of plant genetic diversity throughout the world. This in turn is having direct negative economic, political and social consequences for humanity.

This is not our only option; we could alter our path and explore fully the positive benefits that are likely to result from systematically conserving and sustainably exploiting the world's plant genetic resources. There have been strong movements to halt this loss of plant diversity and enhance its utilization for the benefit of all humanity since the 1960s, largely led by the FAO and Consultative Group on International Agricultural Research (CGIAR) institutes. This text provides a theoretical and practical introduction to plant genetic conservation, the diversity included, the various strategies and techniques available for conservation, and how humankind can exploit plant genetic diversity sustainably. We have previously published several books on various aspects of this topic, *in situ*, *ex situ*,

crop wild relative conservation, crop landrace conservation and breeding, but here we attempt to draw these multiple strands of Plant Genetic Resources for Food and Agriculture (PGRFA) conservation and use together into one textbook. A book we hope will enthuse the next generation to take the actions we ourselves have unfortunately been unable to see through to fruition. With our collective experience, we realize there are no easy answers, but we hope to promote an informed debate of the scientific principles underlying plant genetic conservation and create a more sustainable impact. It looks increasingly as though the outcome for humankind itself may depend on the success of this debate and its implementation.

Precis of Contents

We have approached the subject of systematic conservation and sustainable utilization of plant genetic diversity from theoretical and practical viewpoints, drawing together ideas from published and unpublished sources, and from our own extensive practical field experience, conserving plant genetic diversity and using that diversity to sustain food security around the world. The book is divided into 18 chapters that fall into four parts: ***Part I Introduction*** (Chapters 1 and 2); ***Part II Scientific Background*** (Chapters 3–5); ***Part III Conservation Practice*** (Chapters 6–13); and ***Part IV Plant Exploitation*** (Chapters 14–18). The aim of each chapter is as follows:

- **Chapter 1: Introduction –** provides an introduction and overview to the subject of biological diversity (biodiversity), and more specifically the systematic conservation and sustainable utilization of plant genetic diversity.
- **Chapter 2:** Establishing the Social, Political and Ethical Context – reviews the social, ethical and policy context of PGRFA conservation and use. This is achieved by providing the historical background and introducing the major conventions, treaties and agreements, as well as the key stakeholders from the formal and informal sectors that are concerned with plant conservation and use and the equitable sharing of benefits.
- **Chapter 3: Plant Taxonomy –** provides an elucidation of relationships between taxa (families, genera, species or subspecific taxa), the production of classifications that reflect their evolutionary relationships and how other taxonomic products are derived, including descriptions, synonyms, distribution maps, identification aids and nomenclature.
- **Chapter 4: Plant Population Genetics –** introduces the factors determining, maintaining and changing variation in populations, including the factors affecting changes in allele frequency and how population genetic knowledge can be used to improve *ex situ* and *in situ* conservation and use of plant genetic diversity.
- **Chapter 5: Genetic Diversity Measurement –** provides an overview of genetic diversity and variation, and how to measure this when studying plant genetic resources. It also describes the use of DNA markers for assessing polymorphism, studying diversity and revealing trait associations relevant for searching variation of target characters in plant breeding.
- **Chapter 6: Planning Plant Conservation –** focuses on taxon prioritization, establishing the geographic and taxonomic breadth and most important conservation actions using ecogeographic and gap analysis techniques and the production of strategies or action plans to aid conservation implementation.
- **Chapter 7: Conservation Strategies and Techniques –** introduces the two fundamentally distinct conservation strategies, *in situ* and *ex situ*, and within each, the range of techniques available to maximize the range of plant genetic diversity maintained, the relative advantages of each technique and the fact that *in situ* and *ex situ* should be applied in a complementary manner to maximize impact and conserve resource backup.
- **Chapter 8: *In Situ* Conservation –** reviews the conservation of plant species where they naturally occur and involves the planning, design, establishment, management and monitoring of the viable plant populations to be conserved.

- **Chapter 9: On-Farm Conservation** – provides an overview of the concept of on-farm conservation of plant genetic resources, the maintenance of farmer landraces or traditional varieties in agro-ecosystems. The chapter outlines some of the key steps that need to be considered when implementing an on-farm conservation project.
- **Chapter 10: Community-Based Conservation** – provides a historical perspective on the development of community-based conservation and how approaches are grounded in changes that not only occurred in conservation practice but also in agriculture and rural development.
- **Chapter 11: Germplasm Collecting** – provides an introduction and overview of how to plan and undertake the collection of plant genetic samples in the field, and once samples are collected, how the samples should be processed, stored and made available for utilization.
- **Chapter 12: Seed Gene Bank Conservation** – deals with how to store seeds of crops and wild plant species for medium and long-term conservation, because seed conservation in gene banks remains the most efficient method for conserving plant germplasm of the cultigen and its wild relatives for the majority of plant species.
- **Chapter 13: Whole Plant, Plantlet and DNA Conservation** – reviews the role of both field gene banks and living collections in botanical gardens and arboreta in *ex situ* conservation of plant diversity, and how *in vitro* conservation and cryopreservation techniques are increasingly used for the conservation of vegetatively propagated species and species with recalcitrant seeds.
- **Chapter 14: Plant Uses** – reviews past, present and future use of plant genetic resources, including their use by traditional and indigenous cultures, as well as their overexploitation and barriers preventing sustainable exploitation.
- **Chapter 15: Germplasm Evaluation** – outlines how use of conserved resources are often based on diversity and variability analysis relying on characterization or evaluation data, DNA markers or both, as well as the use of core subsets of the cultigen pool as representatives of the entire collection that ensures the differences among them are truly genetic and reflect overall diversity.
- **Chapter 16: Plant Breeding** – provides an introduction and overview of how plant diversity is used in crop improvement. It describes how collecting, conserving and using plant genetic diversity is linked with the basic principles of plant breeding and thereafter how that diversity is used for crossing and selecting segregating offspring with desired characters to generate new cultivars.
- **Chapter 17: Participatory Plant Breeding** – reviews alternative models of breeding that unite farmers, scientists, extension officers and other actors to generate new cultivars using participatory plant breeding and a participatory varietal selection approach, as well as discussing the advantages and disadvantages of the participatory approach compared to the conventional approach to plant breeding.
- **Chapter 18: Conservation Data Management** – reviews the kinds of data associated with plant genetic conservation, definition of the types of data, how data are recorded, the advantage of data standardization and how efficient conservation data management helps improve conservation outcomes. The importance of access to and ownership of the various kinds of data is emphasized as fundamental to good data management practice.

The book concludes with a list of Acronyms and Abbreviations, a Glossary of scientific terms, a list of References and an Index. Additional information including a General Bibliographies for each Chapter and Useful Websites lists are provided under the Resources tab on the webpage for the book (see www.cambridge.org/9780521806565).

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Danny would like to acknowledge the friendship and mentoring of many colleagues including the late Joe Lennard and Bhuwon Sthapit, and also Danny Bradley, Jimmie Rogers, Mary Taylor, Luigi Guarino, Charles Delp, Prem Mathur, Pablo Eyzaguirre Susan Bragdon, Jessica Fanzo, Braulio Dias, Lidio Coradin and Toby Hodgkin. He dedicates this book to Callum and Imogen, the future guardians and stewards, tasked with making the planet a better, more equitable and compassionate home for the diversity of life that finds itself here.

All three authors have spent a life-time working to improve the conservation and use of plant genetic diversity, primarily working in the centres of plant and crop diversity in developing countries. As such, we acknowledge the unerring support of our work provided by local communities, and therefore we dedicate this text to those communities who provided hospitality and help with our efforts, in the hope this text will be used to improve their lives and livelihoods.

Furthermore, it is obvious that the next generation of environmental campaigners are frustrated with the limited progress we have made in biodiversity conservation thus far, as are the three of us. In the words of Greta Thunberg at the recent United Nations General Assembly (UNGA) Climate Action Summit:

> You have stolen my dreams and my childhood with your empty words. And yet I'm one of the lucky ones. People are suffering. People are dying. Entire ecosystems are collapsing. We are in the beginning of a mass extinction, and all you can talk about is money and fairy tales of eternal economic growth. How dare you!

We applaud her passion and dedicate this text to the next generation of environmental campaigners in the hope they will use our text to succeed where we have failed to make the necessary difference for all humanity.