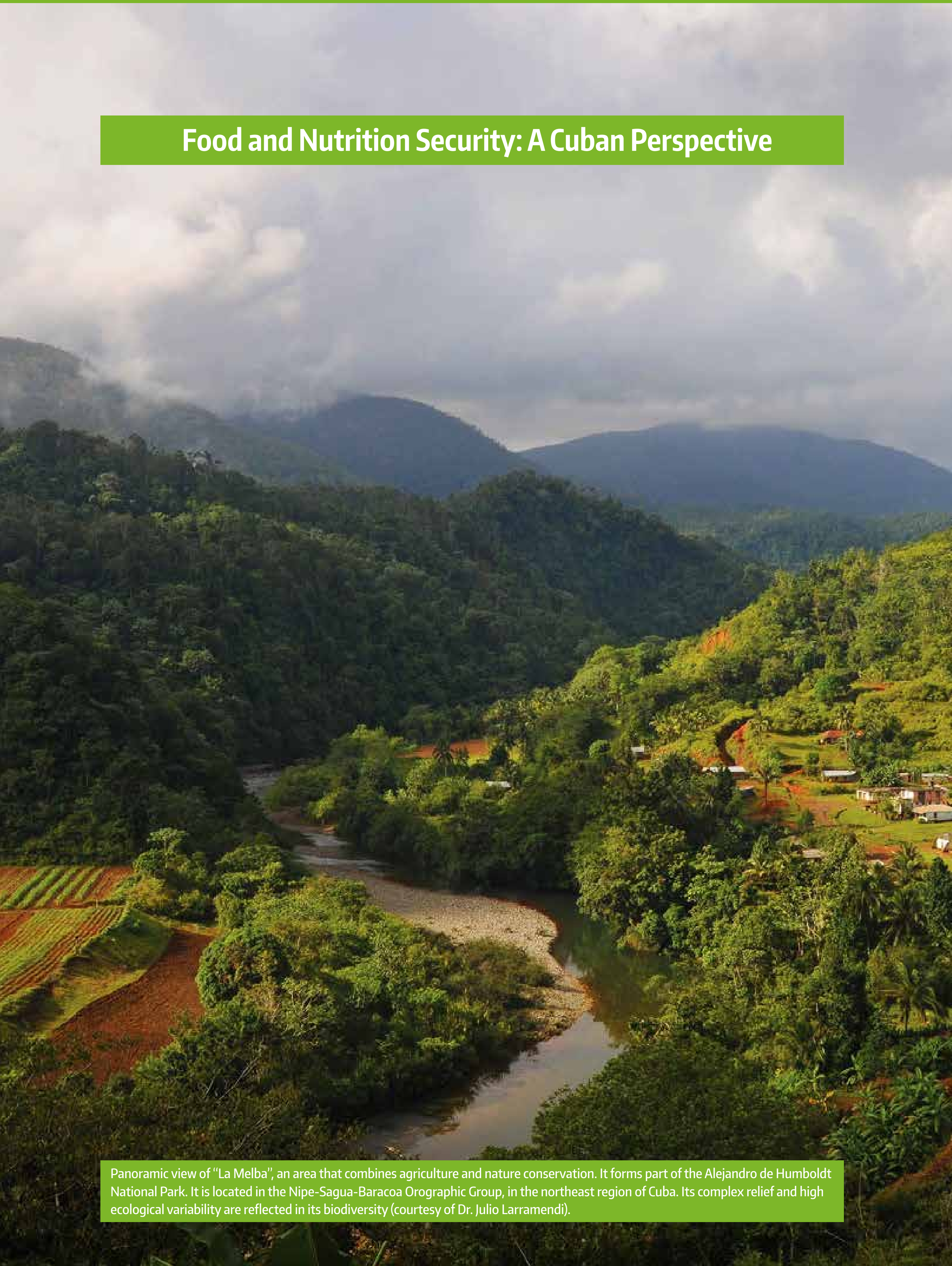
Food and Nutrition Security: A Cuban Perspective



Panoramic view of "La Melba", an area that combines agriculture and nature conservation. It forms part of the Alejandro de Humboldt National Park. It is located in the Nipe-Sagua-Baracoa Orographic Group, in the northeast region of Cuba. Its complex relief and high ecological variability are reflected in its biodiversity (courtesy of Dr. Julio Larramendi).

Cuba

[1] María Teresa Cornide Hernández
[2] Walfredo Torres de la Noval
[3] Ramón Pichs Madruga
[4] René Pablo Capote López
[5] Amelia Capote Rodríguez

Agricultural and livestock production in **Cuba has been sustained for 20 years by the use of ITC results to achieve sustainability.** However, food import dependence continues to have negative consequences for food and nutrition security, which may be exacerbated in the future by the expected competition for water and land use, and the forecast of effects associated with climate change.

Summary

This report presents an integrated perspective of a group of specialists from the agri-food, environmental, economic and scientific management sectors, invited by the Cuban Academy of Sciences to take part in this survey on the country's food and nutrition security in the middle of this century, and outline the country's challenges, strengths and experiences.

Science, Technology and Innovation (STI) are indispensable for developing a sustainable, efficient and resource-based agriculture in Cuba to sustain and increase food production for the entire population. To this end, a state policy was formulated for the *National Economic and Social Development Plan Until 2030*, specifying the key objectives, supported by a Science and Technology system comprising over 200 entities in various ministries. It addresses the status of natural resources, the challenges and projections for their conservation, as well as the potential impacts of climate change and the actions required to increase the country's resilience to them.

It highlights the need to optimize food-production value chains so that potential yields are achieved in production; the importance of designing research with a "multidisciplinary and systemic approach" to complete the cycle "from the laboratory to the field" and to develop models that will incorporate climate risk indicators into the traditional agronomic variables used for these purposes.

By way of an example, this chapter describes successful programs currently underway, based on the principle of Local Development, so that STI can contribute to a high level of food self-sufficiency in the light of changing climatic conditions and the high proportion of new farmers. The municipal government brings together all of the factors which, through direct participation, implement actions for the benefit of its population. These include achieving a safe, stable market for farmers, a broader range of products at affordable prices for the population and job creation. Land use is improved by encouraging the development of non-state forms of family or cooperative agriculture, which account for 69.7% of the total agricultural area.

This chapter also describes health aspects and policy projections for contributing to food and nutrition security from the point of view of technological innovation, human resource training and various economic, trade and social aspects.

I. National Characteristics

Geographic characteristics, population and society

Cuba is an archipelago with an area of 109,884.01 km², 106, 757.60 km² of which correspond to the island of Cuba, and its capital is Havana. It is located in the Greater Antilles near the Tropic of Cancer, at the entrance to the Gulf of Mexico.

The predominant climate type is warm tropical, with seasonal distribution of rainfall in two periods (November-April and May-October), maritime influence and a number of continental features. The country has other localized types of climate, such as those in the highest mountainous areas and the southern coastal strip of the provinces of Santiago de Cuba and Guantánamo, which has a dry tropical climate with low rainfall (ONEI, 2016a).

Its urbanization rate is 76.8%, and it has a total resident population of 11,239,661 inhabitants, of whom 19.2% are aged 60 or over and 49.8% are men. The overall fertility rate is 1.72 (children/women) and its population density is 102.3 inhab./km². Life expectancy at birth is 78.45 years (ONEI, 2016a).

Food and nutrition security, education, health and environmental protection have been prioritized in the design of the country's socioeconomic and environmental policies since the beginning of the revolutionary process in 1959, to ensure the well-being and quality of life of the whole population, and these comprise the strategic objectives of the Cuban socioeconomic development model, currently being overhauled.

Cuba's integral approach to mother and child health has reduced morbidity, mortality and malnutrition rates, as well as moderately and extremely low birth weight rates in children under 5 as well as stunted growth (<5%). It has also promoted gender equity and women's autonomy. As a result of its public health, education and environment (GNI), Cuba is among the countries with sufficient human development indices to enable it to achieve the Millennium Development Goals (UNDP, 2015).

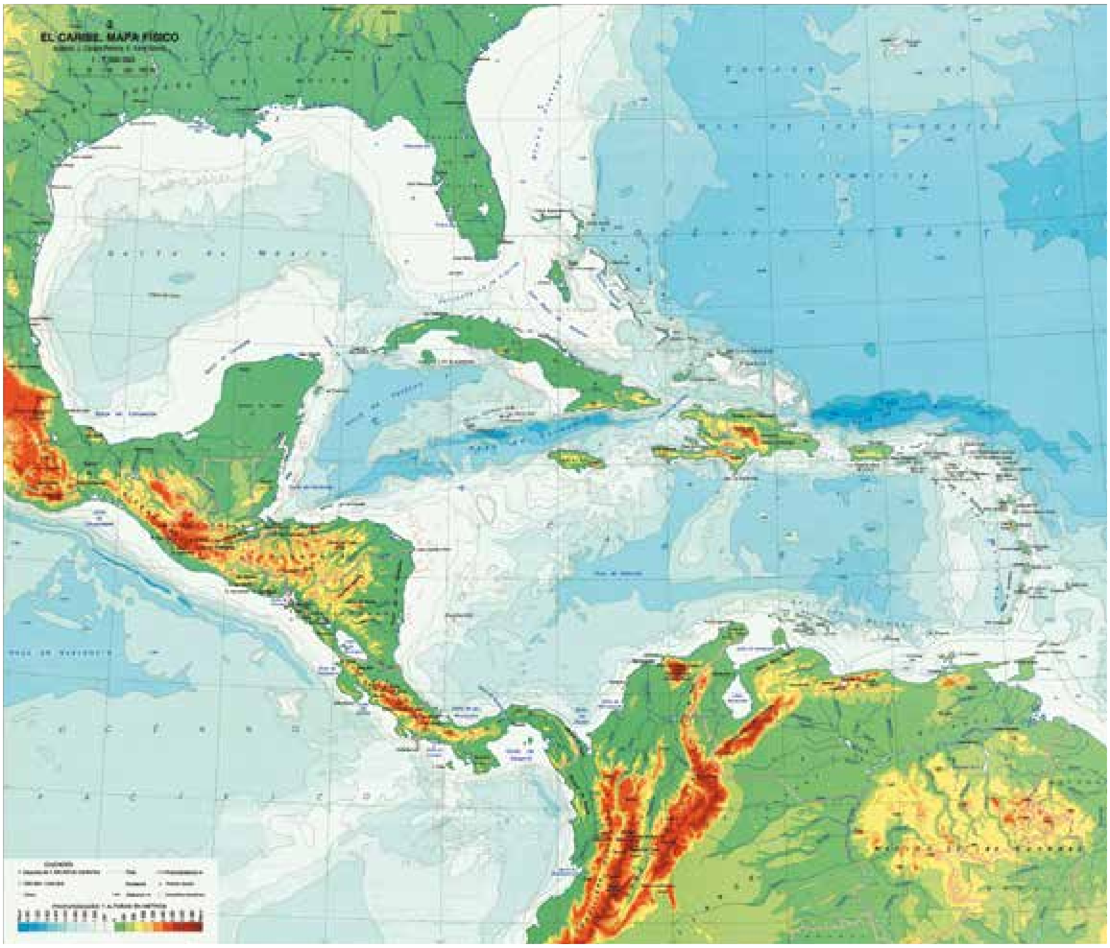
Agricultural systems. Food self-sufficiency and principal threats and challenges

Cuba's total land area (10,988.4 million ha) includes 6,2403 million ha for agricultural use, 2,7336 million of which are cultivated with a Utilization Index (UI) of 43.8%. A total of 3,371.6 million ha is occupied by forests while the remainder comprises aqueous surfaces and other land unsuitable for agriculture. Land ownership of the total agricultural area is distributed as follows: 30.3% belongs to the state sector (UI = 27.7%), 13.9% is owned by peasants (IA = 52.8%) and 21.4%, by usufructuaries (IA = 45.9%). There are three types of cooperativized ownership classified by land ownership and the ownership of communal means of production. Since 2009, 279,021 people have received land in usufruct in return for making them productive and profitable. Non-state forms of land ownership occupy 69.7% of the total agricultural area (UI = 50.8%) (ONEI, 2016c).

Despite the policies implemented since 1959 to achieve the population's food and nutrition security, significant challenges remain. Cuba is a developing state vulnerable to a number of factors such as global changes in the world

[1] **María Teresa Cornide Hernández,** Plant Genetics, Applied Molecular Genetics, Plant Breeding: BSc. in Biology, PhD. in Sciences (ScD.); Senior Researcher at the Sugarcane Research Institute; Full Professor at the Faculty of Biology, University of Havana (UH); Academician of Merit; Coordinator of the Agrarian Sciences and Fisheries Section, Cuban Academy of Sciences (ACC), mtch1646@gmail.com [2] **Walfredo Torres de la Noval,** Fisiología Vegetal en el tema de estreses abióticos: Degree in Chemistry, Doctor of Biological Sciences; Researcher at the National Institute of Agricultural Science (INCA); Academician of Merit, Agricultural Sciences and Fisheries Section, ACC, walfredo48@gmail.com [3] **Ramón Pichs Madruga,** World Economy, Environment and Development: BA. in Economics, PhD. in Economics; Senior Researcher; Full Professor, Faculty of Economics, UH; Director of the Center for Research on the World Economy (CIEM), Ministry of Science, Technology and Environment (CITMA); Head of the Section of Social and Humanistic Sciences, rpichs@ciem.cu [4] **René Pablo Capote López**, Ecología y Conservación de la Naturaleza: BSc. in Biology, PhD. in Biological Sciences; Senior Researcher at the Institute of Ecology and Systematics (IES); Environment Agency CITMA; Full Professor at the Faculty of Biology, UH; Academician of Merit, Section of Natural and Exact Sciences, rpcapote@ceniai.inf.cu [5] **Amelia Capote Rodríguez,** Agricultural Biotechnology. Management and Directorate of Science: Agronomist Engineer, PhD. in Biological Sciences; Principal Investigator of the Alejandro de Humboldt Institute of Basic Research on Tropical Agriculture (INIFAT), MINAG; Head of the National Program of Science and Technique of Human Food, dircientifica@inifat.co.cu

Map 1. Physical map of the Caribbean



economy. Examples include the dismemberment of the Socialist Bloc, which reduced the Gross Domestic Product (GDP) by 35% from 1989 to 1993 and the adverse impact of the US economic, financial and trade blockade, which persists to this day (MINREX,2016), severe constraints on underdeveloped countries in international markets, internal deficiencies and the effects of natural phenomena associated with the fact of Cuba's being an island and its geographical location.

One of the challenges is high dependence on food imports: Cuba imports 80% of the food it consumes and it is estimated that by 2017, this will amount to $1.7502 billion USD. Despite being a net food importer, the productive potential of Cuba's agricultural sector is expected to reduce import dependence by between 35% and 40% (Nova, 2016).

The socio-economic guidelines for the country's development are designed to meet the short-, medium- and long-term development needs of the agro-food sector (PCC, 2016). The goal of the *National Economic and Social Development Plan Until 2030* is to achieve agricultural production and marketing levels that will guarantee a high degree of food self-sufficiency.

To this end, the country has adopted a food security strategy based on a combination of increased agricultural productivity, greater policy predictability and trade liberalization through: (1) the reduction of the main food imports: potato, grains (rice, corn, beans), milk and meat; (2) an increase in the quantity and diversity of agricultural exports of traditional products (sugar, tobacco, coffee, cacao and fruit); (3) the search for new exportable items, and (4) the expansion of existing markets and buyer countries. In 2016, Cuban agriculture grew by 5.9%, well above the 2.5% in the previous year, although not sufficient to satisfy domestic demand or substitute food imports.

Development strategies have included the growth of new industries on the basis of science and technology, available natural resources and the country's economic possibilities. Mining, oil drilling and electricity generation have been intensified. The tourism industry has significantly expanded. The achievements of Cuba's medical-pharmaceutical industry, particularly biotechnological development, have been internationally acknowledged. The main export products and services are professional services, tourism, petroleum derivatives, nickel, biopharmaceuticals, sugar and tobacco products. New structural, functional and policy transformations and projections for the agricultural sector have recently been approved to boost agricultural activity through more decentralized management methods and the support of local production. The country has the political will, practical experience, acquired knowledge and the participation of Science, Technology and Innovation (STI) to achieve this goal.

II. Science, Technology and Higher Education Infrastructure in the Agricultural Sector

National agricultural research systems

In order to contribute to the strategic goal of achieving a high level of food self-sufficiency, the Cuban Ministry of Science, Technology and Environment (CITMA) has prioritized *Food Production from the Perspective of Science, Technology and Innovation*, together with the organization, improvement and implementation of new policies in the various ministries and business groups (linked to food production).

National agricultural research is undertaken by a network of research centers, scientific and technological services and development and innovation units attached to various ministries (such as CITMA, MINAG, the Ministry of Higher Education (MES) and the AZCUBA Business Group). These organizations focus on essential aspects within the National Programs and Projects System, directed by CITMA. Other programs include studies on Climate Change (CC), biodiversity, water resources, energy, meteorology, local development, computerization and socioeconomic problems.

By the end of 2016, 300 projects associated with these programs and 500 institutional and business projects were underway, together with innovation actions, derived from research-development and the application of knowledge, with practical, beneficial repercussions.

The Cuban Academy of Sciences

The Cuban Academy of Sciences (ACC), founded in 1861 as the Royal Academy of Medical, Physical and Natural Sciences of Havana, is the principal, independent scientific advisor to the government on science, attached to CITMA. It is an active member and founder of the main global and regional institutions bringing scientists together: The International Science Council (ICSU) since 1931; the InterAcademy Panel (IAP) Network since 1994; the Academic Network of the Americas (IANAS) since 2004, and the Caribbean Scientific Community (2000).

In addition to its advisory work, it promotes science and technology in society. It links this work to the mass media and organizations in the education sector through its electronic magazine *Anales ACC*, its historical records and liaising with Cuban scientific societies, including three of those with the largest membership in the agricultural sciences. It awards annual prizes in recognition of scientific results that contribute to knowledge and impact the economy, services and production.

The highest authority of the ACC is the Plenary, comprising 250 of the country's' scientists, grouped into five sections, one of which is Agrarian and Fishing Sciences, with 43 senior researchers and eight young research associates. The ACC is the main coordinator and independent organizer of the Cuban scientific community. It encourages debate and brings together the main trends in national development in STI matters.

Research Institutes and Universities

Research in the agricultural sector is undertaken at universities and within the network of 41 scientific organizations with over 11,000 employees, approximately 1,600 of whom are researchers and 600 hold a PhD. in science.

A system of scientific journals publishes the results of national research; 31 are related to agricultural research, certified by CITMA on the basis of their editorial quality and stored in various international databases (six in *Scopus* and two in the *Web of Science*). Efforts are being made to increase the international visibility of these results.

Development of specialized workforce and status of the country's educational systems

Last year, over 420,000 students graduated from various levels and types of education, 49.9% of these were women (ONEI, 2016b). Higher education in agricultural science courses and others where students graduate in similar fields is provided at 22 public universities in different modalities. The current aim is to strengthen distance education in agricultural degree programs to enable the greatest number of students to study from their workplaces or homes.

The country's education systems have established programs which, in the short and medium term, will focus on training skilled workers and mid-level technicians, under the aegis of the Ministry of Education (MINED). Since there is currently a shortage of this type of personnel in many of the productive units related to food production, these programs are designed to increase the trained labor force (non-university graduates) at the basic productive unit level.

Agricultural degree programs can be studied in face-to-face, semi-face-to-face or distance modalities. In order to graduate, students must conduct supervised research culminating in a thesis. Current enrollment in agricultural degree courses is over 5,000, 47% of whom are women.

Research that contributes to national food security involves professionals from natural sciences (biology, microbiology, biochemistry, chemistry, mathematics, food sciences and pharmaceutical sciences), economics (accounting, finance and economics), social sciences (sociology) and technical sciences (computer engineering).

Relative contributions of the public and private sectors

The greatest contribution to the STI activities of the scientific organizations related to the agro-food sector is provided by the Cuban state and government, regarding both financial aspects and material and human resources, and the political support and guidance to enable them to fulfill the missions and tasks with which they have been entrusted. Private sector contribution is still in its infancy with respect to the production of certain types of food. The current business system is contributing to the development of scientific centers in this area as part of the process of improving the system and reorganizing the science units.

III. Natural Resources and Ecosystems

Water resources and challenges for the next 50 years

In the mid-1960s, measures were taken to reduce the impact of the heavy rains and flooding caused by hurricanes and to ensure a sufficient supply of water in quantity and quality for human consumption, agriculture and industry and integrated water-resource management (Fontova et al., 2012).

According to one of the most optimistic forecasts, recent Climate Change models predict a reduction of water availability to 24 km^3 in 2100, equivalent to 38% of today's calculations (Planos, 2014). The current usable potential is 75% of surface water and

25% of groundwater, with a permanent risk of contamination by saline intrusion due to aquifer overexploitation.

For water storage and use, the country has a total reservoir capacity of 9,148.6 Mm^3 and 788.4 km of master channels connected to them. It has an additional 805 micro (>600 million m^3) and an extensive network of irrigation and drainage canals, dams and canals for flood protection and saltwater intrusion (ONEI, 2016). In order to ensure the population's water supply and irrigation in areas severely affected by periodic droughts, three transfers and a new dam with a capacity of 630 million m^3 (Mm^3) have been built (Fontova et al., 2014). In 2015, the water availability indicator was 1,231.7 m^3/inhabitant, with uneven distribution throughout the island (ONEI, 2016). In 2013, the National Water Policy, designed on the basis of contributions from all the users, was approved by the National Institute of Water Resources (INRH).

With regard to water availability, the greatest challenges the country will face over the next 50 years include:

- Implementing the geosystemic and ecosystemic approach to counteract the fragmentation of ecosystems caused by the construction of large, interprovincial transfers.
- Establish cooperation between the agricultural and forestry sectors to mitigate these impacts, and promote connectivity routes between the species and ecosystems affected by these public works.
- Use technology to increase water availability. Examples include sea water desalination, rain harvesting, recycled water use and more efficient irrigation systems.
- Design civil engineering works to mitigate the impact of rising sea levels, which requires technology transfer.

The main strengths lie in the development and stability of the aforementioned national water program and the human resources available to assess water from a multisectoral, interdisciplinary perspective.

Land resources and challenges for the next 50 years

The country's edaphic cover is extremely varied, due to its complex geological structure, divided into 14 categories based on the type of soil formation (Institute of Soils, 1999). The recent land evaluation study for soil degradation monitoring based on the agroproductive potential for 29 crops, using a 1:25,000 soil map, showed that 65% of these had a potential yield reduction to below 50% due to one or more limiting factors, such as erosion, low organic-matter content, compaction, poor drainage and salinity (ONEI, 2016c). Cuba's National Environmental Strategy cites land degradation as the main problem, compounded by the effects of climate change on over a million hectares that form part of fragile ecosystems, such as mountainous areas with a high risk of erosion and coastal areas or adjacent cumulative plains with a salinity risk.

State policies and institutional programs have been drawn up to ensure sustainable soil and water management, such as the National Program for the Management and Conservation of Soil in Agroecosystems (PNMCS), which has benefited 901,000 ha (ONEI, 2016). Six state-funded programs are underway to achieve soil conservation, improvement and sustainable management to mitigate its degradation. The gradual assimilation of 'Conservation Agriculture' methods is essential if its degradation is to be minimized in the coming years.

Renewable Energy Sources (RES)

Cuba is a small greenhouse gas emitter that has maintained its commitment to the Framework Convention on Climate Change to the reduce emissions in keeping with its national circumstances and available financial and technological resources. Since the energy sector is the main emitter, sustainable modernization and technological development have been proposed, together with capacity building in the various sectors.

Based on the potential use of available RES, plans are afoot to install 2,144 MegaWatts (MW) of power connected to the national electricity grid, which includes the construction of 19 bioelectrical plants attached to the sugar mills (755 MW) based on sugar cane and forest biomass, and 13 wind farms (633 MW), particularly in the eastern part of the country. Parks (with 700 Photovoltaic MW) will be built in areas with less than 5 MW of power to connect them to the national grid, together with 74 small hydroelectric plants in small waterfalls. These programs will make it possible to generate over 7,000 GigaWatts (GWh) a year from renewable energy sources, and prevent the release of 6 million tons of CO_2 into the atmosphere (ONEI, 2016).

Biodiversity, conflicts and challenges: problems associated with over-exploitation and the loss of genetic diversity

Cuba boasts the greatest biodiversity of flora and fauna in the Caribbean. It is one of the four islands with the largest number of plant species worldwide, as well as having the highest number of taxa/km². A total of 5,778 native taxa of plants with seeds (51.4% endemic), 11,954 invertebrate species and 655 vertebrate species have been registered in the country. Its faunal diversity includes genetic resources useful for biological control and the development of nature tourism (CITMA, 2014).

The country has laws supporting the policies established for the use and conservation of diversity (CITMA, 2014). It has a system of protected areas approved by the Council of Ministers, six of which are 'Biosphere Reserves' and nine of which have been recognized as the World's Natural Heritage. This system operates on 116,679.6 km² (49.4% of the total area of the national territory in addition to the marine platform) (ONEI, 2016a).

In the Cuban archipelago, biodiversity and terrestrial ecosystems generally comprise mountain ecosystems, with hills and plains, with a predominance of the latter. For conservation purposes, they are divided into inland and coastal wetlands and keys, with large areas of mangroves.

The main causes of biodiversity loss are: alterations, due to the fragmentation or loss of habitats/ecosystems/landscapes; overexploitation of resources; the introduction of invasive alien species, land and soil degradation, and soil, water and air pollution (CITMA, 2014).

Every year, variations in the national pollutant load are evaluated in the main hydrographic basins, mountainous massifs and main bays, to track their evolution from liquid waste of organic and biodegradable origin. Forest fires of varying size and frequency contribute to deforestation, soil degradation and loss of biological diversity.

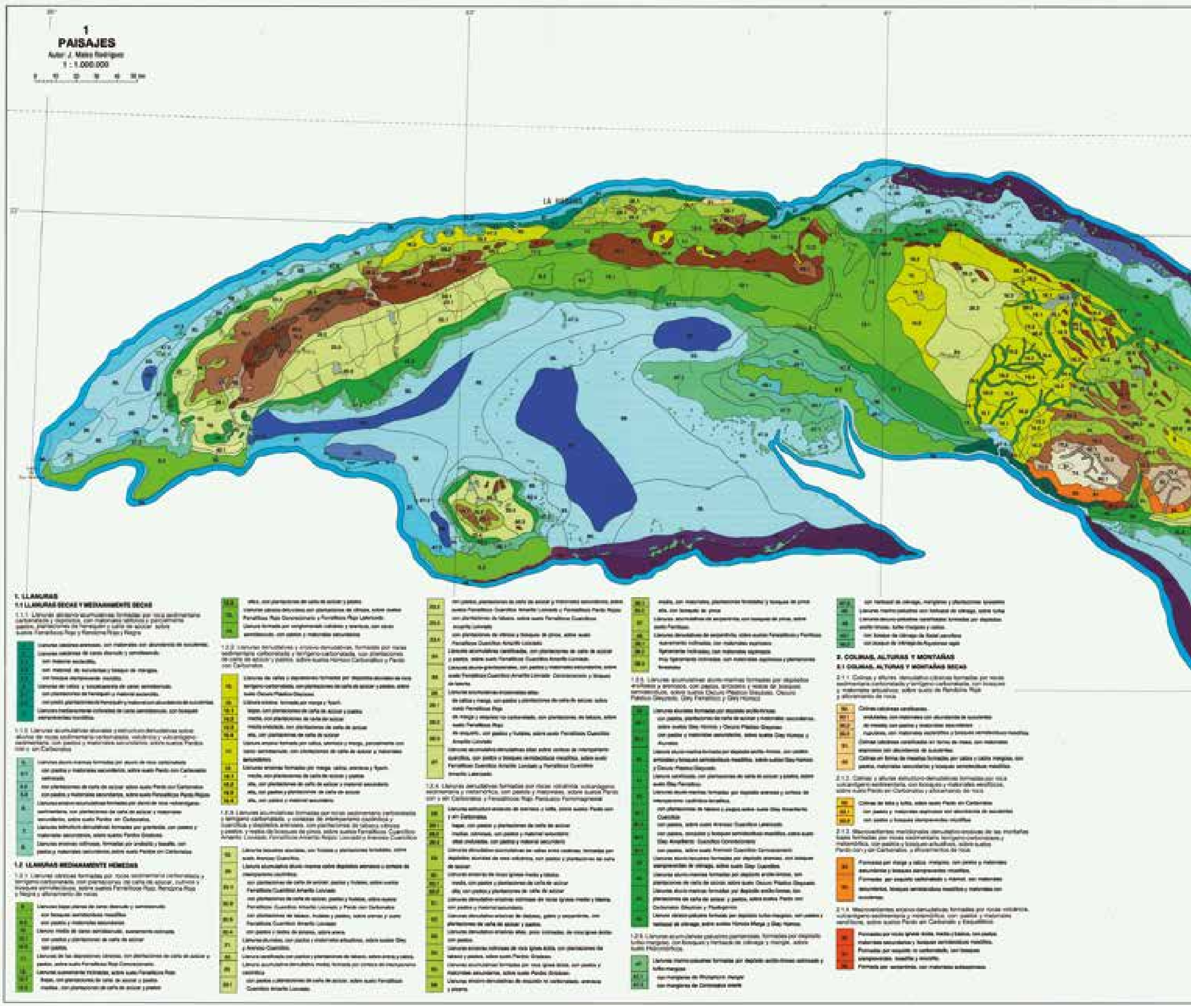
The challenge is to maintain ecosystem services for the country's human and socioeconomic well-being, such as the protection of agricultural lands and human settlements from CC and extreme weather events.

Forest resources

The genetic diversity of tree species has been affected since the 1990s by: resource constraints for monitoring and conservation; fossil-fuel restrictions that encouraged the use of firewood and charcoal, and increased levels of domestic sawn timber production. This was compounded by the decline in competent human resources and materials available for dealing with genetic resources, as well as the cumulative effects of the tropical hurricanes that have affected the country since 2000.

The combined action of these factors has had negative impacts on the genetic diversity of economically important tree species, both native (pine, cedar, mahogany and *Hibiscus*) and introduced. In order to reverse genetic erosion and stabilize forest production (timber and non-timber), the following priority objectives have been set for the forestry sector: maximal protection from the impacts of sea level rise in coastal areas and of the biodiversity of ecosystems in mountainous areas (>200 meters above sea level [masl]), by suspending the economic use of mangroves throughout the country and of several forestry products; expanding the area of artificial forests in flat and undulating areas, with specific productive objectives, increasing agroforestry systems and integrated management (intensive silviculture); intensifying enrichment and reforestation actions in natural forest areas classified as protected and conservation zones; achieving

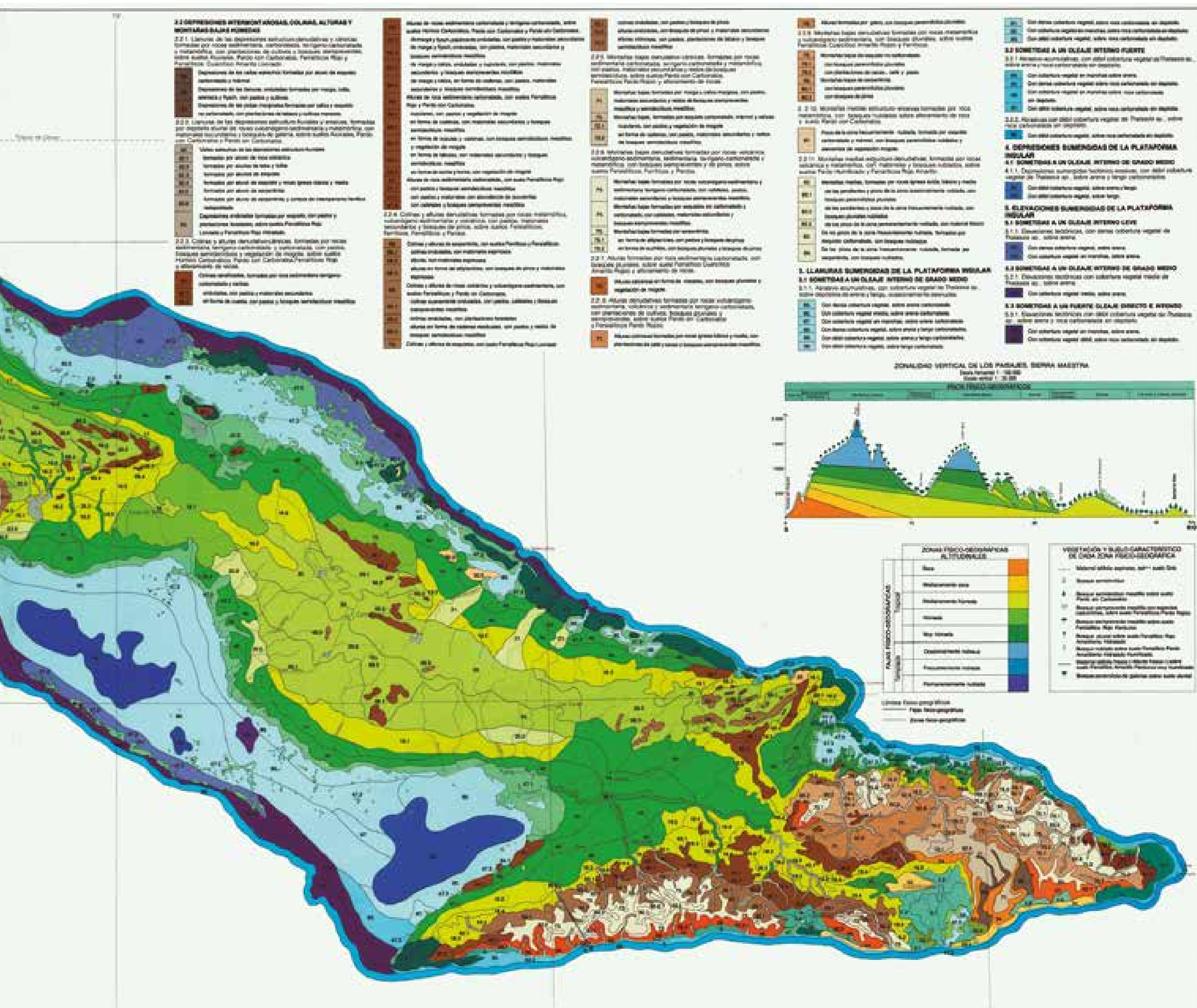
Map 2. Vegetation and soil characteristic of every physical-geographic zone of Cuba



33% of the forestry coverage planned for the country (currently ≥30%), and reactivating breeding programs with newly trained personnel.

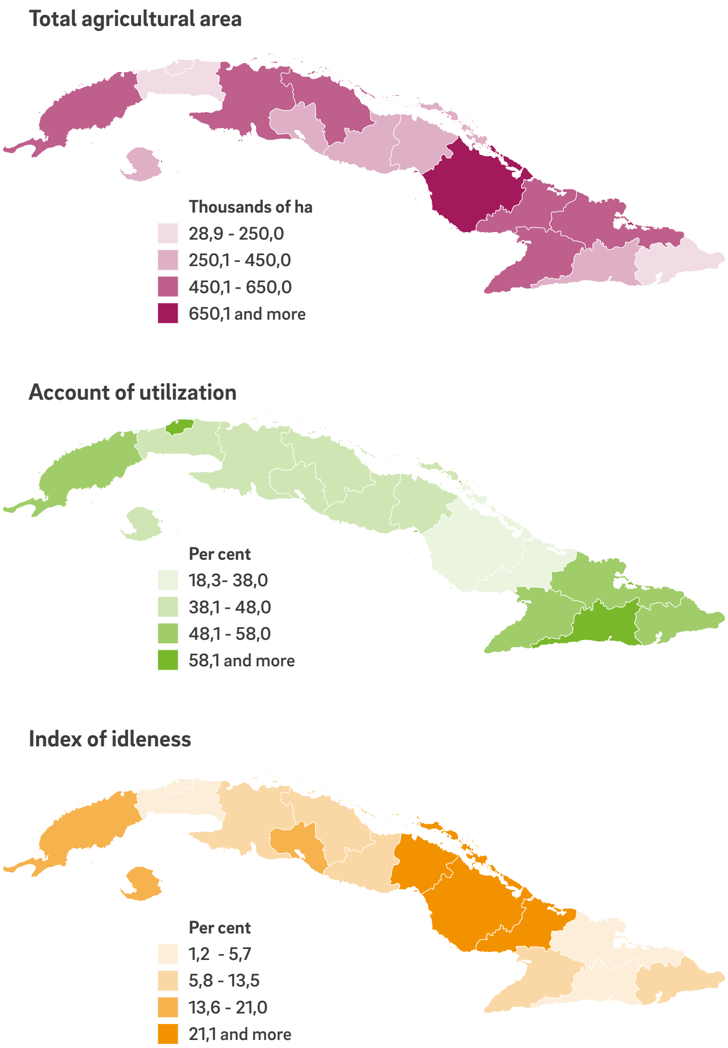
Marine resources

The insular shelf has the relief of a submerged plain, hence the value of coastal and marine ecosystems for the ecological stability of the biota. The greatest wealth of marine species is distributed among the nine ecozones of the Cuban shelf, mostly on the South coast, especially at the eastern and western extremes (CITMA, 2014). The close link between the land and the ocean, as well as the robust state of health of Cuba's marine and coastal ecosystems, supports some of the most important fishing activity in the Caribbean, such as thorny lobster fishing, accounting for 75% of the revenue in that sector.



The high economic value of most of the fishing resources in the Exclusive Economic Zone (EEZ) and the fishing capacity created in the country since 1959 has led to the overexploitation of some of these resources. The statistics (1935-2014) for 25 species show that a steady increase in catches was followed by a steady decline in total catches and most individual species, with several cases of collapse. An analysis of their causes indicates that overexploitation is not the only factor responsible and that various human actions have affected certain habitats, such as fishing, the damming of major rivers, industrial waste pollution and the drastic reduction in the use of synthetic fertilizers since the late 1980s (Baisre and Arboleya, 2007). On the other hand, in the past two decades, the intensity of the cyclonic organisms have been the CC-related events that have most affected marine and coastal biodiversity.

Map 3. Land use in Cuba



Source: National Office of Statistics and Information.

Under these circumstances, the strategy for projecting these resources over the next few years should begin with a program to restore damaged coastal zone habitats, reduce fishing efforts and restore strict control of compliance with the fishing regulations established to prevent illegal fishing and catching specimens below the legal minimal size.

Potential impacts of climate change. Building resilience to extreme events

The country has national and territorial strategies (provinces, municipalities, basins) for managing the reduction of CC impacts (adaptation-mitigation), which it periodically renews, based on the studies on the danger, vulnerability and risk of occurrence of disasters directed and coordinated by the Environment Agency (AMA-CITMA) with the National Civil Defense General Staff (EMNDC) and the participation of various institutions. Cuba's efforts in this field have been recognized: in 2001, it shared with Italy the world venue for "World Environment Day" and in 2006, in the "Living Planet 2006" Report (WWF, *World Wide Fund for Nature*) Report, it was declared the only country to have advanced sustainable development, with a sustainable ecological footprint (ONEI, 2016).

Studies in Cuba indicate that agriculture will develop in an adverse climate environment (Planos, 2014). Net primary productivity and the potential density of biomass will decline; the duration (in days) of phenological phases will be progressively shortened, while the total duration of the life cycles of major crops, including those of animal feed and their potential yields, will decrease. Phenomena associated with CC already influence the development and exacerbation of diseases and pests by acting on host-pathogen-vector-biological controller interactions, and there will be changes in the distribution, seasonality and severity of vector-borne diseases and pests.

The direct impact of rising temperatures and reduced rainfall will affect the productivity of major crops such as potato, soybean, beans, rice, cassava, maize and sugarcane, and animal husbandry. Research will be required on their adaptive response mechanisms to obtain improved materials with higher nutritional value, as well as on the type of management that encourages them. There is also a need to find new genetic sources, preferably native ones or through the introduction of new crops. These CC phenomena will hasten the degradation of agricultural soils, while the salinization of coastal aquifers will affect fishing and aquaculture activities. This, together with the reduction of agricultural areas, will lead to impacts on food production and changes in the population's food culture.

The synergy between the increase in the surface temperature of the oceans and their acidification, the intensity of coastal meteorological events - especially cyclonic organisms - and the gradual rise in the sea level increases the risk of the loss of biodiversity, together with its goods and services, which is already extremely threatened in the coastal areas transformed by man.

Research on the marine and coastal ecosystems comprising the natural barrier of the Cuban archipelago to strong winds, tidal waves and intense waves, and rigorous compliance with conservation measures will contribute to reducing these foreseeable impacts and should be prioritized.

IV. Technology and Innovation to Achieve Food and Nutrition Security

The current infrastructure of agricultural research, with few exceptions, emerged in the 1960s as a result of the political will to develop science and technology because of their intrinsic connection with the country's social progress. In the agrarian sciences, this coincided with the start of the "Green Revolution" and its concepts. Over the next two decades, the human capital and resources of these centers grew considerably. The first results were obtained, and their priorities were defined and refined through planning (Cornide et al., 2006). The period from 1980 to 2010 was particularly important for the agricultural sector:

- The development of new biotechnologies in the medical-pharmaceutical sector was promoted, which was extended to the agricultural field, where the applications of "first-generation biotechnologies" were gradually incorporated into research programs that constituted a methodological advance in research. The most promising ones were incorporated into development programs and services, and included in curricula. The year 1986 saw the creation of a Center for the development of Genetic Engineering and Biotechnology (CIGB), with a division devoted to agricultural objectives.
- As a result of the collapse of the Socialist Bloc, food security became a strategic objective for the population's survival. Within the framework of the socioeconomic guidelines approved for the country, specific research objectives were formulated with a "systemic, multidisciplinary approach" to close the cycle "from laboratory to field". To boost local use of new technologies, two centers were set up in the provinces of Villa Clara and Ciego de Ávila, together with several facilities for the multiplication of high-quality propagules ('biofactories'), the production of bioproducts and Centers for Entomophage and Entomopathogen Reproduction (CREE) employed in integrated pest control (Borroto Leal et al., 2011).

The change in unsustainable production and consumption patterns in Cuban agriculture, begun for economic reasons and encouraged by new biotechnologies for raising yields, was a success that was confirmed by its coincidence with the Agenda 21 of the *United Nations Conference on Environment and Development* (Rio de Janeiro, Brazil, 1992) and the agreements of the *Summit on Sustainable Development* (Johannesburg, South Africa, 2002). Among other measures, the priority of this strategy was supported by the creation, in 1994, of CITMA as the Central State Administration Authority responsible for proposing STI and Environment policies and controlling their implementation on the basis of management coordination and control by the agencies responsible for their implementation.

Out of the necessary multidisciplinary and systemic conception of work and in order to optimize available resources, organizations were created to bring together several institutions from different sectors, fostering the multisectoral and transdisciplinary discussion of common issues and cooperation links. ISO (*International Standards Organization*) standards and various systems to accredit the facilities were assimilated. The development of a culture of patenting, registration and protection of plant varieties was reinforced, with emphasis being placed on the need for new economic indicators and methods to forecast and impact the measurements applied to the planning and execution of research projects, scientific and technical services and production.

Food production for human and animal consumption

Agricultural research yielded the following benefits for agriculture: new varieties, animal breeds and technologies for their management; recommendations for differentiated fertilization with the available mineral fertilizers and their national alternatives including registered biopreparations; livestock feed; methods of diagnosis and epidemiological surveillance, and vaccines (Borroto Leal et al., 2011). These have also been used in technical collaboration with other countries, some of which have received international awards.

At present, lines of work are being implemented to continue practices that have proved successful, and incorporate new technologies and the sustainability approach. Priorities for the period-in-development (2013-ca. 2025) (CITMA, 2015) include:

Genetic improvement and plants and livestock management

- Introduction of new methods and technologies to improve the evaluation and conservation of genetic resources.
- Traditional and biotechnological improvement of cultivars (sugarcane, rice, potatoes, vegetables, tropical meats and grains, and others for animal feed), and elite livestock breeds and species (dairy and beef cattle, pork, buffalo, rabbit, poultry, sheep and goats), to boost their productive potential and nutritional quality, as well as tolerance to abiotic stresses derived from CC, improved water use and resistance to emerging or high-risk diseases, together with the technological package for their exploitation.
- Development of new biopreparations and means of biological control and technological transferences to adapt them to the new production scenarios.
- Design of databases from agricultural research, historical series of programs for development and the productive behavior of results, using advanced computer methods and interactive computer tools to aid decision making.
- Studies of the horizontal and vertical models of extensionism and their coexistence and mutual empowerment, to achieve adaptation to local systems and the participation of decision makers and actors in each territory.

New foods for human and livestock consumption

- Diversification of food fortified for human consumption; formulation of new foods; manufacturing technologies with a predominance of local raw materials; products to preserve quality; and new methods for the analysis of the chemical, microbiological and toxicological safety of these foods.
- Formulation of grasses and fodder based on gramineae and legumes to increase their productivity under unfavorable conditions (low rainfall period, salinity, degraded soils, biotic stresses) and the nutritional balance of livestock; technologies for their management and rehabilitation; study of the nutrient recycling in the soil-plant-animal system and the development of silvopastoral systems, and technologies to increase hay and silage production.
- Microbiological studies for the management of legumes and to obtain activators of ruminal fermentation and food supplements and additives based on by-products or agroindustrial residues available in the country; and the use of physical, chemical and biological options to increase their nutritional value, conservation and form of presentation.

Agricultural health

Agricultural health research supports the Agricultural Health System and, because of its strategic importance, Cuban institutions work in collaboration with networks both inside and outside the country. Researchers participate in research projects on disaster prevention and mitigation and in training projects with various international organizations. The highest priority topics are:

- Identification, characterization and diagnosis of pests and diseases; molecular characterization of phytopathogen populations and etiological agents of emerging and re-emerging diseases to determine their origin and predict their evolution.

- Development of integrated pest management systems; design of bioproducts that support other methods of control.
- Studies of host-pathogen interactions and participation in genetic improvement programs to obtain pest- and disease-resistant materials and in livestock programs through the characterization of various populations of veterinary interest affecting species prioritized for human consumption (cattle, pigs, buffaloes and goats).
- Development of vaccines of veterinary interest; design and optimization of systems to produce diagnostic tools and vaccines.
- Toxicosis studies for diagnosis, control and treatment.
- Study of the danger, vulnerability and risk of the occurrence of health disasters; assessment of the effectiveness of management programs, and issuance of early warnings for decision making.

New biotechnologies: Genetic Engineering and Functional Genomics

In Cuba, obtaining Genetically Modified Organisms (GMO) using Genetic Engineering (GI), molecular biology and *in vitro* culture techniques, has made it possible to obtain biological models to determine the structure and function of hereditary material. These models are used for gene isolation, marker-assisted selection in traditional genetic improvement programs, the development of methods for the molecular diagnosis of pathogens and vaccines for veterinary use on the basis of immunogens, and the study of gene regulation in plants and animals (Borroto Leal et al., 2011). The goals of biotechnological work include:

- The introduction of new biotechnologies to produce high-quality seed and bioproducts, *in vitro* and in vivo production technologies of substances of pharmaceutical and industrial interest, and obtaining genetically improved materials and research tools that generate new knowledge and genes.

New generation biotech products. (A): 'GAVAC' is an immunogen against ticks (*Boophilos microplus*) obtained recombinantly, after a peptide from the PO ribosomal has been identified as a vaccine antigen. 'Hebernem', a nematicide of biological origin. Both products are marketed in Cuba and several Latin-American countries (courtesy of Bio-CubaPharma).

- Obtaining transgenic soybean lines and transgenic dry maize hybrids for animal feed, significant areas for these imports.
- Use of new genome sequencing technologies and their products (transcriptome, proteome and metabolome) to predict the genetic value of improved individuals and populations, contribute to animal feeding and obtain new genetic modification tools such as specific genome editing without gene transfer between species.
- Production of new-generation veterinary vaccines for bird and livestock species.
- Obtain veterinary vaccines and growth and immune system stimulators from organisms used in aquaculture to eliminate or reduce antibiotics and chemicals in animal protein production.

The use of transgenic plants is legally regulated in Cuba under the principles of the Cartagena Protocol to which it is a signatory. In the 1980s, legislation was established to regulate research and the commercial use of GMO and, in particular, transgenic plants in terms of food safety, by the National Institute of Hygiene, Epidemiology and Microbiology (INHEM,MINSAP); (CNSB,CITMA), and biodiversity (novelty) and its technological usefulness in order to be registered as a seed by the National Plant Health Center (CNSV,MINAG) in each of the transgenic events that can be produced and marketed in Cuba, establishing a mechanism of evaluation and approval on a case-by-case basis.

Medium- and long-term projections

In today's world, species of economic interest and technologies and inputs for their management are protected by various types of intellectual property and are often marketed together (technology package). The growing privatization of this activity at the global level coupled with the trend toward the industrialization of improvement programs herald the risk of the food sovereignty that developing countries will experience by the middle of this century unless they have traditional and biotechnological improvement programs for plants and animals that should guarantee food sufficiency with majority control by the public sector.

The following measures are proposed for STI to contribute to the achievement of a high level of food self-sufficiency in 2050:

Technology development and transfer

- Optimization of the value chains of the main crops, meat, milk and egg.
- Optimization of biotechnological processes based on *in vitro* cultures, controlled conditions and field transfer in anticipation of temperature changes; implement a level of automation and low-cost quality-control methods; develop management schemes to improve the use of facilities under controlled conditions, and enhance the efficiency and stability of the processes involved.
- Genetic and economic optimization of genetic improvement programs for priority species, with a strong state-sector component.
- Development of modeling and computerized simulation for data analysis, studies of environmental impacts (abiotic, biotic and management) and comparison of recommended alternatives and their prognosis.
- Adaptation of technologies based on "Conservation Agriculture" for soils and crops, regarding the farm as a basic management unit, and the river basin as a geographic physical space to be protected.
- Transfer of irrigation technologies adapted to the new agrotechnical packages; design or innovate equipment, machinery and implements in food production systems in keeping with current energy and environmental policies.
- Build human capacities for bioinformatics support and improve training in the management of economic and market indicators in personnel associated with agricultural research and services.
- Implementation of means for data mining, storage and processing (meta-analysis, robotics) ("Big Data" challenge).

- Develop computer infrastructure and remote access communication to scientific-technical services to provide information for decision makers, technical staff and farmers regarding risks, biosecurity, production records, the market, and computer tools to use them in decision making in real time.

Proposed future objectives for research and development programs

- Expansion of genetic basis: Obtain and introduce new genotypes and crops tolerant to unfavorable environments; livestock breeds resistant to high temperatures and water deficit; and microorganisms for new biopreparations.
- Prioritize studies on the physiological bases of the adaptation of main crops to biotic and abiotic impacts with a local, sustainable approach.
- Seek efficient physiological indicators for selection; introduction of high-non-invasive, high-precision evaluation methods based on physical sensors and image processing.
- Gradual implementation of Genomic Selection for dairy cattle and prioritized crops.
- Use of new technologies to obtain improved genotypes and recombinant products with proven safety. Provide the scientific bases for improving the provisions of regulatory bodies.
- Functional genomics research for a better understanding of the genetic basis of productivity and adaptation to stress (oxidative, antioxidant and tolerance to abiotic factors) at the molecular level. Develop new products to be used within the framework of the "Precision Agriculture" approach.
- Establish an STI Program for the sustainable development of fisheries and aquaculture as food sources for human and animal consumption, restore damaged coastal-zone habitats and recommend measures for their exploitation and control, based on the biological and ecological aspects of species and ecosystems and the sources and scope of the impacts that affect them.
- Extend and improve feasibility studies, forecasts and estimates of the impact of STI work.

Constraints

In order to contribute to the solution of the main constraints, physical and human infrastructure of the following should be strengthened:

- Research centers and service laboratories essential to sustaining and developing the agro-food sector. Encourage personnel, especially young people who will be the generational replacement.
- The system of diagnosis and monitoring of the main agricultural pathologies and their associated productions and the reproduction of biopesticides in CREE.

V. Increasing the Efficiency of Food Production Systems

Despite CC-related effects, the production potential of crops and livestock species is expected to continue to increase in the coming decades as a result of STI contributions to improvement, management and sanitation. Their practical contribution is expected to be limited by competition for water and land between the two food sources and between the sector involved in agricultural production and other human activities. At the same time, the role of socioeconomic factors such as local priorities, human health and sociocultural values will determine the balance of these resources in terms of food security (FAO, 2006). This points to the importance of having an efficient, flexible management throughout the value chain of the activity.

In Cuba, local development strategies are conceived of as participatory processes in which participants are summoned by the municipal government, which organizes and implements actions that mobilize local factors that will directly benefit its population in order to achieve a safe, stable market for producers, a broader supply of products at affordable prices for the population and job creation, by encouraging family or cooperative farming.

The National Program for Local Development is linked to three national priorities associated with food security: food production for human and animal consumption, combating CC and water. It seeks to achieve municipal self-sufficiency by leveraging the participation of the non-state sector and facilitating mechanisms for its direct insertion into the management of local development. The participatory and local nature of this scenario will help to reduce territorial imbalances; technological change induced by innovation and technological diffusion for the benefit of business development; change food consumption habits, and establish a quality-price balance in order to improve the population's quality of life.

Agricultural companies work until the cycle ends with the commercialization of fresh products, which are processed by various industries. Waste is processed to obtain organic matter, biogas and other forms of energy. Grains and seeds are preserved and dried. Materials are transported by highway and railroad.

Several successful examples of this strategy are already underway: (1) The program for the **Optimization of the value chains of milk**, meats and various crops; (2) the **Urban, Sub-urban and Family Agriculture Program**; (3) the **Local Agricultural Innovation Project** (PIAL), and (4) **Territorial Environmental Strategies**. These programs focus on local action to preserve the environmental achievements attained and undertake new actions for sustainable development. They have contributed to building local human capacities, reforestation, the recovery of abandoned agricultural land and promoting local food security.

VI. Health Considerations

At the end of last year, health indicators showed a birth rate of 11.1/1,000 inhabitants and 99.9% of live births in health institutions. The total mortality rate of the population is 8.9/1,000 inhabitants, while the number of children <1 year is 4.3/1,000 live births. The two main causes of death at all ages are heart disease (218.3/1,000 inhabitants) and malignant tumors (215/100,000 inhabitants), followed by cerebrovascular diseases (82.6/100,000 inhabitants) (MINSAP, 2015).

Over the past 50 years, Cuba has established one of the world's most comprehensive social protection programs, which has made it possible to draw up action plans to eradicate or minimize the most important food and nutritional problems identified by the Food and Nutrition Surveillance System and national health and food consumption surveys: (1) high prevalence of iron deficiency anemia in pregnant women and children under five; (2) upward trend in overweight and obesity; (3) low prevalence of exclusive breastfeeding; (4) problems of food availability during disasters (hurricanes and drought); (5) poor food culture, and (6) dietary and nutritional problems associated with aging.

The Surveillance System detects and controls outbreaks of food poisoning and investigates the evaluation of microbiological hazards in food of animal origin with recommendations to improve production processes; diagnosis of pathogens in food for animal and human consumption; hazards, vulnerabilities and risks for pests and diseases with an impact on the health, social, environmental and economic orders, and toxicological and ecotoxicological methodologies for preclinical testing of new products.

VII. Policies to Contribute to Food and Nutrition Security

The projections of policies related to the goal of achieving agricultural production and marketing levels to increase the food and nutritional security of the population and the quality of life are found in the *National Economic and Social Development Plan Until 2030* (PCC, 2016).

Projection of policies in this area

One of these challenges is the high dependence on food imports, meaning that their purchase represents an important part of the expenditure of most Cuban families (Anaya and García, 2016).

Moreover, prices not regulated by the State are high for foods such as fruits, vegetables, beans and sources of animal protein, which encourages the consumption of products that lead to obesity and other associated health problems. Treatment of this problem is a high priority and requires a systemic approach in the midst of ongoing socioeconomic transformations aimed at: 1) increasing the production, productivity, competitiveness, marketing and environmental and financial sustainability of the agri-food production chains of prioritized non-sugarcane crops, and the sugar agroindustry and its derivatives; 2) developing a sustainable agriculture, based on the integrated management of STI and a new business management model to guarantee the productive use of the results, as well as the optimization of available capacities and the various productive scales that would increase this activity and create jobs among the local population; 3) prioritizing the conservation, protection and improvement of natural resources; 4) restoring the production of quality cultivars and species; 5) promoting the use of national bioproducts; 6) developing a comprehensive program for the maintenance, protection, conservation and development of watersheds, dams, hydro-regulatory strips, mountains and coasts; (7) increasing the efficiency of fisheries by complying with the quality of catches and preserving the marine and coastal environment, and 8) developing aquaculture with modern farming techniques.

Issues related to international trade and market challenges

Due to a myriad of factors, the country has very few comparative advantages in food products. Except for sugar exports, in most other products, the volume is small or very small and concentrated in very few countries and markets.

At the international level, policies are required to expand and consolidate price-protection mechanisms for the agricultural and food products Cuba sells, such as sugar and coffee. In the current and foreseeable context, in which the price of commodities (including food) has dropped, exports and income generation must be boosted, and the high dependence on financing that is now covered by revenue from other sectors should be reduced. It is essential to use quality systems with established standards and market demands to ensure food safety and healthy nutrition, and to systematize the identification of new production scenarios, taking into account customs, food habits and other conditions, such as agroecological foods.

Internally, policies must tailor agri-food production to demand and transform marketing, restructure the current system of marketing inputs and equipment for agriculture, in line with the new scenario of the agri-food activity and financial mechanisms implemented.

On the distortions caused by subsidies and other agricultural policy instruments

Cuba must weigh up the challenges and opportunities arising from the international commercial context in order to make responsible, careful choices. It is important to capitalize on the benefits of the principle of Special and Differential Treatment (SDT), whereby developing countries obtain privileges and are able to undertake reforms according to their capacity and development needs.

As imports of subsidized food increase, support should be provided to make farmers aware of new policies and forms of trade, to avoid their being affected, and to encourage the production that has been displaced by subsidized trade.

The product subsidy policy should be replaced by subsidies targeting people with specific needs.

Technological innovation policies and human resource training

Technical change driven by innovation and technological dissemination is seen as the most important driving force in food and nutrition security and in reducing poverty in developing countries. The country should implement policies and programs that foster constructive interactions between researchers and companies (state and non-state forms of production). A broad, sustained process of technological dissemination is required throughout society.

There should be an awareness that all the sectoral and global policies implemented, involving either health, education, employment, agriculture or taxes, have a positive impact on national scientific and technological performance.

Beyond a narrow vision of economic development, Cuba must employ STI personnel and results to address social problems.

In addition to focusing on high-level skills, professional technical careers must be strengthened in areas such as design, logistics and management, which will require changes in funding priorities within higher education. Raising the level of business innovation will require greater investment in human capital and the incorporation of qualified personnel into business activities together with the high knowledge component required by innovative solutions. Policies should encourage mobility between companies and public research organizations, facilitate student practices in industry and promote more investment in human resources by companies.

Policy design for the Cuban agri-food sector, which is highly sensitive to the effects of applied fiscal and monetary policies, should consider the impact of macroeconomic policies. For example, in monetary terms, a more objective exchange rate could create incentives to substitute imports and promote exports, which would have a positive influence on the sector's profitability.

VIII. Conclusions

Cuba is a developing state which, because of its insularity and geographical location, is vulnerable to the impact of climate change and certain natural disasters, as well as to global changes in the world economy. This chapter outlines Cuba's strengths and challenges in terms of food and nutrition security for the middle of this century (Epigraph I). It describes the Science, Technology and Innovation (STI) infrastructure the country has for its socioeconomic development and its measures-in-place for its management (Epigraph II). It analyzes the current status of natural resources, the main causes that threaten their conservation, the foreseeable trends of their evolution and the main institutional and legal measures-in-place to curb their deterioration (Section III). It also explores the role of STI in the present, the near future (2017-2030) and in the longer term, until the middle of this century (2030-2050) (sections IV-VI).

Agricultural production has been maintained for two decades with the application of STI results such as seeds and breeds, inputs and agricultural management systems and health and veterinary control methods. The acute economic crisis of the 1990s triggered a shift toward sustainability, driven by the new biotechnologies used in the agricultural sector. Nonetheless, food import dependence persists, with negative consequences for food and nutrition security, which could be exacerbated in the future due to the expected competition over water and land use, and the forecast of the effects due to climate change. New STI goals, currently underway, have been set to raise potential yields and other programs such as local development in order to optimize the value chains of the main agricultural products and lay the foundations for a new business-management model, which will strengthen the capacities available in the country, recognize the various production scales and contribute to promoting innovation and technological dissemination.

There is a need to prioritize knowledge of the physiological mechanisms of adaptation to the changing effects in space and time associated with climate change, and to hasten the obtainment of new genetic materials and bioproducts through the application of new technologies.

This chapter outlines the main policies supporting the agri-food sector, the challenges of the international market to expanding trade and recommended policies for promoting technological innovation, providing human resources with better business training and strengthening the current STI infrastructure.

Since today's solutions may not suffice to meet the challenges of tomorrow, it is suggested that the impact of all the sectoral and global policies implemented in the agricultural sector be evaluated in a timely manner, especially regarding their scientific and technological development.

The match between current and future STI objectives in terms of environmental conservation and food security, and those of the latter and the policies developed to support them, is neither a coincidence nor forced. On the contrary, it is the result of the joint, integrated design of three basic sectors: the environment, agri-food and the economy, based on the experience acquired in the sustainable development of Cuban society during the 2011-2016 period.

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