

Marine genome resource sustainability in Central America

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Abstract In an effort to raise awareness of the major environmental challenges facing the region's coastal and marine ecosystems, and to highlight the potential research and socioeconomic benefits of this program, the authors provide summaries of key lectures and conclusions presented in the international conference on Central American Marine Biodiversity and Genomics, in April of 2012, dedicated to "Genomic Archiving and Coastal Marine Biodiversity Exploration, Conservation and Sustainable Development", and describe the main components of the initiative for the benefit of other actors, stakeholders and donors in the field of marine biodiversity.

Keywords: Central American Marine Genomic Initiative, Marine biodiversity

INTRODUCTION

The lands and oceans of the Central American region are home to an extraordinary amount of biodiversity. All together, the seven countries of the region occupy 201,594 square miles of land. The Mesoamerican Isthmus, which includes the southernmost states of Mexico with the countries of Central America, has more than 20 distinct eco-regions, and is home to an estimated 7% to 10% of the world's known biodiversity (Miller et al. 2001), including 17,000 plant species, 440 species of mammals, 690 species of reptiles and 550 species of amphibians (McGinley and Hogan, 2008). Considered one of Earth's "mega-diversity hotspots", Mesoamerica's abundant biodiversity is found not only on land but also in the surrounding oceans. The Mesoamerican Barrier Reef, for instance, extending 994 miles along the Atlantic from Mexico to Honduras, is the largest coral reef system in the Western Hemisphere and second largest in the world.

Much of Central America's marine environments are the least protected and least explored in Mesoamerica. The prohibitive cost of equipment and training for exploration, insufficient capacity building for successful scientific research, the lack of national policies to promote local research and innovation, and difficulties in accessing the oceans' greater depths are some of the factors hampering research development. This is particularly true in Nicaragua, Honduras and El Salvador, which have insufficient funds and resources to devote to education, science and technology.

To address these difficulties, the Molecular Biology Center (MBC) of the University of Central America (UCA, Nicaragua) has launched a new initiative to study and preserve local marine biological diversity and ecosystems while promoting sustainable social and economic development in the Central American region. This Central American Marine Genomic Initiative will build regional capacity in education, research and the conservation of marine ecosystems and will establish a genomic archive

to study and preserve the diminishing biological diversity of the oceans along the coasts of Central America. Early focus is on Nicaragua, extending to other countries in the region in the future.

To lay the foundation for this program, the UCA organized an international conference on Central American Marine Biodiversity and Genomics in April of 2012 dedicated to "Genomic Archiving and Coastal Marine Biodiversity Exploration, Conservation and Sustainable Development". In an effort to raise awareness of the major environmental challenges facing the region's coastal and marine ecosystems, and to highlight the potential research and socioeconomic benefits of this program, the authors provide summaries of key lectures and conclusions presented at this international conference and describe the main components of the initiative for the benefit of other actors, stakeholders and donors in the field of marine biodiversity.

International Conference on Marine Biodiversity and Genomics

For more than a decade, the Molecular Biology Center of UCA has been at the forefront of organizing and hosting an international conference series titled the Nicaraguan Biotechnology Conferences. The strategy behind these conferences has been to promote science education and research, both nationally and regionally, as a way to foster better economic and social conditions in Central America. They began as simple, yet ambitious academic meetings and have evolved into a well-established forum for research in all areas of biotechnology, becoming the preeminent scientific event in Nicaragua (Roustan-Espinosa et al. 2006). Beginning in 2002, UCA has been holding these conferences every two years with the active participation of the international scientific community. These conferences provide networking opportunities and a local platform for sharing the latest achievements in biotechnology, as well as for discussing industrial needs and research opportunities in the region. In addition, they serve to strengthen ties between the academic, governmental and private sectors interested in biotechnology innovations.

Drawing upon previous success, and to promote the Central American Marine Genomic Initiative, the 2012 conference was focused on marine biodiversity and genomics to highlight the importance of strengthening research on biodiversity and marine ecosystems in neglected Central American countries and to establish cooperative links between international research groups.

The conference was organized by the MBC-UCA, in partnership with scholars, scientists and authorities from the Massachusetts Institute of Technology (MIT), the Biotechnology Center of Excellence Corporation (BCEC), Ocean Genome Legacy (OGL) and New England Biolabs (NEB). It took place at an ecologically friendly resort along Nicaragua's Pacific coast in April 2012. The diversity of over 100 registrants from different regions of Nicaragua contributed in large part to the success of the conference, including members of the scientific community from Nicaragua's Caribbean Coast, an economically disadvantaged and marginalized area, rich in biodiversity and indigenous cultures. Other participants hailed from Mexico, Belize, Honduras, Belgium and several prestigious U.S. institutions. The event attracted considerable media attention, reflecting a growing interest in this area of research. Attendees included General Moisés Halleslevens and Mr. Jaime Morales, current and former Vice-Presidents of Nicaragua; Mrs. Guadalupe Martínez, Director of Nicaragua's Science and Technology Council; and Dr. Mayra Luz Pérez and Dr. Renata Rodrigues, President and Vice-President of the University of Central America (UCA).

A series of plenary lectures and panel discussions formed the backbone of the conference which included presentations by experts from a variety of disciplines to review regional activities currently underway in genomics, water resources, aquaculture, marine biodiversity research and conservation; and to explore ways to share this information and combine efforts on a regional basis. The agenda featured five sessions, each consisting of stimulating and challenging plenary talks and discussions, and included the active participation of conference attendees. Presentations addressed the following topics: environmental metagenomics, systems biology and next generation sequencing of uncultured microbes, the effects of common pollutants on coastal marine ecosystem health, effects of climate change on ecosystem processes, development and application of models to aid coastal ecosystem preservation, novel bioactive compounds from the marine environment, environmental aspects of marine biotechnology, genomic archiving, ethical issues of biodiversity exploration, conservation, national concerns regarding sharing biodiversity genomic data, among others.

The scientific sessions were inaugurated by Nobel Laureate Sir Richard Roberts (of New England Biolabs, Ipswich, MA., USA), with a keynote lecture entitled "Opportunities and Challenges of the Genomics Revolution". The final session was comprised of two plenary talks and closing remarks by Dr. Jorge Huete-Perez, President of the organizing committee. An additional session for young investigators, "Meeting with a Nobel Laureate", was held on the evening of the first day of the Conference with many young investigators in attendance, each of whom participated enthusiastically in the encounter with numerous questions for Dr. Roberts. The final day of the Conference was dedicated to a tour through the Juan Venado Nature Reserve, an island covered by mangrove forests in the northwest of Nicaragua's Pacific coast. The reserve is home to a wide range of Nicaraguan fauna including at least 195 species of birds, reptiles, amphibians and mammals, along with the Olive Ridley, Leatherback and Green Sea Turtles (all endangered).

Opportunities and challenges of the genomics revolution

In his remarks, Richard J. Roberts emphasized that "at the present time, when studying a new organism, it has become almost mandatory to first determine its DNA sequence". According to Dr. Roberts, the genomics revolution is quickly taking over the practice of biology. As the speed of DNA sequencing increases and its cost decreases, we are in danger of being overwhelmed by the sheer volume of data that is being generated and our rather meager abilities to interpret that data, he said. Dr. Roberts began his talk by focusing on the current challenge for those working in field of bioinformatics in understanding the actual function of genome sequences. He spoke about COMBEX (COMputational BRidges to EXperimentation), a project being run out of Boston University with the aim of engaging the biological community in supplying better functional annotation of genomes. It involves large scale collaboration among biochemists, biologists and bioinformaticians to generate databases of predicted functions for genes in bacterial and archeal genomes, followed by biochemical testing of the predicted functions. Dr. Roberts explored some of the areas in which the genomics revolution can be of great support, pointing out areas of especial interest to Nicaraguan scientists.

Dr. Roberts stressed that science can be used to help Nicaragua and the region solve their most pressing problems. Indeed, biotechnology has proven to be an important tool for providing enormous benefits to small countries. Cuba presents an excellent example of applying biotechnology to generate substantial income for the nation. Nicaragua could make use of its vast biodiversity, including marine biodiversity, to improve education, research and development. He also described the fear of genetically modified products in certain parts of the world as absurd and hindering research in several areas of relevance for developing countries.

The structure of microbial diversity in the ocean

Microorganisms account for more than 90% of ocean biomass, contributing to nutrient cycling and primary production. They are also key players in maintaining Earth's stable climate. In his presentation, Dr. Martin Polz of the Massachusetts Institute of Technology (Cambridge, MA, USA) said that the ocean is primarily a microbial ecosystem with both biomass and biogeochemical processes greatly dominated by microbes. He added that although patterns of community composition and variation in the microbial world are being continuously discovered, the biological mechanisms by which such patterns arise remain poorly understood. Accordingly, to improve our appreciation of ocean systems, it is essential to distinguish microbial populations with predictable ecological functions. Dr. Polz explained that recent findings indicate that ocean communities consist of diverse groups of bacteria organized into genotypic clusters of closely related organisms. Using coastal vibrios as a model, he showed that such clusters correlate to ecologically differentiated populations. Although such patterns are similar to those of metazoan communities, the underlying mechanisms for microbial population differentiation differ substantially, he explained. Professor Polz provided data on how microbial populations evolve in spite of the potential for horizontal gene transfer across widely divergent genomes. Lastly, Dr. Polz discussed his observations linking ecological function to microbial diversity while advising against making inferences based on a single ecological factor (Thompson et al. 2004; Preheim et al. 2011; Materna et al. 2012; Shapiro et al. 2012).

Aquaculture: The Blue Biotechnology of the future

Patrick Sorgeloos' presentation on aquaculture provided a much needed overview of the practical applications of biotechnology in the field of fisheries and aquaculture. He reviewed the history and

status of world aquaculture, assessed commercial opportunities, and addressed safe and sustainable food production as a vital component in integrated systems for the production of energy, food and non-food products and for environmental bioremediation.

According to Professor Sorgeloos of Ghent University, Belgium, aquaculture has become the fastest growing food-producing sector worldwide. It has evolved from a marginal industry in the 1970's (producing less than 5% of aquatic consumption products with the other 95% being harvested from the sea and freshwater rivers and lakes) to a very successful bio-industry meeting almost 50% of global needs for aquatic protein. With the expanding world population and stagnation in some fisheries catches, aquaculture will continue to grow at a rate of over 7% per year to meet market demands in the decades to come, according to Dr. Sorgeloos.

In regard to the use of modern biotechnology "OMICS", consisting of DNA, RNA and protein microarrays, mass spectrometry, bioinformatics and other techniques enabling high-throughput analyses, Professor Sorgeloos argued that these techniques are having an enormous impact on aquaculture, leading to its evolution "from an empirical science to a knowledge-based biotechnology". There is currently much more emphasis on fundamental research facilitating the understanding of the essential mechanisms in growth and product quality of aquatic species, their endocrinology, immune systems, behaviour, etc. Application of proven experience from other disciplines in agriculture and animal production offers unique opportunities for significant progress in seafood production in the decades to come, said Dr. Sorgeloos. In analyzing aquaculture's successful recent history, it appears we have reached a turning point. We should reflect on previous success based on the empirical experience to try to understand the underlying mechanisms, paving the way for aquaculture to move into "blue biotechnology", and leading to multiple opportunities for countries in Central America.

Professor Sorgeloos provided some examples on the uses of biotechnology research in aquaculture. He discussed a novel technique using bacteriophages (viruses that infect bacteria) to control pathogenic bacteria. With this strategy, phages used as biocontrol agents in aquaculture are preferentially selected on their ability to infect a wide range of pathogenic strains (Defoird et al. 2011).

In his final remarks, Dr. Sorgeloos called for increased attention to the vast biodiversity of aquatic organisms, largely untapped and unexplored. Such studies might reveal new species of interest for farming as a renewable bio-resource for extraction of value-added products for food and non-food industries, with the remaining biomass as a valuable ingredient for animal feeds. He commended the organizers of the conference for creating awareness towards marine biotechnology in Central America for food and energy security, the development of novel drugs, new treatments for human health and the sustainable use and management of the seas and oceans.

Prospects for marine biotechnology in Central America

A special symposium within the conference addressed Science, Technology and Innovation (STI) issues related to biotechnology development in Nicaragua and Central America, with a focus on marine biotechnology. A talk by Dr. Ramón Padilla (Economic Council for Latin America and the Caribbean, ECLAC, Mexico) entitled "Science and Technology Policies for Development" described the role of scientific research as a major contributor to economic growth. The case of biotechnology development in Latin America is "concentrated on the importance of science and technology policies as essential tools for social and economic development". Dr. Padilla presented evidence showing that in Central America, STI policies have gained ground in recent years, although there are significant differences between countries. The region has created institutions and public organizations responsible for designing and implementing programs, however a linear vision prevails and financial and human resources are lacking. Because of the enormous potential for the development of new products and processes, biotechnology is being considered a new technological paradigm. The region is increasingly more aware of the adverse effects of seafood borne diseases which negatively affect public health and local economies. The challenge is to use molecular and genomic technologies to establish rapid diagnostic assays that guarantee the safety of seafood, assuring at the same time the dynamism of the emerging aquaculture and seafood industry.

Implications of commercial bioprospecting for marine biotechnology in Central America

The talk entitled “Implications of commercial bioprospecting for marine biotechnology in Central America” by Fernando Quezada (BCEC, MA, USA) focused on opportunities for using modern technologies in the marine sciences and the promise of these technologies for research and socioeconomic benefits.

Ongoing advancements in scientific and technological research tools have enabled new levels of precision and effectiveness in the identification, collection, processing and utilization of novel natural substances for applications in medical, agricultural or industrial innovation efforts. In recent years, commercial bioprospecting activities in Latin America and the Caribbean have assumed various forms and approaches in accordance with the target markets, the country context and specific business models involved. While prospecting for medicinally or industrially valuable substances derived from natural resources is not a new phenomenon, the systematic search for biologically active compounds in nature has gained a new significance as a component of biodiversity conservation strategies. Particular firms and institutions described by Fernando Quezada represent different sizes, commercial strategies and organizational structures which reflect their respective positions in the productive value chain in each of the associated industry sectors. He provided a brief introductory overview of biodiversity prospecting in terms of the principles and practices which have defined it both historically and currently.

A discussion was held regarding stakeholders and issues involved in the formulation of national policy, particularly in regard to the implementation of the Convention on Biological Diversity, access and benefit sharing, recognition of indigenous knowledge, prior informed consent, intellectual property protection and others. Discussion of the implications for marine biotechnology in Central America focused on concerns for establishing the relevant baseline information as well as the needed human resource infrastructure. Special attention to traditional knowledge and rights of indigenous groups must also be considered in any bioprospecting of marine resources in the region. It was mentioned that some limited lessons can be drawn from other regions of Latin America (Quezada et al. 2005).

The Marine Genome Resource Sustainability Initiative

There is an urgent need to study, document and preserve the existing and rapidly vanishing biological diversity of the world's oceans. Marine life is being drastically altered by human activities, particularly the effects of activities associated with population expansion.

A number of factors place increasing strain on the Central American region's biodiversity and natural resources. Among these factors are high population growth rates, high levels of unemployment, low-income jobs and heavy reliance on natural resources, leading to land, forest and water degradation and pollution. Aquaculture enterprises such as shrimp farming and agricultural practices such as pesticide dependent farming and the cutting down of forests to create grazing land also threaten the region's biodiversity as a whole, as well as threatening many species with extinction.

Climate has affected the region's biodiversity as well. Emission of greenhouse gases puts biodiversity at risk. For a number of years, global warming has caused massive coral bleaching episodes in the Caribbean, resulting in the decline of coral reefs on a large scale. Scientists predict that by 2030, the rise in ocean temperatures and acidity will increase the overall threat of extinction to 90% of the Caribbean's coral reefs (Burke et al. 2011). Experts believe that eliminating ambiguity in estimating coral reef prospects requires better understanding of past responses to rapid climate change, as well as physiological responses to interacting factors, such as temperature, acidification, and nutrients (Pandolfi et al. 2011). Due to the lack of sufficient knowledge about past events, it is difficult to make accurate predictions for the near future.

The importance of coral reefs and mangrove forests in terms of fisheries, livelihoods, shoreline protection and tourism is well known. Central America is fortunate to have both of these ecosystems within her boundaries. Yet possibly 40% of mangrove species present on the Pacific and Caribbean coasts of Central America are threatened with extinction (Polidoro et al. 2010). At least 15% of the coral reefs in Nicaragua and 34% in Honduras are threatened by human activity alone. Although mangroves are protected by international treaties and other instruments, exploitation and destruction of these vital forests continue.

In recent years, notable progress has been made in some countries in the region in protecting the biodiversity of their land and coastal waters. About 8% of the region is now under some form of conservation protection, including the establishment of over 16,000 protected marine areas. International collaborative projects such as the Mesoamerican Biological Corridor which link together protected areas, biodiversity-friendly cultivated areas, agro-forestry systems and private reserves throughout the region, have contributed to sustainable development and environmental protection by taking biodiversity into consideration when designing best practices in business, and environmental policies and legislation.

While significant research has been conducted on the coastal ecosystems of some countries in Mesoamerica, the same cannot be said for Nicaragua, El Salvador and Honduras. There is little data on the state of Nicaragua's marine biodiversity and the government lacks the resources (funding, research materials, scientific expertise, and trained investigators) to conduct its own research and surveillance activities in this area. The scarce or non-existent knowledge on marine research in these countries points toward insufficient human resources and limited facilities in laboratories and research stations. A study on the status of marine biodiversity in the Caribbean based on the Census of Marine Life program lacks information on the distribution patterns in both Honduras and Nicaragua (Miloslavich et al. 2010). The low number of species and the poor diversity of species reported most likely reflect a gross underestimation of the true marine biodiversity present along the Caribbean coast of these two countries. This situation could be attributed to the limited taxonomic expertise available in these countries as well as to the lack of appropriate instrumentation and modern molecular biology techniques, among other factors. Current data on ocean acidification, population numbers and variety of species for these countries' coastal regions is non-existent. As a result, any loss of biodiversity could go undetected. Nicaragua, Honduras and El Salvador have no large scale national research programs on marine biodiversity nor do they participate in the Association of Marine Laboratories of the Caribbean (AMLC), a not for profit organization dedicated to advancing marine and environmental education in the region.

The new program spearheaded by the Molecular Biology Center (MBC) of the University of Central America (UCA) in Nicaragua is trying to improve the knowledge base on marine biodiversity and the region's ecosystems. It draws upon ongoing and successful international cooperation between the MBC-UCA and New England Biolabs (NEB) and the Ocean Genome Legacy Institute (OGLI) in Massachusetts, aimed at creating a public archive of marine life specific to the Pacific and the Caribbean coasts of Nicaragua. Gradually the program will expand to neighbouring countries.

Using state-of-the-art technologies, including modern OMIC technologies (genomics, transcriptomics, proteomics and metabolomics), the program of the MBC will provide public access to marine organism tissues and genomic DNA samples to the scientific and academic communities for research and educational purposes. The MBC is assiduously seeking partnerships with similar programs throughout the world, particularly those with experience in sustainable value creation from natural resources. The creation of the archives entails the collection, preparation, preservation, identification, documentation and storage of genome resource samples; the development of methodologies for best practices in archiving; designing, creating and managing databases; collaborating with other international archives, researchers and academic institutions; and establishing norms for sharing data with the international community for education and research purposes.

The genomic archive of Nicaragua's marine biodiversity is above all an educational and research tool. The program is designed to build capacity for the study and conservation of marine ecosystems in the Central American region. It combines a series of pedagogic innovations for teacher training and technological resources, including integrated activities to guarantee the creation of local capacities. The structure of the program includes training in pedagogy and bringing current methods up to date in genomics and marine biology; professional development and critical reflection on the practice of teaching; incorporating new information and communication technologies; and the creation of multi-media learning resources to strengthen teaching.

Archiving in the Cosigüina Peninsula Natural Reserves

Through the creation of a dynamic genome archive of marine life, the program is establishing a baseline registry of the current state of marine biodiversity of sampled areas. The initial collections have already produced interesting discoveries. With funding from the UCA, the MBC collected marine

organisms from 24 sites within the Cosigüina Peninsula Natural Reserves focusing on fish, crustaceans, gastropods and bivalves from the Padre Ramos and Estero Real Estuaries. We gathered more than one thousand organisms representing more than 200 different species and have described them by standard taxonomic description as well as by molecular taxonomy using the gene for the mitochondrial cytochrome oxidase c subunit I (DNA barcoding). This pilot project allowed us to initiate the first tissue and DNA archive of marine organisms in those biological reserves, including a catalogue and genetic documentation, and barcodes of sampled species, for incorporation into the genomic archive databases. Samples are now being collected on the Caribbean coast as well.

Tissue samples collected and their genomic DNA stored at the genomic archive provide a valuable baseline for determining fluctuations in species and populations, as well as adaptations to changing environmental factors, illustrating the significance of genomic archives and their potential for increasing our understanding of significant biological questions. This archive respects and adheres to the Convention on Biological Diversity. Its main value lies not only in making it possible to carry out a broad range of research, but also in supporting the responsible and sustainable use and conservation of the region's valuable marine biodiversity.

In light of this presentation's discussion, the plenary concluded that UCA's marine genomics initiative serves the development objectives of Central America by building the region's science and technology resources and by helping to preserve the rich natural asset base of its coastal zones. Not only are the coastal ecosystems vital for continued sustainability of marine harvesting but they also present a unique opportunity for the formation of a knowledge-based approach to marine-resource commercialization. The new tools available for genomic and post-genomic research will continue to broaden the opportunities for marine scientists in Central America. The challenge will be for the appropriate public, private and academic institutions to respond in a timely manner and exercise the needed leadership at both national and regional levels.

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