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Developmental Biology in Central America, the northern region of South America and the Caribbean

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ABSTRACT This review highlights the history of Developmental Biology studies in Latin-American countries of Central America, the northern region of South America and the Caribbean and their impact on the field. For this, we have compiled the contributions made by investigators in various institutions of the region, including universities, as well as agricultural, research and health centers. Most of the contributions focus on particular fields, among them, Evo-Devo, regenerative biology, nervous system development and health related issues. A large share of the contributions originates from a subset of countries, primarily, Colombia, Costa Rica, Ecuador, Panama and Puerto Rico. In addition, we underscore the new investigators and the ongoing research in the region.

KEY WORDS: *Evo-Devo, regeneration, nervous system, health issues*

Introduction

At first glance, the region that encompasses the Latin-American countries in the northern part of South America, Central America and the Caribbean, might not appear to have a rich history of research in Developmental Biology (DB) (Fig. 1). However, as one probes deeper into the region's contributions a different panorama emerges. A significant compendium of publications arises; some of them have had major impacts on the DB field while others have helped establish DB firmly in particular countries. Most contributions are made by investigators in certain academic institutions or local university consortia, such as those formed by the different campus of the University of Puerto Rico (UPR) (Fig. 2A) or the one formed by the Universidad de Antioquia-Universidad Nacional de Colombia joint research group. Others originate from research Centers, such as the Smithsonian Tropical Research Institute (STRI) in Panama (Fig. 2B) whose main focus is ecology and evolution in the Neotropics or the International Center for Tropical Agriculture (CIAT) in Colombia that focuses on tropical crops. DB related work can also be found associated to governmental institutions involved in health problems that affect human development, particularly those related to pre-natal and pediatric issues. Publications from these non-academic sources usually bypass the DB radar, but their findings are, nevertheless, of scientific relevance to the field. Likewise, some of the DB-related research may not be published in peer-reviewed journals but is available in government or local technical reports that are not easily accessible. In addition, many investigators in this region have established links and collaborations with universities or institutes in Europe or North America, where the participation of the local institution is diluted within the contributions from the larger international group.

A handful of countries have taken the lead in establishing and expanding DB in the region. Among these, Colombia, Costa Rica, Ecuador, Panama, and Puerto Rico provide the most extensive amount of work that covers several decades and is the product of the research of several investigators[1]. In general, two trends can be observed among the group of investigators doing DB research. First, those that have done their training elsewhere and once back in their home countries, continue the doctorate line of work. Most of these studies are done using classical model systems such as fruitflies, amphibians, or zebrafish. A second trend has been taken by investigators that utilize the local fauna or flora to develop non-traditional model systems. These investigators usually identify problems and/or organisms to explore a particular DB process.

The research topics explored by the region's investigators might appear heterogeneous and eclectic; ranging from flower development to neuronal plasticity, from molecular analyses to phenotypic

[1] It has been a challenge to identify and compile DB-related studies from this region. Because of these limitations, this review should not be construed as encompassing all developmental biology studies or researchers in the region. I would prefer the readers to view it as an effort to identify some of the work that has been performed in the region and some of the key researchers that have been active. (Puerto Rico might be overrepresented since it is the country of the author).

Abbreviations used in this paper: DB, developmental biology.

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Fig. 1. Ibero-American countries in the region covered in this review. *1. Cuba, 2. Dominican Republic, 3. Puerto Rico, 4. Guatemala, 5. Honduras, 6. El Salvador, 7. Nicaragua, 8. Costa Rica, 9. Panamá, 10. Colombia, 11. Venezuela, 12.Ecuador, 13. Peru, 14. Bolivia.*

comparisons, among many others. However, by casting a wide net, most of the published research from the region can be clustered around particular subjects.

Since most of the studies have been performed within the last half-century, investigations have targeted new or upcoming areas in the DB field where the niche remains available for new investigators. Among these is Evolutionary Developmental (Evo-Devo) Biology, where the rich biodiversity of the region has been mined for organisms that have different developmental processes. The study of these organisms provides information on how DB processes have evolved. A second niche where investigators in the region have made experimental gains is in Regenerative Biology, a process where mechanisms that are active during embryological development are re-organized to form new cells, tissues and organs that have been lost following injury or disease. The boom in studies of the nervous systems has also attracted some of the region's investigators. Many of these have focused on the peripheral nervous system and on the process of synaptogenesis. Finally, DB studies in the region have explored health issues where DB processes are involved. These studies focus on local or regional health problems that usually affect the citizens of a particular country.

In addition to recapitulating past works and the researchers that have advanced DB in different countries, this review also highlights new investigators and the current work that, hopefully, may continue to bloom and expand DB in the region. In particular, I should emphasize on the tremendous effort some of our institutions and research groups have undergone to carry out research on tropical, non-model organisms, a difficult task that has begun to be internationally recognized.

Evo-Devo

Evo-Devo pioneers

The region encompassing Central America, the northern part of South America, and the Caribbean includes areas that have been widely recognized as "biodiversity hotspots" (Myers 2000). The rich fauna and flora of the region has attracted the interest of scientists since the XVIII century. The region has also been the source of interest of local and foreign researchers who have discovered and described unique developmental processes and their evolutionary implications. Though many of these studies preceded the rise of the Evo-Devo field, they certainly paved the way for it. Take for example the pioneering discoveries made by Dr. Eugenia del Pino from the Pontificia Universidad Católica del Ecuador (PUCE). Her finding and descriptions of marsupial frogs from Ecuador riveted the scientific community and the general public (Del Pino and Elinson 1983, Del Pino 1989, 2018) (Fig. 3A).

I will not dwell on her many studies using these organisms, since they are best described in the accompanying autobiography in this issue (Del Pino in this issue). Nonetheless, it is important to highlight that her studies went beyond the development of the frogs (see Del Pino *et al.,* 2004, 2007) covering many other areas, including oogenesis (Del Pino *et al.,* 1986), metabolism (Alcocer *et al.,* 1992), *in vitro* systems (Del Pino *et al.,* 1994), and more recently

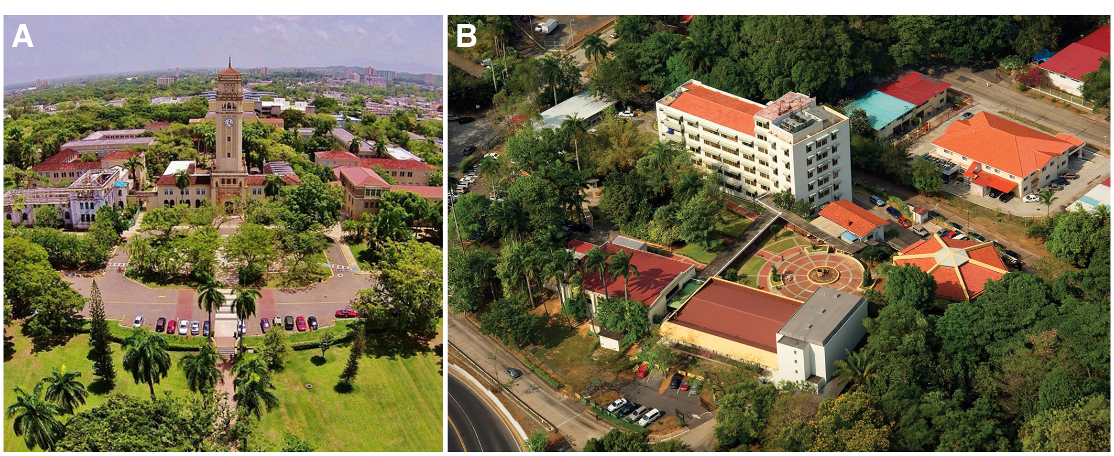

Fig. 2. The University of Puerto Rico (UPR) (A) and the Smithsonian Tropical Research Institute (STRI) in Panama (B). *These represent two of the main institutions in the region where research in developmental biology has been ongoing for the last 50 years.*

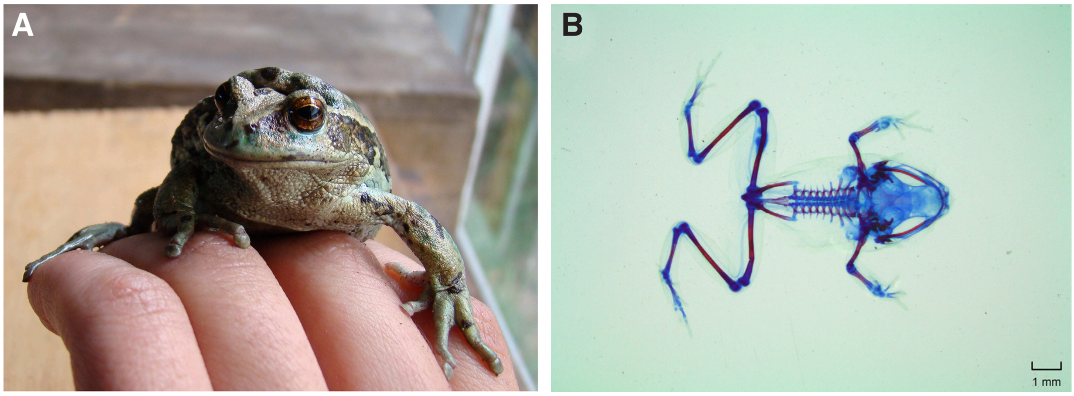

Fig. 3. Amphibians with different developmental strategies *such as the marsupial frog* Gastrotheca **(A)** *(note the tadpoles on the dorsal side of the animal) and the direct developer frog* E. coqui **(B)**, *(cleared and stained to determine anatomical abnormalities) have provided useful models for Evo Devo studies.* (Gastrotheca *photo credit Juan Diego Santillana-Ortiz,* E. coqui *credit, Zuania Colón).*

molecular studies (Benítez and Del Pino 2002, Venegas-Ferrín *et al.,* 2010, Sudou *et al.,* 2016). Equally important to the advance of DB in the region has been her involvement in the training of students, keeping collaborations with established scientists at top universities who not only participate in the ongoing research projects but also visit Latin-America for seminars and workshops (Del Pino 2003).

A second trailblazer, whose work has had enormous influence in the Evo-Devo field is Dr. Mary Jane West-Eberhard (Fig. 4). For 10 years Dr. West-Eberhard was a professor at the Universidad del Valle in Cali, Colombia. She then joined the Smithsonian Tropical Research Institute in Costa Rica and the Universidad de Costa Rica, where she devoted her research efforts to study interactions among the local fauna and flora for more than three decades (West-Eberhard 2009). Her main interest focused on the evolution of social behavior for which she delved on the social behavior of tropical wasps (West-Eberhard 1996). Her findings helped explain the production of alternate phenotypes, and the identification of external factors involved and their significance for evolutionary theory. Examples of these are her contributions to defining concepts such as phenotypic accommodation (West-Ebenhard 2005a) and the study of the proximate factors that modulate the phenotype, such as the role of juvenile hormone in determining worker vs. queen phenotypes (Giray *et al.,* 2005). She helped explain how phenotypic novelties are not random variants but arise from adaptive developmental plasticity (West-Eberhard 2005b). In 2003 she published her seminal book *Developmental Plasticity and Evolution* where she connects the potential changes during the development of an organism to the genetic bases of evolutionary theory (Fig. 4). This work, detailing the role that the environment plays in determining the phenotype of a particular species, is now a fundamental piece of work to the Evo-Devo field.

The region's biodiversity also attracted researchers from abroad who used the local organisms in their studies. Such was the history of Dr. Richard Elinson (see Elinson in this issue) who developed an extended his field of work using the tree frog *Eleutherodactylus coqui*, a direct developing amphibian native to Puerto Rico (Callery *et al.,* 2001, Elinson 2013). His many contributions explored the cellular changes and their underlying molecular basis for such metamorphic variation in amphibians (see for examples Elinson 1994, Elinson and Fang 1998, Elinson *et al.,* 2011, Chatterjee and Elinson 2013).

Tropical amphibians continue to be studied for Evo-Devo and Eco-Devo as shown by the article in this issue from the lab of Dr. Romero-Carvajal at PUCE. Likewise, the laboratory of Dr. Carla Restrepo at UPR has used *E. coqui* to study the possible effect of environmental changes on amphibian development, showing that habitat disturbance can cause, among other outcomes, a reduction in the size of the frogs and an increase in bilateral asymmetry (Delgado-Acevedo and Restrepo 2008). More recently, Dr. Restrepo's laboratory has focused on investigating the effect of temperature on the formation of skeletal abnormalities during development (Colon-Piñeiro 2017, Fig. 3B).

Regional marine species biodiversity has also attracted research interest from Developmental Biologists worldwide. Among these is Dr. Rachel Collin at STRI in Panama. Her work has documented the alternative modes of development exhibited by marine invertebrates (Collin 2012). Many of her studies focus on sexual phenotypes, reproductive parameters and embryological development of mollusks (Collin *et al.,* 2005, 2007, Collin 2013). However, Dr. Collin has also studied embryological aspects of other animal groups, among them

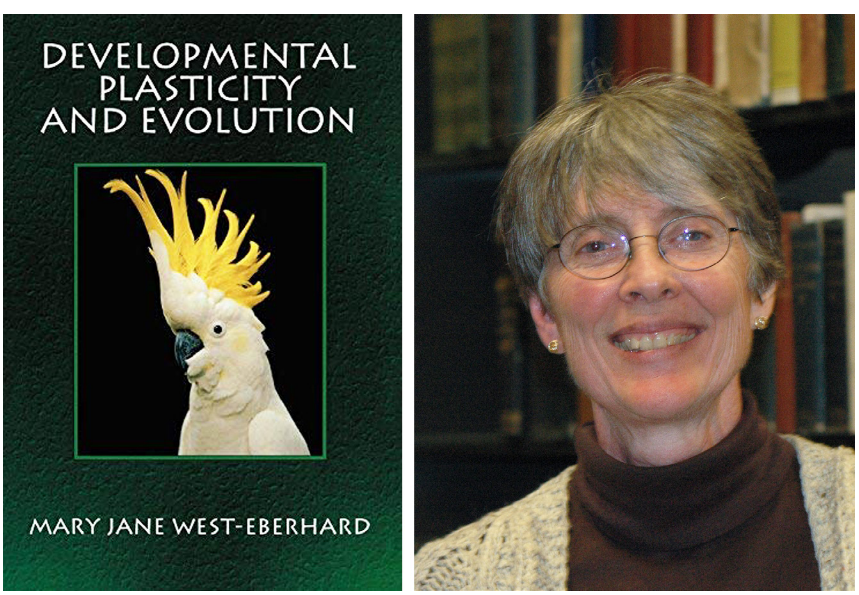

Fig. 4. Mary Jane West-Eberhard and her seminal book *in which she explores the relationship between phenotypes, genotypes and evolution.*

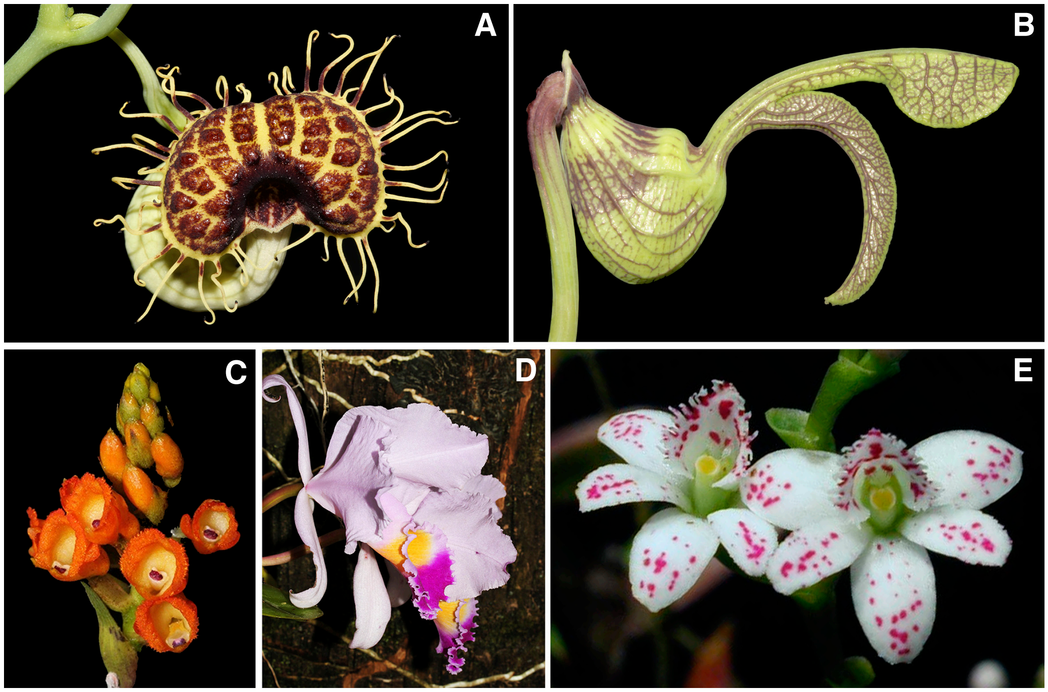

Fig. 5. The diversity of plant species in the region has provided investigators with multiple examples of developmental mechanisms involved in flower and fruit production. *Examples show:* **(A,B)** *Early diverging flowering plants in the Aristolochiaceae (Piperales)* Aristolochia fimbriata*, and* Aristolochia ringens *respectively.* **(C-E)** *Representative orchids from the tropics:* **(C)** Elleanthus aurantiacus, **(D)** Cattleya trianae *and* **(E)** Epidendrum fimbriatum. *(Photos- courtesy of Dr. Pabón-Mora).*

the development of hemichordates and echinoderms (Collin and Chan 2016, Collin *et al.,* 2019). Altogether, she has approached the subject in an integrative broad spectrum that runs from transcriptomics to field studies (Collin and Salazar 2010, Lesoway *et al.,* 2016). Dr. Collin is also a contributor to this issue (see Collin *et al.*). Additional contributions to the Evo-Devo field using marine organisms have come from the laboratory of Dr. Federico Brown who worked at the Universidad de los Andes in Bogotá, Colombia. (Brown has now moved to the Universidade de Sao Paulo in Brazil). During his tenure in Colombia, Brown's group studied the central nervous system of flatworms, the development of mollusks and the developmental mechanisms of colonial tunicates (Quiroga *et al.,* 2015, Gutierrez and Brown 2017, Velandia-Huerto *et al.,* 2018). Finally, the late Dr. Oscar D. Pérez[2] at PUCE also used marine organisms to study evolutionary patterns of embryonic development (Chávez-Viteri *et al.,* 2017, see Moreano-Arrobo *et al.,* in this issue).

Flower power

Plant Evo-Devo has taken a particular hold in Colombia. This might be viewed as a natural development since the flora of the country accounts for a relatively high percentage of the taxa found worldwide, in addition to a large number of endemic species. Two researchers have helped advance this field, Dr. Natalia Pabón-Mora, at the Universidad de Antioquia in Medellín, and Dr. Favio González, at the Universidad Nacional de Colombia in Bogotá (Fig. 5). They have combined a strong expertise in plant systematics and morphoanatomy with a modern approach on the molecular basis of plant development. In particular, their research has focused on understanding the molecular basis of the formation and patterning of flowers and fruits (for a sampling of their work see Pabón-Mora *et al.,* 2014, Arango-Ocampo *et al.,* 2016, Suaza-Gaviria *et al.,* 2016, Madrigal *et al.,* 2019, Ortíz-Ramirez *et al.,* 2019, Pérez-Mesa *et al.,* 2019, Suárez-Baron *et al.,* 2019). More recently, they have started to investigate the morphological and molecular changes underlying vegetative meristem maintenance and the transition to flowering in parasitic and epiphytic plants (Dr. Pabón-Mora is a contributor to this issue).

Agricultural settings

Research in plant development is not limited to Evo-Devo studies, but also takes place in agricultural settings where research has a direct impact on crop improvement. In this scenario, agricultural and forestry stations play a major role. Research undertaken at the Forestry Institute of the University of Costa Rica by Dr. Eugenia Flores Vindas offers an example of this type of contributions. She performed extensive studies on tropical forestry and published several papers on the germination and development of tropical species (Flores 1977, Flores *et al.,* 1986, Alvarenga and Flores 1988, Flores and Moseley 1989,)

Equally, agricultural stations have also contributed to our understanding of plant development. Investigators at the CIAT, in Colombia, focus their studies on tropical crops, in particular

[2] Dr. Oscar D. Pérez passed away recently. He was a young investigator who had already made important contributions to the DB field. Oscar worked with Dr. del Pino and Dr. Elinson prior to establishing his own research lab at PUCE. His lab was active in a variety of topics including Vegt, oogenesis in amphibians (including caecilians), descriptions of early development in several frogs (including a Gastrotheca species with direct development). He was president of the National Society of Biology of Ecuador and the representative from Ecuador to the Board of the Latin American Society for Developmental Biology (LASDB).

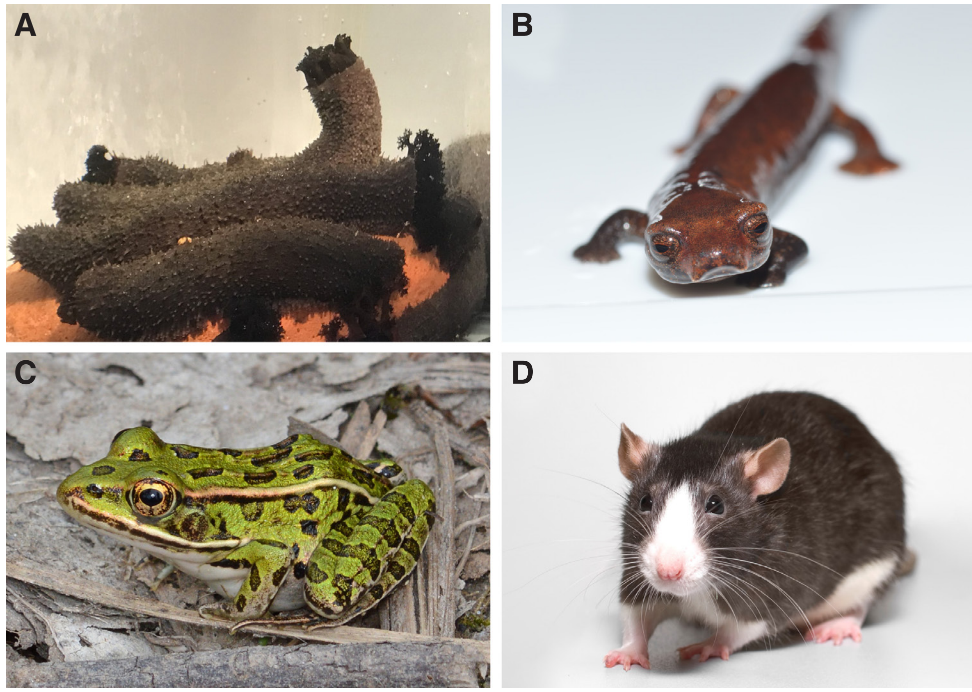

Fig. 6. Animal models used to study regeneration *range from novel models such as* **(A)** *the sea cucumber* Holothuria glaberrima *and* **(B)** *the South American salamander* Bolitoglossa ramosi, *to established models such as,* **(C)** *the frog* Rana pipiens *and* **(D)** *the laboratory rat* Rattus norvegicus. *These organisms are used to study intestinal (sea cucumber) nervous (sea cucumber, frog and rat) and limb regeneration (salamander). (Salamander photo courtesy of Dr. Arenas-Gómez. Rat photo by Alexey Krasavin (at flick.com) used under the Creative Commons Attribution 2.0 Generic license)*

cassava, but they also participate in other studies via international collaborations. Publications by Ademeyo *et al.,* (2017), Jiménez *et al.,* (2019), and Ramos-Abril *et al.,* (2019) offer some examples of the ongoing work from this Center that overlaps with the interest of plant developmental biologists.

Dr. Pablo Bolaños-Villegas, at the Fabio Baudrit Agricultural Station of the University of Costa Rica is another example of developmental research performed at an agricultural station. His studies have centered on genome haploidization and the design and isolation of mutations in meiotic genes (Bolaños-Villegas *et al.,* 2018, Bolaños-Villegas and Argüello-Miranda 2019).

Regenerative biology

Several investigators in this region have contributed to our knowledge of regenerative biology. One of the first was Dr. José R. Ortiz, a biologist at UPR who, in the 1980-1990's published several works using the newt *Notophthalmus viridescens*, a well known model in regeneration research. Dr. Ortiz who received training from Dr. Tuneo Yamada at the University of Tennessee, returned to UPR where he was involved in projects related to the signaling molecules modulating lens regeneration (Velázquez and Ortiz 1980, González *et al.,* 1987, Torres *et al.,* 1988, Ortiz *et al.,* 1992, Goins *et al.,* 1994, Herreño *et al.,* 1994). In these studies, his group assessed the role of endogenous and synthetic compounds on the trans-differentiation of dorsal iris cells into lens cells, the cellular process by which lens regeneration occurs in newts. Dr. Ortiz, together with one of his colleagues, Dr. Graciela Candelas, offered one of the first DB workshops in the region. This workshop entitled "Genes and Development" was funded by the International Cell Research Organization (ICRO-UNESCO) and was offered at UPR in 1999.

Three other groups at UPR also focused their studies on regenerative biology, Dr. Rosa Blanco using the amphibian *Rana pipiens* to study optic nerve regeneration, Dr. Jorge Miranda focusing on spinal cord regeneration in rodents and my own group using the sea cucumber *Holothuria glaberrima* to study intestinal and nervous system regeneration (Fig. 6). Dr. Blanco research team has done extensive work on the factors that modulate retinal ganglion cell survival and optic nerve regeneration following injury. Her studies on the amphibian model mainly focus on retinoic acid and factors such as FGF-2, BDNF, and CNTF where she combines molecular and anatomical analyses (Duprey-Diaz *et al.,* 2002, 2016 a&b, Vega-Melendez *et al.,* 2014, Blanco *et al.,* 2008, 2019).

In contrast to the work using amphibian models, my laboratory has pioneered the use of a local echinoderm, *H. glaberrima* as a model to study regeneration. This species has been mainly used to study intestinal regeneration (see Quispe-Parra *et al.,* in this issue). More recently, it has also been used to study the regeneration of the radial nerve cord (San Miguel-Ruiz *et al.,* 2009). Our findings have shown, among other things that (1) radial glial cells dedifferentiate to give rise to the new glia and neurons of the regenerating cord (Mashanov *et al.,* 2013), (2) there are major changes in gene expression during radial cord regeneration (Mashanov *et al.,* 2014) and (3) some of these gene including myc and transposable elements might play an important role in regeneration (Mashanov *et al.,* 2012 a&b, 2015 a&b).

The third group doing regenerative biology work in Puerto Rico is that of Dr. Jorge Miranda. He studies spinal cord injury by mimicking in rodent models, the type of contusion that occurs in most human patients. His research aims to study the factors that promote spinal cord regeneration and the mechanisms involved (Figueroa *et al.,* 2006, Cruz-Orengo *et al.,* 2007, Rodriguez-Zayas *et al.,* 2010, Arocho *et al.,* 2011). In particular, he has studied in depth a protective role of estrogen in this process (Mosquera *et al.,* 2014, Colon *et al.,* 2014, 2016).

Regeneration studies are also being done at the Universidad de Antioquia in Medellín, Colombia. It is here where Dr. Jean Paul

Delgado, trained in the laboratory of Dr. Jeremy Brockes at University College London, has set up his own research group (Fig. 6). His group has focused on species native to Colombia whose regenerative prowess might shed some new light into the process of limb regeneration (see Arena-Gomez *et al.,* 2017, 2018 and Arena-Gomez and Delgado in this issue). His lab also established the first axolotl colony in Colombia, now with over 500 individuals. The research team is currently focusing on the reactive oxygen species metabolism during limb and tail regeneration in axolotls and the standardization of transgenic protocols in this species.

Nervous system development

Nervous system studies in this region have addressed, not only the regenerative aspects described above, but also normal developmental processes. Dr. Jonathan Blagburn, working at UPR has studied the formation of synapses in insect auditory systems (Blagburn 1995, Marie and Blagburn 2003, Blagburn and Bacon 2004, Pezier *et al.,* 2014). His former student, and now colleague, Dr. Bruno Marie has continued some of these studies. His work uses *Drosophila* to determine the molecular basis of synapse formation during embryological development (Maldonado *et al.,* 2012, West *et al.,* 2015, Alicea *et al.,* 2017).

Past work from my laboratory has also contributed to better understand nervous system development. In this case the work involves the follow-up of my post-doctoral studies in the laboratory of Dr. Nicole LeDouarin at the Insitut d'Embryologie, in France. These studies of the development of the sympathoadrenal system in avian embryos and the role of soluble factors in the determination of peptidergic phenotypes that began in her laboratory, were then continued and expanded upon my return to UPR (Garcia-Arraras *et al.,* 1992, Ramirez-Ordonez and Garcia-Arraras 1995, Barreto-Estrada *et al.,* 1997, 2003).

Developmental studies focused on the nervous system might be expanding in the region as suggested by a recent publication from the laboratory of Dr. Veronica Akle at the Universidad de los Andes, in Bogotá, Colombia (Agudelo-Dueñas *et al.,* 2020). In this article, her group analyses the expression and localization in early zebrafish brains of an important ECM developmental protein (Spondin) that has been associated with axonal growth.

Health issues

In some cases, developmental studies have addressed public health issues. Such was the case in the early 1980's in Puerto Rico when an outbreak of premature thelarche cases occurred (Bongiovanni 1983). This condition is characterized by premature breast development and precocious puberty. An increase in children with this condition, particularly in girls, was made public by two physicians, Dr. Carmen Saenz de Rodríguez, Pediatrics Director at the Hospital de Diego in San Juan and Dr. Adolfo Pérez-Comas, a pediatric endocrinologist in private practice (Pérez-Comas 1982, Saenz de Rodriguez *et al.,* 1985). The cause was never clearly identified, although environmental contaminants were suspected, particularly the estrogens used in the poultry industry to accelerate growth in chickens (Freni-Titulaer *et al.,* 1986). Later studies pinpointed to the presence of phthalate esters in the blood of girls with premature thelarche (Colon *et al.,* 2000).

In a different context, one can find studies on factors that alter pre and post natal human development such as one published by Herrera and collaborators (1997) at the Universidad del Valle in Cali Colombia. Thus, medical institutions have their share of studies that should be of interest to developmental biologists. Such is the case of studies where technical advances of interest to particular therapies are made. This can be exemplified by studies performed at the Centro Internacional de Restauración Neurológica (CIREN) in Cuba and at Centro de Investigaciones of the Universidad El Bosque in Colombia. These institutions developed techniques for *in vitro* culture and novel findings related to stem cells and to cellular plasticity (See Almaguer-Melian *et al.,* 2016, Vickery 2010, Calderón-Martinez *et al.,* 2002). Additional studies that touch upon human development, such as these, can possibly be found by targeting more specific medical journals or health department reports of individual countries. Although, this lies beyond the aims of this review, let me conclude this section with another example of a DB-related health situation that had a profound impact on this region: the Zika epidemic.

In recent years this region saw an epidemic of Zika virus. Being

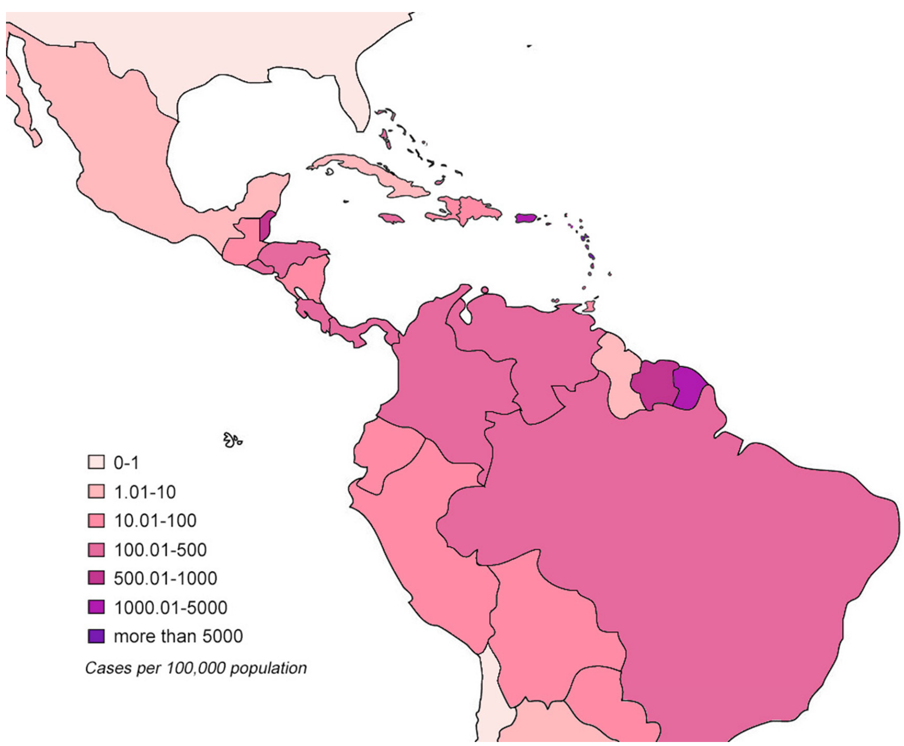

Fig. 7. From 2013 to 2017 Ibero-America suffered a Zika virus epidemic. *(The map shows the countries impacted by 2017). The development of hundreds of children was seriously compromised. Studies are still in progress to determine the mechanisms by which the virus affects embryological development and what are the long term consequences. The data was obtained from the Panamerican Health Organization (PAHO)/World Health Organization (WHO) and represent the cumulative cases as of December 2017.*

a tropical disease, all of the countries in the northern part of South America, Central America and the Caribbean were severely afflicted (Fig. 7). This mosquito-borne virus directly affects the development of the human nervous system, and can cause great damage to the developing fetus. During and following the epidemic, hospitals, health centers and physicians in the region collaborated with outside institutions to study the virus effects on the local population. (Krauer *et al.,* 2017, Yepez *et al.,* 2017, Medina and Medina-Montoya 2017, Peña *et al.,* 2019). Findings from these studies described some of the developmental abnormalities in children born to mothers that were infected with Zika during pregnancy (Sebastian *et al.,* 2017, Rice *et al.,* 2018, Gely-Rojas *et al.,* 2018, Ochoa *et al.,* 2019, Mulkey *et al.,* 2019, Santos-Antonio *et al.,* 2019,). Most important, patient cohorts that were born during this epidemic are being followed in longitudinal studies to determine the long-term effects of Zika infection (Cortes *et al.,* 2018, Wilder-Smith *et al.,* 2019).

New blood

A new generation of researchers is now advancing DB in this region. Many of them are returning from training in top laboratories around the world and have brought their ideas, techniques and enthusiasm to various universities in the region. Others are homegrown, but in this new global era, have established collaborations with scientists worldwide and have benefited from local and international meetings and workshops. As Dr. Alejandro Sanchez-Alvarado says in his interview (Sánchez-Alvarado, in this issue): "*I see talent overflowing from its scientists at all levels: from students to faculty*".

Among the investigators that are setting laboratories in the region we can highlight Dr. Edward Malaga-Trillo at the Universidad Peruana Cayetano Heredia. He has established the zebrafish model to study the molecular components associated with nervous system development. Several young investigators are advancing DB in Ecuador: Drs. Andrés Romero-Carvajal from PUCE (see article by Salazar-Nicholls *et al.,* in this issue), Dr. Ivan Moya at the Universidad de las Americas and Dr. Andres Caicedo at the Universidad San Francisco de Quito. The latter two are probing processes that are common between embryogenesis and oncogenesis. Dr. Moya is returning from a very productive training at the University of Leuven and the VIB Center for the Biology of Disease Center for Human Genetics in Belgium (Moya *et al.,* 2019) while Dr. Caicedo has established his research projects after training at the Université de Montpellier (see Caicedo *et al.,* 2015, Aponte *et al.,* 2017, Luz-Crawford *et al.,* 2019). We also have new investigators advancing DB in Puerto Rico. Dr. Amaya Miquelajauregui, who recently joined UPR, aims to understand brain developmental processes from embryonic to postnatal stages and to characterize the alterations caused by genetic and environmental factors using rodent models of neurodevelopmental disorders. Also at UPR is Dr. Edwin Traverso who is focusing on the role of MUSA1, an F-Box containing protein, on muscle development, using *Xenopus* as a model system. Finally, Dr. Martine Behra at UPR is using the zebrafish model to study the development and regeneration of lateral line cells (Rodriguez-Morales *et al.,* 2020).

Contributions to the DB field are also originating from other fields, particularly from genomics. Take for example the recent triad of publications that makes use of *Heliconius* butterflies for interdisciplinary studies on genetics, evolution and development (Concha *et al.,* 2019, Edelman *et al.,* 2019, Lewis *et al.,* 2019). These investigators also take advantage of the region's biodiversity, specifically the large number of *Heliconius* species and their hybrids in the northern region of South America and the Caribbean. Genomes of different species (and hybrids) are then analyzed to probe the relationship between genotypes and phenotypes. Equally important to highlight is that among the international group involved in these experiments are investigators from UPR, the STRI in Panama and the Universidad del Rosario in Bogotá, Colombia.

Conclusions

It is safe to say that most of the studies in the region have been performed by individual researchers focusing on a particular model system. These investigators are usually isolated within an institution, where few of their colleagues share their interest in DB. Nonetheless, the documented studies represent Developmental Biology gold nuggets which shine some light on developmental processes and contribute toward their understanding. In this context, those individual efforts should be highly commended, as sometimes they represent a solitary light that kept the study of DB alive in a region and usually single handedly in a whole country. Some of these are highlighted in this review.

In closing, we must alert that young investigators still face many perils at their home institutions. For one, returning students who have obtained their degrees from institutions in North America or Europe and choose to continue to work with thesis-related projects will be confronted with few funds, sub par equipment, large bureaucratic hurdles, favoritism and heavy teaching load. This type of environment makes it difficult, if not impossible to advance their research in a very competitive global environment. In several countries, investigators are forced toward biotechnological or applied science projects, with very limited funding options for basic science studies. We have noticed that many are engulfed by administrative and/or teaching duties and slowly drop their research commitments. Legal entangles also hinder investigators development in some countries. For example, in Colombia and in other countries in the region, the same laws that serve to protect the country's biodiversity discourage researchers from studying the native organisms (Prathapan *et al.,* 2018, Wight 2019). Therefore, institutions must not only aim to recruit investigators with the potential to advance the study of DB but also support these young investigators in their attempt to settle and develop a competitive research program that will be an asset to the institution and to the country itself. Young investigators themselves must also recognize the importance of establishing and maintaining a strong network of scientific interactions that will help them in overcoming their scientific isolation. One promising, mutually beneficial strategy to overcome such difficulties consists of establishing international cooperation with universities or research institutes in Europe, as well as in North America. At the same time, we need to underscore the importance of professional societies such as LASDB or IBRO in fostering DB in this region be it by sponsoring Symposia, Conferences, or Workshops and by promoting collaborations.

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