

B IODIVERSITY AND MARINE ANNELIDS: HISTORICAL, ENVIRONMENTAL, AND INDIVIDUAL TRANSITIONS

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ABSTRACT

In this contribution some questions inherent to the study of biodiversity and of marine annelids (mainly polychaetes) from a perspective of historical and environmental transitions are addressed. The origin of the term biodiversity is revised and its quick displacement of the political discourse in favor of sustainable development is briefly commented, although the last one has been difficult to specify and reach. The importance of marine annelids is summarized within a perspective of contemporary environmental crises that have been more severe for the marine realm. The history of the oceanographic explorations is briefly analyzed from the marketing of spices to the discovery of species, and of the transformation of the cabinets of curiosities to natural history museums. A brief review is presented for the museums housing marine annelids, including historical and current specialists and an appendix listing the main publications available of world collections. The relevance of latitude and temperature for explaining the distribution of the species is reviewed including the early establishment of biogeographic regions and provinces, and on the contrasting situation among marine annelid species because most were considered cosmopolitans until the 1980s, when planetary revisions became more frequent. This contribution contains a series of proposals including one for renegotiation and reduction of the burden of external debt payment in each nation, and other medullary aspects as the formation of human resources, the need to upgrade infrastructure and laboratories, to carry out inventories, catalogues or illustrated keys, and to clarify the confusions in the regional fauna, to make studies on speciation, and on the need for having national monitoring programs and actions facing climate change.

RESUMEN

En esta contribución atiendo algunas cuestiones relativas al estudio de la biodiversidad y de los anélidos marinos (principalmente poliquetos) desde una perspectiva de las transiciones históricas y ambientales. Se revisa brevemente el origen del término biodiversidad y su rápido desplazamiento en el discurso político por el de desarrollo sostenible, aunque este último ha sido difícil de especificar o alcanzar. La importancia de los anélidos marinos se concibe desde las crisis ambientales contemporáneas, que han sido más severas en el medio marino. Se analiza la historia de la exploración oceanográfica desde el mercadeo de especias al descubrimiento de las especies, y de la transformación de los gabinetes de curiosidades en museos de historia natural. Se repasan los museos que contienen colecciones de anélidos marinos incluyendo los especialistas históricos y actuales, y se agrega un apéndice con las publicaciones principales sobre las colecciones del mundo. Para explicar la distribución de las especies se revisa la importancia de la latitud y de la temperatura incluyendo el establecimiento de regiones y provincias biogeográficas, y en la situación contrastante en las especies de anélidos marinos porque la mayoría eran consideradas cosmopolitas hasta los años 1980, cuando las revisiones planetarias se hicieron más frecuentes. Se presenta una serie de propuestas incluyendo una para renegociar y reducir la carga del pago de la deuda externa para cada nación, así como otros aspectos fundamentales para la formación de recursos humanos, la necesidad de actualizar la infraestructura de los laboratorios, de realizar inventarios, catálogos o claves ilustradas, y para clarificar las confusiones en la fauna regional, estudiar la especiación, y en la necesidad de realizar programas nacionales de monitoreo y de acciones para atenuar el cambio climático.



Keywords: Taxonomy, polychaetes, external debt, science policy, research.

Palabras clave: Taxonomía, poliquetos, deuda externa, política científica, investigación.



TO THE MEMORY OF DR. PAULO DA CUNHA LANA
(20 APRIL 1956-30 JUNE 2022)

INTRODUCTION

This contribution was generated because of two factors. First, an invitation by some Peruvian colleagues to address the importance of advancing the study of marine annelids in their country. Second, the announcement of the opening remarks by the late Dr. Paulo Lana for the Symposium of Latinamerican Polychaetes, which would include his perspective for future studies on the group.

My first scientific popular note dealt with the importance of polychaetes in the marine realm (Salazar-Vallejo 1981a). I had just finished my Biologist degree thesis on the collection of polychaetes of the University of New León (Salazar-Vallejo 1981b), and I did this once the collection was organized, which by then it contained 74 species, 59 genera and 26 families. This shows that I have had an interest in the thematic of the Peruvian meeting during the last 40 years. At the same time, I thanked the opportunity to review some relevant background information, and address other issues that could empower the study of biodiversity and polychaete taxonomy. In this area of science policy, during the last 20 years I have tried to promote discussions and specific actions, including a brief 6-yr plan for advancing science (Salazar-Vallejo 2001).

I will present below the general ideas in a frame of transitions. The Cambridge Dictionary defines transition as a noun: a change from one form or type to another, or the process by which this happens; or as a verb: to change, or make someone or something change, from one form or situation to another. A change is involved, indeed, and this is precisely what I hope to emphasize in this contribution. Then, I will emphasize the changes that we can, and we should do as individuals (even as nations) for the study of biodiversity, although I cannot offer precise recipes, some experiences or concrete proposals will be introduced.

In the same fashion, I will also refer to the importance of environmental transitions to understand the changes in the regional biotas as the ecological horizon (Salazar-Vallejo et al. 2014), defined by temperature, salinity and substrate, are being modified. The final part of this note is to propose a series of action plans, to supplement those proposed by Tarazona et al. (2003) and Aguirre & Canales (2017) especially for biodiversity research in Peru.

I will emphasize that the relevance of temperature and latitude for explaining the species distribution was early recognized, and that contrary to what was the case for other benthic invertebrate groups, polychaetes were considered anomalous because many species were apparently cosmopolitan. This idea became deeply incorporated in faunistic studies up to the 1980s, when we began making direct comparisons with type material (revisions). This is a critical transition (personal and institutional) that might be difficult to carry out but is very important for advancing knowledge.

In science policy, I will comment on the inherent problems for all nations because of the burden of paying their external debt and the need to reduce the payment for having additional resources to invest in improving food production and supplies, education and health services and, of course, to strengthen the structure and function of science.

My conclusions are: 1) the marine annelids are ecologically outstanding because of their biomass, abundance, and ecological relevance (and for reducing our ignorance). 2) although the interests in the exploration of biodiversity were intensified by commercial activities, once nations attained a sort of economic freedom the interests changed towards knowing little relevant organisms for direct marketing, because of an increase in other types of values (aesthetic, recreational, knowledge); and 3) the biodiversity crisis is not new, despite its current severity.

BIODIVERSITY

HISTORY

Biodiversity is an integrative concept that was proposed and popularized by the formicologist Edward Wilson (Wilson 1988) to understand structural and functional aspects of the organisms in a defined space, their genetic variability, the ecosystems that conform, and the landscapes or regions where they occur, including the ecological and evolutionary processes involving them. The popularity and success of the concept are manifested because in Costa Rica the National Institute of Biodiversity settled down in 1989, with private funds and with the main objective of generating biological collections, whereas Mexico generated a trusteeship to establish the National Commission for the Knowledge and Use of Biodiversity (CONABIO after its Spanish name) in 1992. CONABIO's largest successes center on databases of Mexican biota, and a great number of books on the same subject. We were lucky enough to generate a book on Mexican marine and coastal biodiversity (Salazar-Vallejo & González, 1993) that was recently improved by a series of volumes carried out by many authors, and also endorsed by CONABIO.

It is interesting that in the ecological processes included in the biodiversity concept our interaction with nature was also considered, but our use of the natural resources was likely not emphasized enough. It should not be surprising that another integrative concept, 'sustainable development,' was more quickly incorporated into the political discourse. The concept arose in 1987 after the Report of the World Commission on the Environment and Development, better-known as the Brundtland Report because it was led by the Norwegian Gro Harlem Brundtland, president of the commission (Naciones Unidas 1987). The commission concentrated on five items: population and human resources, species and ecosystems, energy, industry, and urban challenge. Thus, although the report considered that many species were at risk and that the situation deserved primary political concern, species were considered as resources for development. The commission characterized the concept of sustainable development "as the one that guarantees the necessities of the present without decreasing the possibilities of the future generations to satisfy its own needs." The difficulties for bringing the concept into reality were noted early. Furthermore, and even a special number of the journal *Ecological Applications* conjugated several perspectives and recommendations that were not followed, emphasizing the diverging perspectives of scientists and decision makers (Salazar-Vallejo & González 1994). This conflict between proposals and reality was noted in Mexico regarding tourism development (Salazar-Vallejo & González 1995).

In fact, there is a long history of divergence between environmental concerns and recommendations given by scientists, and the resulting negative consequences of factual natural resources management led by decision makers (Diamond 2005). For example, the proposals by Meadows et al. (1972) were regarded as alarmists and

were not followed, and probably not fully understood. Regretfully, most provisions have been shown to be accurate (Hall 2022). We must be optimistic and become more involved in changing the current conditions, but we cannot be naïve by expecting the current problems to be solved without additional efforts. We must do it by ourselves.

The importance of the problems currently faced by humanity cannot be underestimated, such as health preservation and improvement, education, food supplies, or access to drinking water and sewage treatment. Further, acute famine or drought crises in many countries are becoming chronic in several regions of the world, rendering obtuse any call of attention for dealing with other human concerns. In fact, in an economy in crisis, in any nation, there is usually a very limited or no economic freedom for including other pending issues. I will return later on to this matter, especially because the burden of external debt suffocates the economy of many countries, but let me turn to other issues to provide a more comprehensive background for the following issues in this contribution.

MARINE ANNELIDS

Annelids are one of the main metazoan groups living in the marine benthos; although the group includes some representatives in continental waters and even humid tropical forests, most of the more than 21,000 described species lives in the sea (Read, 2019). Marine annelids were considered as equivalent to polychaetes, separated from other groups such as echiurans or sipunculids, as well as the more traditional classes of oligochaetes and leeches. Recent studies show that these divisions are not supported by the information provided by genetic markers, such that polychaetes is currently used as a colloquial term and not as a taxonomic group, like it was in the past, although for didactic purposes this distinction is still widely used (Harris et al. 2021).

Although we have written records about marine organisms from Aristotle, a recent estimate indicated that 90% of marine species could be undescribed (Mora et al. 2011). The estimate also included the time and cost inherent in finishing our task: we would need 1,200 additional years on one hand, and over the other hand, if we take into account that describing a new species amount to about 50,000 US dollars, we would need about 360 thousand millions of American dollars. Even if these figures are taken in half, the number of undescribed species would still be overwhelming, and finding the estimated funding for describing them is so high that it cannot be expected to be available for taxonomists.

BIODIVERSITY CRISIS

The expectation for being able to continue doing taxonomy during the next 12 centuries, and to get the required funding seems unreachable, especially because the transformation of the planetary naturalness has reached such a negative point that many believe we are in the sixth mass extinction, with a current extinction



Figure 1. Changes in size and abundance of fishes in Florida in 50 years: 1957-2007 (reproduced with authorization: Corey Malcom, Florida Keys History Center).

rate of 7.5-13.0% (Robin 2011, Cowie et al. 2022). In the American continent, the most drastic environmental changes introduced after the arrival and success of the European expansion, and later conjugated with the American pattern for the excessive use of natural resources began to be noted from the 1800s (Jackson 1997). We can easily extrapolate this to the marine realm to understand that marine ecosystems have been chronically impoverished.

Elton (1927) proposed that the structure of the abundance of the organisms in the different trophic levels resemble a pyramid, with the organisms in decreasing numbers coincident with an upward movement in successive trophic levels. Probably a less well-known fact is that the same author warned that the great abundance of any animal species does not imply an escape from extinction (Elton 1927: 113), but numbers have guided our extraction quotas, regrettably. Thus, the loss of the top predators implies that the pyramid is truncate, and the disappearance of top predators has been referred to as ecological truncation. It is well known that there are drastic effects in the ecosystem, and this approach has been used for general analysis (Trebilco et al. 2013).

Environmental changes are better documented in continental ecosystems. For example, the distribution of the medium-sized predators, or meso-predators, has increased by 60% in the United States during the last two centuries (Prugh et al. 2009), mainly after the disappearance of wolves, cougars, and jaguars. Although we have different quality and duration of statistics, Pacoureu et al. (2021) showed that the populations of sharks and rays had decreased by 71% from the 1970s. While Pinsky et al. (2019) emphasized that marine ectotherm species are more susceptible to global warming than terrestrial ones, because the impacts on marine biotas are larger.

Two publications by Daniel Pauly deserve to be commented for understanding the disaster of marine fisheries in the world, and for supplementing the panorama of changes for marine organisms. In the first one, Pauly (1995) coined the concept of the 'shifting baseline syndrome' and indicated with it that the perception that different generations of fish biologists

gather by generating their own database, avoid taking into account any anecdotic information, critical for indicating earlier accounts of fish size and abundance (Fig. 1), and he added two stressing statements: 1) off the Atlantic Canadian coast the fish biomass had decreased to less than 10% of what it was two centuries ago; and 2) the top predators of the past trophic networks collapsed because they should have smaller fecundity and resilience before fishing than the species we now exploit. In the second note, Pauly et al. (1998) indicated that fisheries have been operating at descending levels in the trophic networks, as a consequence of the populational depression of top predators, and that this implies that the production can be increased initially (as it was often the case), followed by a halt and then becoming stagnant or collapse.

TRANSITIONS

HISTORY: SPICES AND SPECIES

The consumption of spices and their marketing is as old as human populations, especially in the region from India to Indonesia. For example, towards year 2000 before our era the Route of the Cinnamon existed among Indonesia, Sri Lanka, Madagascar, and eastern Africa (UNESCO 1993). Spices popularity and their use as flavorings, aromatizing, perfume, or medicines reached the Roman Empire with the Route of the Silk, about 100 years before our era, and this route had a continental part and a marine one (UNESCO s/a). The marine route reached the Mediterranean through the Persian Gulf or the Red Sea, and in both paths, tribute was charged by the Arabs, which often increased the prices of the spices a lot; they were sometimes worth their weight in gold.

In the XV century the Age of Exploration began in Europe, and this time has also been called the Age of Discovery. It started mainly to find a shortcut to those spice-producing regions, then known as the Indies. This was a consequence of the fall of Constantinople in 1453 before the Ottoman Empire, which interrupted the routes through land (Cartwright, 2021). Spain and Portugal undertook the search for a marine route, Christopher Columbus crossed the Atlantic in 1492 and

he met with America, while Bartolomé Dias in 1488 and then Vasco da Gama in 1497-1499 followed the African continent and although Dias hardly surrounded Good Hope's Cape, it was da Gama who arrived in India. The great wealth that these two empires reached was due to the exploitation of the spices from India to Indonesia for Portugal, and the gold, silver, and other products of America for Spain, including corn, tomato, beans, pumpkins, and potatoes (Mann 2011; Grose 2019).

However, the biological exploration was not headed by the Spaniards or Portuguese. Rather, the domain of marine marketing changed to Dutch, French and English fleets, and these latter countries were those that carried out most of the expeditions for searching species, no longer for spices. The transition of the domain of the seas was made after the successful introduction of tea to Europe and America (Rappoport, 2017; Karlsson, 2022), and during the Golden Age of Piracy (1650-1726), when the governments of France, Holland and England strengthened their fleets and encouraged the attacks to the merchant ships in the Atlantic (RMG, s/a). There are other important features that must be considered. For example, some regard that the defeat of the Spanish Armada in England in 1588, besides the 80-year war against Holland, from 1568 up to 1648 (Johnson, s/a a), also damaged a lot the Spanish treasure. The advances of Dutch and Englishmen societies were initiated and maintained by their companies of marine marketing: East Indies Company, settled down in 1600, and the Dutch East Indies Company, established in 1602 (Clulow & Mostert 2018). The British company had an army twice as large as the English Army (Johnson s/a b). These nations retained their success from the 1700 after the succession war in Spain (1701-1714), that later depleted the Spanish treasure. It is interesting that although the great majority of pirates were male, some women also participated (Vencel 2018).

SCIENTIFIC EXPEDITIONS

Wikipedia (s/a c) listed 70 scientific expeditions from 1735 to 1899. Among them, and despite the fact that there were several involving several countries, it stands out that the British carried out 29, the French 24, the Russian 5, the Americans 3, the Italians 2, and with one each Germany, Austria, Belgium, Denmark, Spain and Sweden. The main objectives included territorial expansions, and samples of organisms were usually brought back to the corresponding countries. The impact of their results on the knowledge of marine annelids depended on the inclusion of people collecting and later processing and identifying the organisms. This explains why we find familiar the names of some expeditions such as those made with the ships *Belgica*, *Challenger*, *Discovery*, *Eugenie*, *Galathea*, *Gazelle*, *Novara*, *Valdivia* and *Vittor Pisani*. The Expedias note did not include the expeditions of the *Albatross* of the United States which also had outstanding results for our research field (see Read 2019 for more details on this).

In the XX century, some expeditions by famous research vessels stood out: *Atlantis*, *Calypso*, *Discovery*, *Galathea*, *Investigator*, *Meteor*, *Polarstern*, *Siboga*, *Snellius* and

Vityaz, as well as the trips carried out by the Paris Museum commonly called Musorstom Expeditions (Salazar-Vallejo 1999), and the many multinational expeditions to the Antarctic. Some other data can be seen in the compilation by Wüst (1964) for the period 1873-1960, as well as some other notes on the history of oceanography (Anon. s/a). A large part of those materials was processed, but interestingly, another significant part continues without being fully processed and they are deposited in several museums. As it has been emphasized repeatedly, a large part of the planet's biodiversity has already been collected, but it continues without being studied, such that the new discovery expeditions are taking place in the museums of the world (Salazar-Vallejo, 2018).

CABINET OF CURIOSITIES TO MUSEUMS AND SOCIETIES

A glance at the history of the botanical gardens and museums of natural history in Europe will facilitate understanding the above generalization. The medicinal use of plants is indeed as old as humanity, but the interest to cultivate exotic, medicinal plants or not, paved the road for non-utilitarian curiosity and research. Maintaining plants of different regions for their beauty or other properties, implied an interesting transition in the perception of nature, and some interesting developments for botanical gardens were carried out through universities or research societies.

The oldest botanical garden was established by the University of Pisa in 1544, and by 1595 it had a museum of natural sciences (Wikipedia, s/a a). Other Italian gardens of the XVI century were settled down in 1545 (Padua; Florence) and 1568 (Bologna). The first one in Spain was in Valencia (1567), and then would come later those of Leiden (1590), Montpellier, and Heideberg (1593). Others that deserve to be mentioned are the ones in Paris (1635), and those of Amsterdam (1638) and Uppsala (1655) because Linnaeus worked in both. Another showcase of the war havocs is that the gardens of Madrid and Lisbon were installed much later; the first one in 1755, and the second in 1873.

The equivalent initiative of botanical gardens for the study of animals is the zoological garden; however, the early manifestation of the curiosity for exotic things, including minerals and organisms or their parts, were the cabinets of curiosities or rooms of marvels (Wikipedia s/a b). Their collections sometimes promoted the establishment of some natural history museums. The oldest cabinets are considered Dutch (1520), but the first one documented was in Naples (1599).

Although from the Renaissance, the feudal gentlemen, or other members of the royalty, usually included artists, engineers, inventors, and natural historians, the scientific societies arose in the XVII century, being the English (1660) only six years older than the French (1666). However, what are regarded as the first scientific journals were launched by these academies in 1665; despite the almost 400 years since then, scientific articles have changed little as tools for scientific communication (Gibson 1982).

Many cabinets remained private, but large, long-term collections often turned out to State institutions as monarchies were transformed into republics. As for the museums of natural history (Farrington 1915), personal initiatives continued to be very significant; first, by generating collections or by gathering funding, and second, by moving into founding museums. The doctor and Irish naturalist Hans Sloane generated great wealth thanks to the commercial success of selling as candy the mixture of chocolate with milk and sugar, and he transferred his huge library and collections made in Jamaica to the Museum of Natural History of London (1759). James Smithson, an English that never stepped on the American continent, inherited its fortune such that an academic entity could be settled down in the United States for impelling knowledge; with their inheritance money the Smithsonian Institution was established, and now includes, among others, the National Museum of Natural History in Washington (1846). Regarding the quest for funding, Louis Agassiz negotiated, sometime before the Civil War in the United States, 200,000 dollars to establish the Museum of Comparative Zoology in Harvard (1852), then it was consolidated in 1867 with the contribution of 150,000 dollars by George Peabody, and another similar amount for establishing another museum in Yale. In the United States, some academies of sciences also impelled the establishment of museums, such as that of California, in San Francisco, or the one of Philadelphia, whereas others have been established by municipal or county governments such as those of New York, and Los Angeles.

Other important museums were established by the corresponding Empires, such as the museums of Natural History of Amsterdam and Leiden, Berlin, Brussels, Copenhagen, Hamburg, Paris, and Saint Petersburg. In most cases, the transition of empires to republics was not as turbulent as to suspend them, and they continue active up to now.

The importance of the collections depends, in good measure, on the number of specimens that they store (Fig. 2). In that sense, in decreasing order the list would be Washington, London, Paris, New York, Berlin, Los Angeles, Chicago, Harvard, San Francisco, and Sydney (Novacek and Goldberg 2013).

For the marine annelids, the above hierarchy could be modified by considering the deposit of materials made after expeditions, as well as the permanency of expert taxonomists that have enriched each collection, and generated publications after their materials. The names of the involved authors will indicate the relevance of each collection and they go in alphabetical sequence for the city where the collections are now. Appendix 1 includes a list of the available publications dealing with these collections.

Berlin (and Wroclaw, Poland) contains the materials of the oldest German expeditions, studied by Ernst Ehlers and Adolph-Edouard Grube. In Berlin the curator is Birger Neuhaus. In Wroclaw they are limited to the material processed by Grube, who became the museum director; the responsible person is Jolanta Jurkowska.

Copenhagen stores the materials studied by Grube and gathered by Örsted and Mörch in the American coasts, as well as those that were studied by Elise Wesenberg-Lund, Jørgen Kirkegaard and Danny Eibye-Jacobsen. The last one is the curator of the collection.

Stockholm contains the materials studied by Johan Kinberg and other Swedish specialists that followed him. The curator is Lena Gustavson.

Hamburg contains some materials studied by Grube, but mainly those published by Hermann Augener and Gesa Hartmann-Schröder. The curator is Jenna Moore.

Harvard maintains the materials that Augener and Ehlers studied after the *Albatross* expeditions in the Great Caribbean. The curator is Adam Baldinger.

Leiden received the materials of the former museum in Amsterdam, The Netherlands; these two collections contain the materials of the *Siboga* expedition in Indonesia, partially analyzed by Rutgerus Horst, and what could be the most important collection of serpulids, organized and studied by Harry ten Hove. The curator is Hannco Bakker.

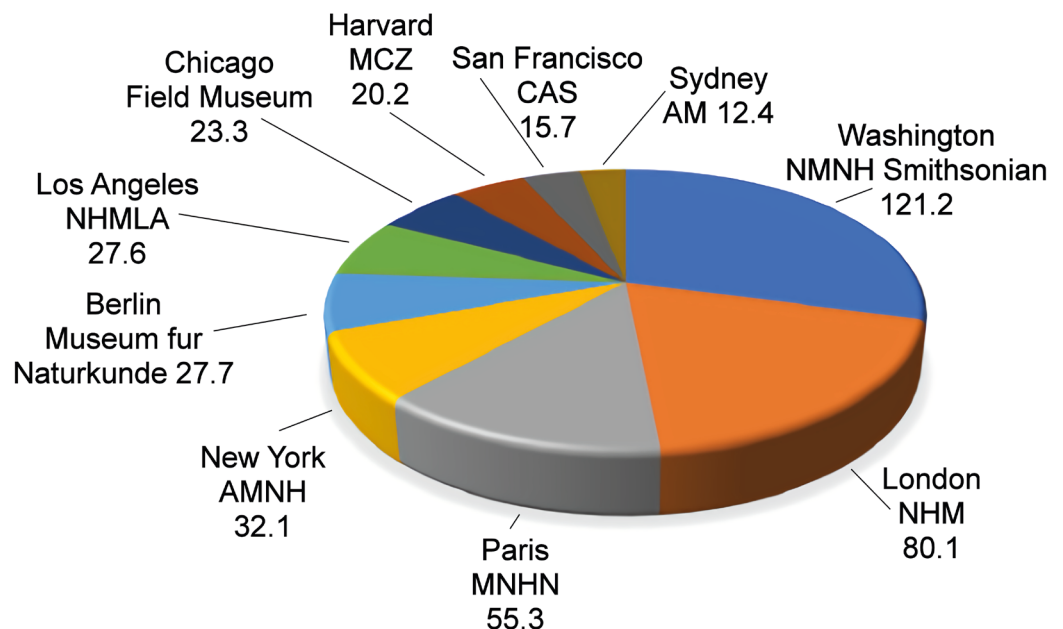


Figure 2. Largest museums in the World after the specimens they contain (in millions) (redrawn after Novacek and Goldberg, 2013).

Los Angeles contains the abundant materials studied by Olga Hartman and Kristian Fauchald, mainly along the Eastern Pacific, although they also have large collections of other oceanic basins. Their current staff includes Leslie Harris and Kirk Fitzhugh, both have been very generous by supporting Latin American students during their research visits there.

London contains the collections carried out by English ships and studied by William McIntosh, Frank Potts, Cyril Crossland and Charles Monro, and there were two specialists for many years: Alex Muir and David George. The curator is Emma Sherlock.

Paris contains most of the materials studied by Pierre Fauvel, although the collection of slides remains in Angers; and the materials of Armand de Quatrefages and those of the Baron de Saint-Joseph, among others. Charles Gravier divided his time between corals and polychaetes. The curator is Tarik Meziane.

Saint-Petersburg, Russia, includes the materials of the Russian specialists from Annenkova and Zachs, and there used to be three specialists working simultaneously: Pavel Ushakov, Galina Buzhinskaya and V.G. Averintsev. The non-type materials and others resulting from the expeditions of the *Vityaz* and other Russian ships are in Moscow, in the Shirshov Institute of Oceanology; it contains the largest amount of deep sea specimens from many localities around the World, some of them were studied by Raisa Levenstein. The curator in Saint-Petersburg is Sergei Gagaev. The contact in Moscow is Andrey Gebruk.

Sydney includes the biggest collections of Australian polychaetes, and many from adjacent regions. Patricia Hutchings was the curator for many years, and she is now accompanied by Lena Kupriyanova; the curator is Alexandra Hegedus.

Uppsala contains the materials of the species described by Arwidsson, Eliason, Hessel and Johansson. The contact is Erica Mejlon.

Vienna includes part of the materials of Lwdvig Schmarla, and those studied by Paul Langerhans, Emil von Marenzeller and Werner Katzmann. The curator is Pedro Frade.

Washington received the material of all the expeditions made with US federal funds including the materials analyzed by Ralph Chamberlin, or Aaron Treadwell, and there used to be three simultaneous curators: Marian Pettibone, Meredith Jones and Kristian Fauchald. Karen Osborn is now in charge of the collection.

Yale Peabody Museum (New Haven) contains the type material described by Addison Verrill and Katherine Bush, including the materials of Bermuda. The contact is Eric Lazo-Wasem.

I will finish this section by commenting three outstanding questions. The first one, type material is unrecoverable such that if we decide to study it, we must be extremely

careful when manipulating or observing the organisms, to avoid further damaging them. Second, the availability of museum materials has been diminishing, such that it is advisable to concentrate type material in one or a few institutions to make an optimal use of time and available funds; however, Germany, France and Holland have incorporated natural history museum material as national heritage, rendering it more complicated their loan overseas, the institution, or both. Third, most museums face financial problems, which have impacted their staff, growth or maintenance of their collections, despite a widespread acknowledgement of their relevance or importance (Naggs 2022; Rohwer et al. 2022). Although there are some signs of improvement since there are currently some funding available for postdoctoral scholarships, and funds for making research visits, this is far from being generalized.

An additional question is that the importance of the type material depends on the need to compare type or non-type specimens with recent specimens to solve possible confusions. In our countries, we need regional reference collections for the corresponding biota, and a national museum to harbor type materials of the species that current or forthcoming taxonomists will describe. There is no Mexican Museum of Natural History including polychaetes, such that our collections depend on the institutions harboring them, and, because of their content, most collections are regional.

ENVIRONMENT

The Greeks Parménides and Aristotle classified the planet into torrid or tropical, temperate or frigid areas according to their latitude. The knowledge extended soon in connection with the distribution of plants in the continents, and the relevance of temperature was recognized including the type of soil, the slope or elevation, and the insolation. Among these factors, the easiest one to measure was temperature, such that it is not surprising the relevance of temperature has had to not only explain the distribution of plants, or climate, but the distribution of biotas over the Earth. This is very well-known. What might not be so well understood is that our perception of this fact is hardly 200 years old, since there was not so much clarity before in the geography, nor were there enough, or sufficiently coordinated, meteorological stations, producing information as to generate a map of the world. Alexander von Humboldt was the first one to generate that synthesis. First, he carried out, with Aimé Bonpland, a study on the distribution of plants (de Humboldt and Bonpland 1805), then he coined the concept of isotherm in 1816, and he communicated in 1817 that he would make a compilation of the available information, but this task took him 30 years. He published the map of isotherms of the world in 1845 (Klein 2018).

The extrapolation to the animals and the distinction of geographical kingdoms came one decade later. Sclater (1858) analyzed the distribution of birds, and then Wallace (1876) incorporated that of mammals and other animal groups and presented the biogeographic regions that we know and continue to use (Wills 2020). Another

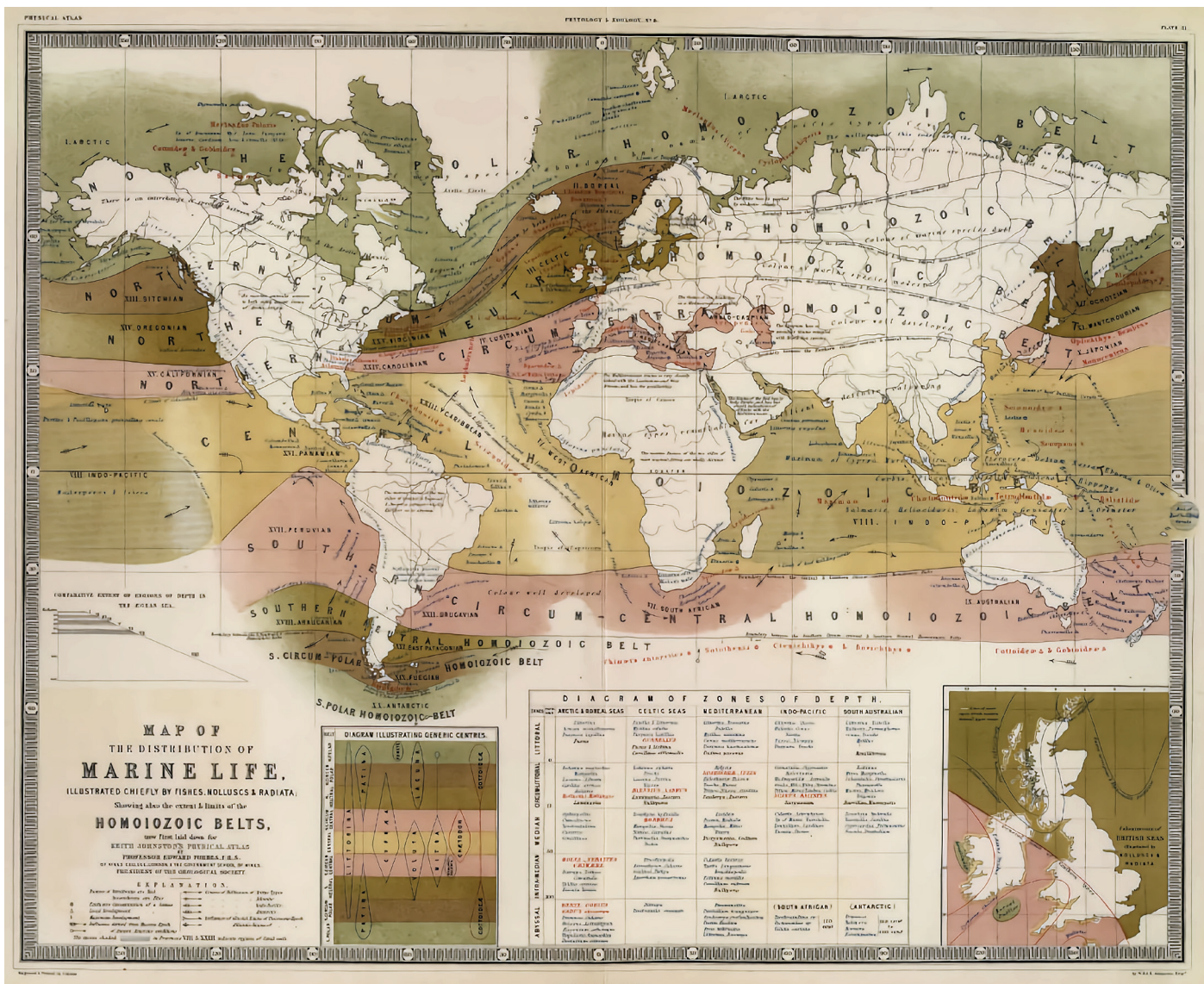


Figure 3. Map made by Edward Forbes (1856) with the distribution of marine life and the homoiozoic belts along the planet, after the presence of fishes, molluscs and radiates (<http://www.davidrumsey.com/maps940057-24718.html>).

less well-known fact is that Forbes (*in* Johnston, 1856) compiled the distribution of the marine fauna (fish, mollusks and radiates) in belts in a map (Fig. 3), and that Woodward (1856) presented the division in continental or marine provinces that he defined by having 50% of exclusive (endemic) species, based on the distribution of mollusks (Hedgpeth 1957: 360). Some other historical issues are available elsewhere (Ebach 2015), but my intention here is to show that the distribution of several groups of marine organisms was clearly understood during the second half of the XIX century.

It is interesting that de Quatrefages (1864, 1865) considered that marine annelid species had a restricted distribution. However, despite including an enormous amount of information in his later monograph (de Quatrefages 1866), he did not dare to present a map indicating regions or provinces in the planet (Salazar-Vallejo 2020). In fact, there were no similar efforts made by specialists of marine annelids, and despite the available evidence of the restricted distribution documented for marine mollusks, Fauvel (1925) rejected it for marine annelids, and his perspective was accepted by his contemporaries. However, de Quatrefages ideas were openly rejected and severely criticized by Claparède (1867) and despite the defensive arguments provided by de Quatrefages (1868, 1869), there was a

widespread disdain for his *opus magna*. Not surprisingly, many researchers introduced European species group names for distant faunas, sustaining the idea of widely distributed species.

Fauvel's ideas could be summarized in two parts: 1) the species that have been described as different from other ocean basins are the same as those present along French seas if organisms of similar size are compared; and 2) the species of the Indian Ocean are also present in western Africa and in both tropical coasts of America. Consequently, most marine annelid species seemed cosmopolitan, and in following this idea or its derivation incorporated into faunas or catalogues for some countries, there lies the explanation for the presence of Mediterranean, Scandinavian, South African, and even Polar species names in the faunistic lists of some tropical American countries.

Peru is interesting regarding its faunistic lists. The influence of Gesa Hartmann-Schröder was acknowledged by the late Dr. Juan Tarazona, since in his list of secondary species (Tarazona 1974) only one of the publications by Olga Hartman on tropical Eastern Pacific polychaetes is incorporated, and two by the German specialist. I mean, the polychaetes sampled during the series of expeditions of the Allan Hancock Foundation with their ships *Velero III* and *Velero IV* (Fig. 4), which

sampled from southern California to Peru, although there were not many stations in the latter.

By the way, the perspectives of these distinguished polychaete specialists could not be more divergent; Hartman considered that many species were cosmopolitan, whereas Hartmann-Schröder apparently regarded most of the species as having restricted distribution (or were undescribed). On the other hand, in the study of the rocky shore fauna of Lima (Paredes et al. 1999), 30 polychaete species were listed and at least 6 records are anomalous for that region.

In fact, Hartman showed a peculiar tendency regarding the proportion of widely distributed species. She considered that the fauna of the north Pacific could include less than 2% of widely distributed species (Hartman 1955: 43). A different perspective was shown by Marian Pettibone in her study of New England species; 182 species were included, with 103 species being not limited the North Atlantic, but rather they were regarded as present in at least two major world ocean basins, meaning 57% of the total species (Pettibone, 1963). This large percentual difference between the north temperate faunas of the Eastern Pacific and Western Atlantic could be the reason why Hartman changed her perspective since, in the Atlas of the polychaetes from California (Hartman 1968, 1969), the proportion of widely distributed species was modified to 34%. On the other hand, among Panamian polychaetes the widely distributed species fraction was 36% (Fauchald, 1977).

The cosmopolitan species perspective was modified from the mid-1980s. Faunistic and baseline publications were continued (as they will certainly do for a long time). However, some specialists took a different path by making revisions, and clarifying confusions, especially for some species having anomalous records in different environmental

conditions from the ones where they had been originally described. Another relevant factor for promoting the transitions towards making revisions was the start of the international polychaete conferences that began in Sidney, Australia (Hutchings 1984). Hutchings and Kupriyanova (2018) made an extended discussion on this subject and interested parties should consult it for further details.

We have already commented on the importance of taxonomic revisions (Salazar-Vallejo 2018, 2019; Salazar-Vallejo and González 2016, 2020). However, because of the pressures and needs for publishing brief documents, and because this type of publication will continue dominating the world taxonomic scenario, we should remember Fauchald's reflections (Fauchald 1989: 749):

"A significant fraction of current papers are routine descriptions of a few new taxa, usually with a review paper as authority for the separate status of the new taxa; the material examined is minimal and comparison with types of previously described species is rare ... Detailed and rigorously performed reviews of previously described taxa are lacking for nearly all polychaete families and very few are now on the horizon. Most of the investigations in which the bulk of new material is collected have poorly, or inappropriately defined, goals; however, one requirement runs through most of them: No matter what the stated purpose of the investigation is, the organisms collected must be identified to species. This requirement forces the researchers to make rapid, often incorrect decisions. A careful definition of study goals would leave both ecologists and polychaetologists happier and the few polychaetologists working full time on polychaete taxonomy less overwhelmed."

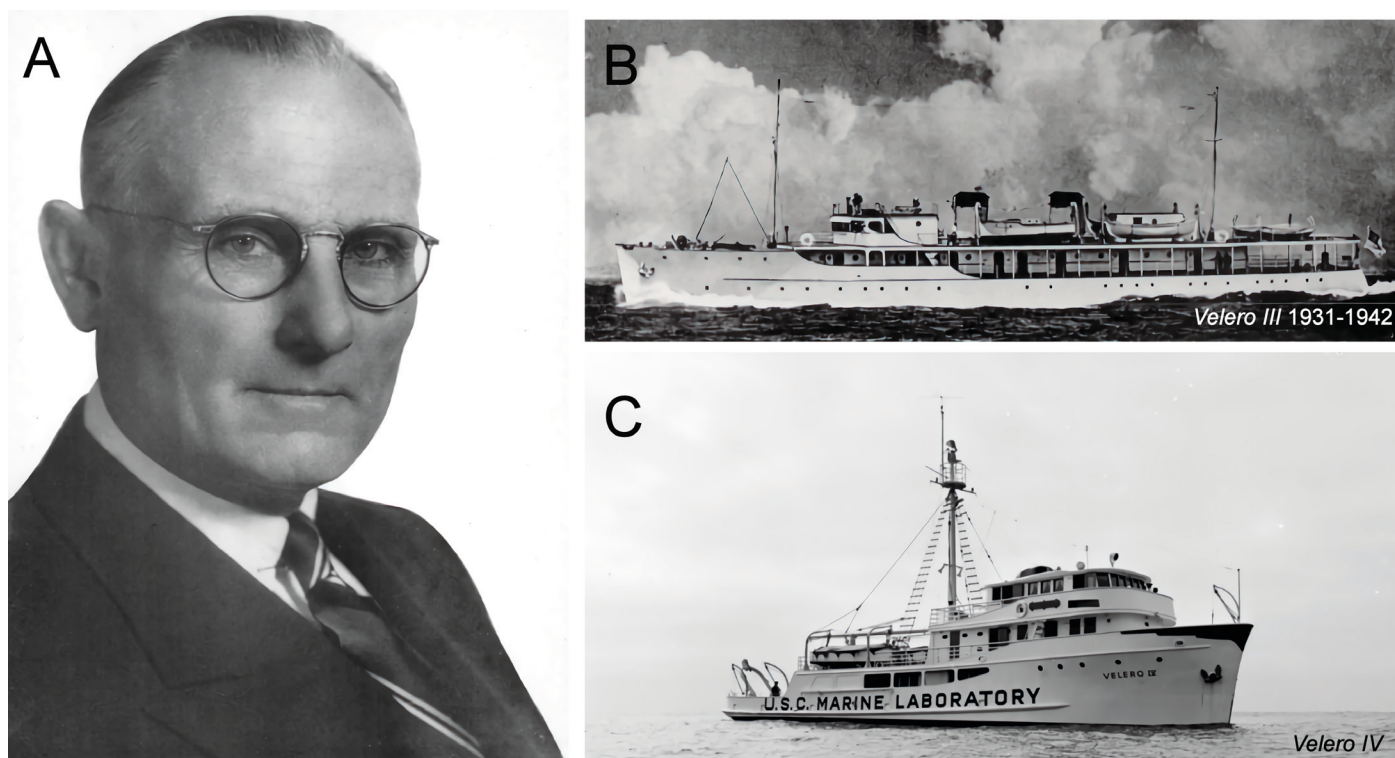


Figure A. Allan Hancock. **B.** Velero III. **C.** Velero IV, research vessels belonging to the Allan Hancock Foundation, University of Southern California, used for sampling from California to Peru (photo source: A, Fraser, 1943; B, C, <https://library.ucsd.edu/dc/object/bb43355540>).

PROPOSALS AND RECOMMENDATIONS

As indicated above, this is the series of proposals and recommendations for supplementing the syntheses by Tarazona et al. (2003) and Aguirre and Canales (2017). Some transitions or recommendations can be carried out for the interested parties in a personal way. However, the most important ones must stem from well-planned and organized collective strategies by institutions or nations, including a time schedule beyond political times (Salazar-Vallejo et al. 2007, 2008). Then, two fundamental aspects must be considered for empowering these transitions: the economy, especially actions for relieving the burden of external debt payments and plans for the future.

The current situation regarding the burden of paying external debt for all nations is so remarkably delicate that it has been regarded as a megathreat (Roubini 2022). The World Bank and the International Monetary Fund have prepared a strategy that we should have in mind for improving the current conditions, and it consists of four steps in what they denominate the Common Framework (Estevão 2022) wherein countries should:

1. "establish a clear timeline for what should happen when in process: the creditors committee, for example ought to be formed within six weeks.
2. suspend—for the duration of the negotiations—debt-service payments to official creditors for all Common Framework applicants.
3. assess the parameters and processes of the comparability of treatment and clarify the rules for its implementation.
4. expand the Common Framework's eligibility requirements, which are currently limited to 73 of the poorest countries. They should be expanded to cover other highly indebted and vulnerable lower-middle-income countries as well."

Fulfilling the conditions of paying the external debt implies a serious economic bleeding for every country because it consumes a large part of the national treasure, and this leakage has widespread repercussions, including the disinvestment in science (Rodríguez-Gómez 2021, Torres-González 2022). Certainly, now that the door is open for renegotiations, any process for alleviating this must be well-organized. The cancellation would be the best outcome, but it will be difficult to carry out (Anon. 2022). Consequently, national negotiators should point to only covering 50% of current annual payments such that independently of the national growth in each country, or of the success of their tax collection, the released money would help fulfill sharp and chronic needs. Then, the first proposal must be to establish a working group in the ministries or corresponding state secretaries, with an eye toward arriving at this type of agreements with international banks. If this type of initiative prospers, there will be additional resources to assist many other pending national issues, including the development of science.

The current Mexican situation can be illustrative. We currently have an inflation rate of slightly over 8%. The national budget for 2023 will exceed 8 trillion Mexican pesos and the distribution shows interesting trends (Fig. 5). For example, the Secretary of Education (SEP) will have an increment of 7%, the same as that for the Navy (SEMAR), while the Secretary of Health (Salud) will receive an increment of 5%, and the Army (SEDENA) and the Council of Science and Technology (CONACYT) will have increments of 4%. The most spectacular increments are expected in the Secretary of Tourism (Turismo) with 115%, that of the well-being (Bienestar) with 32% that includes the pensions to seniors and unemployed citizens, and that of Government (SEGOB) with an increment of 22%. Now the cost of paying the external debt has risen 9.1% and it is estimated to be 869,000 million Mexican pesos. This means, roughly, 10% of the national budget for 2023, and the quantity widely overcome investments for education and health combined, both essential for any country, and the cost of the external debt also overcomes what will be dedicated to education and well-being.

Of course, since we are scientists, not politicians or decision makers, the recommendation must point out to understand the changing conditions of world banks and push our politicians to move forward for releasing federal money for empowering critical areas.

The second recommendation is establishing a program of national development, without committing it to political parties or the duration of the presidencies or congresses. The program must include optimizing education and health services, and improving the labor market. As part of this development program, the education or science ministry must take charge of the program corresponding to higher education and scientific research. A program like this would fulfill the needs pointed out by Tarazona et al. (2003) and Aguirre and Canales (2017), and to incorporate some supplementary aspects, especially the development of academic research groups to attend regional and national research problems.

Of course, the perspective of the marine biodiversity will go bound with other more general initiatives about food supplies, health and education services in each nation; however, those interested in each topic or subtopic must prepare a long-term perspective trying to delineate what the desirable conditions would be for the future and how to reach them, so that they commit with the UNESCO initiative for the ocean sciences decade for sustainable development (IOC 2021). The economic improvements will allow us to reach the wanted future, and although we have already mentioned the matter, it is worthwhile to reiterate it.

HUMAN RESOURCES

The best incentive to promote interest in science among young students is that jobs are available. Then, it is advisable to consider recruiting in a progressively adjusted proportion, such that in 20 years, only *la crème de la crème* (10-20% of the PhDs available) would be hired to carry out research activities. This means that

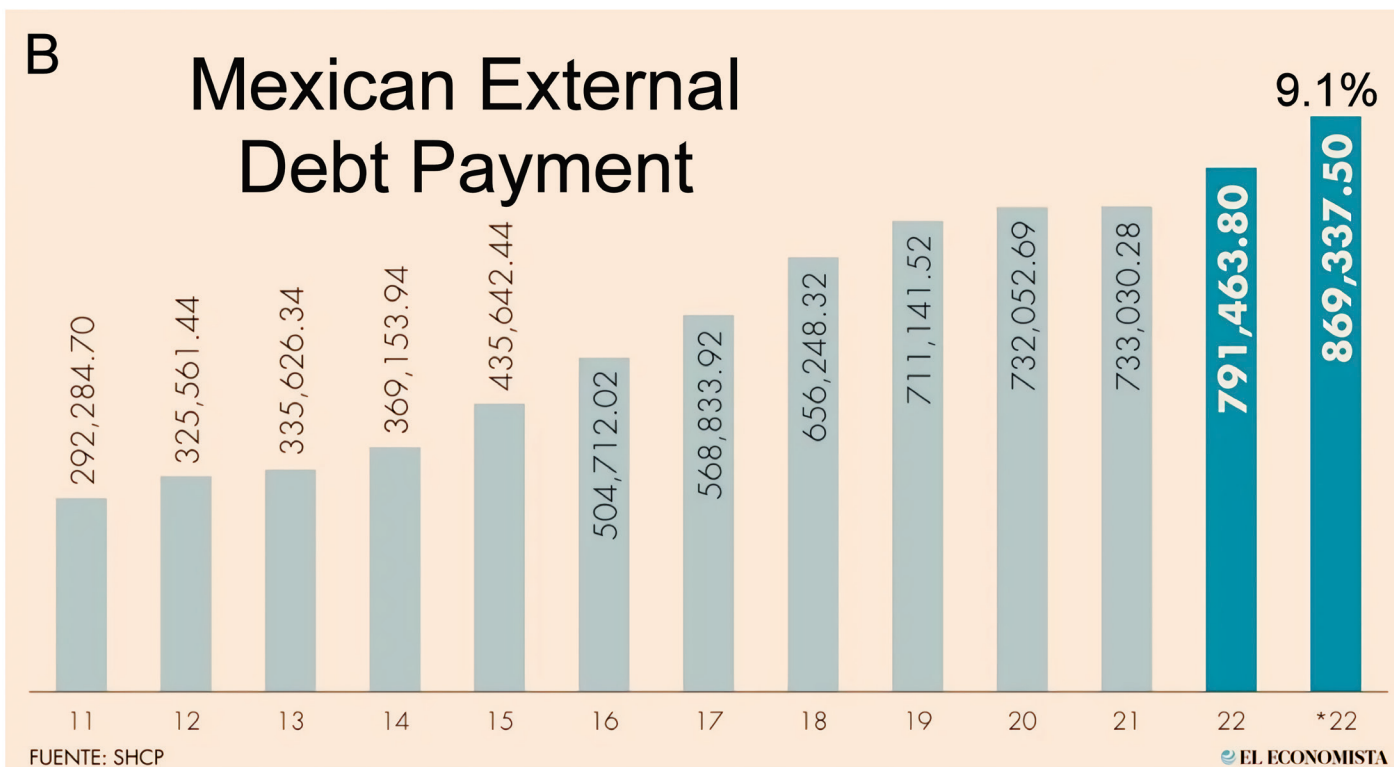
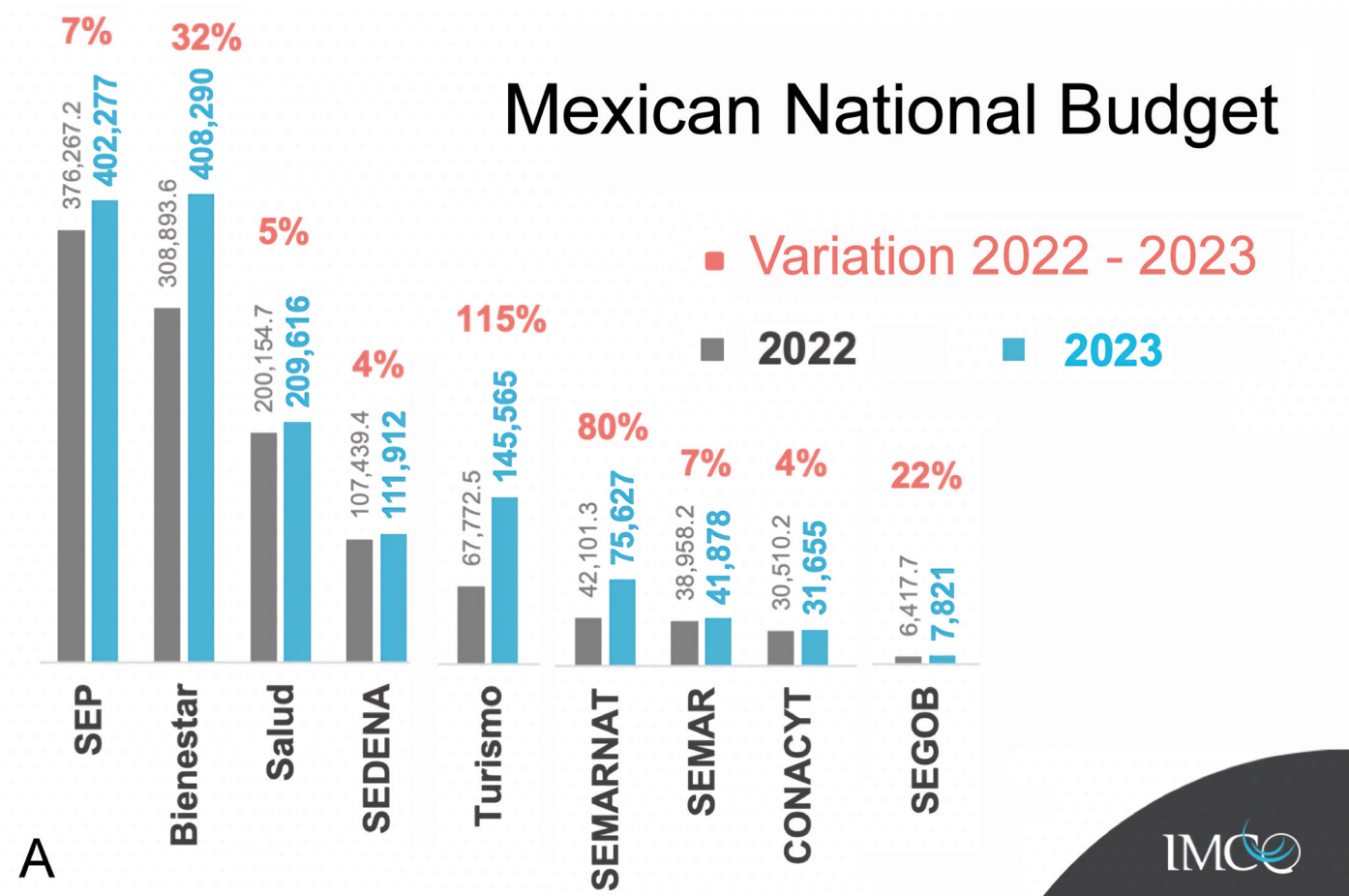


Figure 5. A. Mexican national budget for 2023 (only a few sectors are shown, modified from IMCO 2022). B. Burden of external debt payment (modified from Saldívar, 2022; all figures in millions of Mexican pesos).

because taxonomy is in such a critical condition, most graduates should be hired in the short term, and then a progressive reduction as the number of researchers reach a saturation point. After that level is reached, then hiring should be directed towards a renewal of positions when senior researchers approach retirement. Throughout this process, universities and research

centers should try to balance hiring between those who have got their degree overseas with those from national programs. As for training, both traditional morphological and modern molecular methods must be emphasized. By the way, it will also become a positive transition that some current practices regarding authorships are left behind; i.e., incorporating all committee members as

coauthors, especially if they have not had a significant involvement in all phases of the investigation (McNutt et al. 2018). It is desirable that the increased interest in becoming authors in publications, result in an increment in the number and quantity of academic products, instead of solely enlarging the number of authors per paper.

INFRASTRUCTURE AND LABS

The mechanism for recruiting researchers in Mexican universities has been by using a proportion depending on the number of students, since teaching is prevalent over research in most institutions. There are other pressing approaches making universities request their academic staff to cover a large number of classroom hours, as well as to fill different follow-up formats that nobody revises nor studies. If a similar case operates in your country, my proposal is that universities should the establishment of research centers and regional natural history museums, and this could work independently of any numeric relationship based on the number of students. Infrastructure will need modernization and the laboratories, should have reference collections in Peru. Aguirre and Canales (2017) indicated that there are only two collections, and that in both the material has not been fully processed, a certainly very widespread problem.

INVENTORIES

Having inventories is a positive idea. However, taxonomists should move to the generation of illustrated catalogues or keys for regional species, in what Dr. Alberto Carvacho (1935-2017) denominated social-service taxonomy, and to clarify confusions in the regional fauna. The latter implies comparisons with the type material of the species in question. Of course, the empowerment of these actions also requires a coordination effort as part of a national research program. Catalogues and keys might not be regarded as directed to be published in a paper, especially during its initial results, because it is expensive and somehow limits upgrading the included information.

Instead, it is advisable to think about on-line accessible documents, such as PDFs or interactive keys that might promote interest in the group, and studies in benthic ecology. On this ground, we made a book including many families of tropical American marine annelids (de León-González et al., 2021), but their utility is rather limited for the temperate South American fauna. Another recommendation for promoting the development of faunistic studies is to start with the most outstanding families, after their abundance, species richness, biomass, or ecological role including the provision of secondary space, as it is often the case for onuphids or sabellariids. Kristian Fauchald (1935-2015) recommended me, in 1979, to focus on one or a few polychaete families, such that I could understand the fine details of their morphology and of the corresponding literature (Salazar-Vallejo 2016). I did not follow his advice, but up to 1990 when I undertook studies of concrete groups and his recommendation to concentrate on one or a few families can be forwarded to any interested colleague.

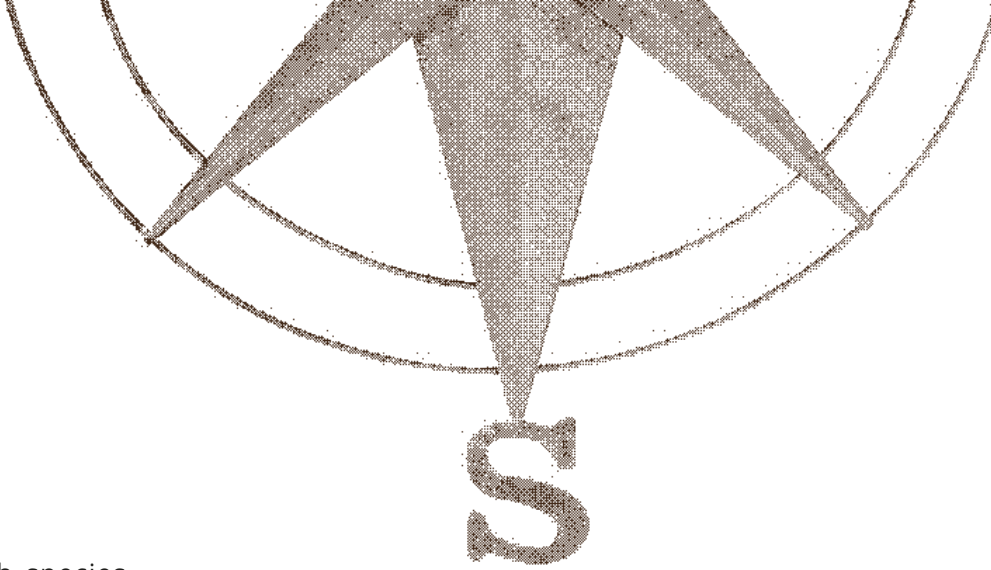
In our research group we tried study to the main families of the Mexican Caribbean and added keys for identifying all species in the Grand Caribbean region. Because the Peruvian coast has tropical and temperate environments, it is advisable that their geographic study area includes a little far beyond their southern border along the northern Chilean coast after their oceanographic similarities, perhaps as far south as 15° South (Longhurst 1998: 317), which is above the northern Chilean border and belongs in the Peruvian or Humboldt province (Ibanez-Erquiaga et al. 2018), and by supplementing the keys that we made for the tropical annelids. At the same time, these traditional faunistic efforts might be supplemented by COI-barcoding methods, including meta-barcoding (Brandt et al. 2020).

I should emphasize the necessity to publish our results, as soon as possible. It is a well-known fact that research efforts are finished only when they are published. It does not matter how brilliant any ideas or discoveries are, they will be relevant after they are openly available to other interested parties, present or future. Forgive me for repeating it: You must publish your results. Other reasons for pressing all interested parties for making publications are twofold: 1) Older results become progressively less relevant because the natural landscape is changing rapidly, and 2) Delaying the publication of our results puts our colleagues in risk of repeating research efforts because your earlier results are not available. Another reason for making publications might fall on the ground of professional ethics. We have certain privileges by undertaking a postgraduate degree, especially in countries with limited education, and this privilege becomes even more significant if we manage to have a job in a university or research center (Salazar-Vallejo 2022). Further, we should remember that our commitment is to investigate outstanding problems, as Peter Medawar recommended (Medawar 1979), and that our results should become available soon because, as the Romans used to say, *Mors certa, sed hors incerta*.

ENDEMISM, SPECIATION, AND MONITORING

Global warming has rendered complicated the delimitation of distribution ranges. It has been noted that tropical marine species migrate pole-wards six times faster than continental species (Poloczanska et al. 2013; Lenoir et al. 2020), and that the equatorial regions are reducing their species richness (Chaudhary et al. 2021). Consequently, it is advisable to understand that marine communities are being progressively modified. Studies on speciation should consider the above migration, and it can be carried out with a fine analysis of ecological (substrate, granulometry, depth, symbionts), or reproductive segregation (activity peaks, timing).

On the other hand, if the institutions are on the shore, or relatively close to it, it is advisable to incorporate facilities for carrying out experimental studies, including reproduction and ecological segregation, because these research areas have been scarcely attended, despite the fact there are several compilations. This would include approaches resembling those made on the ecological



segregation of sandy beach species (Bellan 1977), life-patterns (Reish 1977), or reproductive biology (Clark 1977).

To carry out monitoring programs where every single organism must be identified to species is very complicated in Caribbean reef environments (Campos-Vázquez et al. 1999). It can be less cumbersome in sedimentary environments in so far as an adequate sampling approach is defined including sampling frequencies, number of stations, and minimal identification level. It is desirable that all nations have monitoring programs to estimate our environmental impact after landscape transformation, or of the chronic disposal of pollutants. It is advisable to delineate programs where the reports offer satisfactory and timely results for promoting improvement actions for any resource management. The example of Southern California has not been repeated elsewhere; the municipalities or cities have a legal obligation for carrying out monitoring of the environmental impact of sewage discharges. This program has been successful after the organization of SCAMIT, the Southern California Association of Marine Invertebrate Taxonomists (www.scamit.org).

In Mexico, the Navy carries out microbiological monitoring (fecal coliforms) in the main national beaches to advise swimmers and visitors about their quality. In Peru there are similar programs in the Institute of the Sea, but they rarely have taxonomic objectives, or polychaetes are not identified, and samples are sometimes discarded (L. Aguirre-Méndez, Oct. 2022, pers. com.). There are several methods focusing on taxonomic sufficiency that, although they do not improve the knowledge of the regional fauna since they reduce the identification effort (Salazar-Vallejo 1991), at least they can provide timely information on our environmental impact or natural resources management. The method has progressively been used by different research groups because the number of taxonomic specialists has been decreasing (Terlizzi et al. 2003).

CLIMATE CHANGE

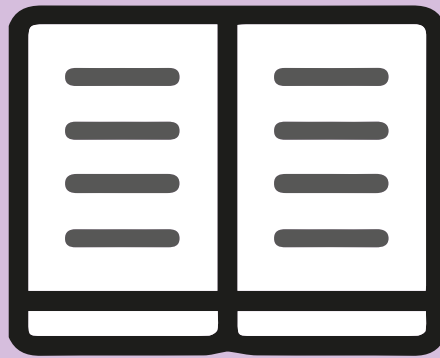
Global warming and the modification of rainfall patterns is causing changes in the whole planet; higher temperatures, increasing acidification, and deoxygenation will have a widespread impact (Kleypas 2019), and some repercussions are also expected on mean sea level. In fact,

the nations have not undertaken ambitious programs to mitigate the effects of climate change rendering a somber planetary panorama. The best recommendation is to promote and implement national initiatives and concrete actions to reduce the upcoming changes we have caused. Some initiatives have been published in many countries, including Mexico (DGPC 2013), and Peru (DGCCD 2020), but the concrete actions still need to follow the publication of the plans. We should also include this activity and promote changes by contacting politicians and other decision makers.

Epilogue. I like to say that the current condition of science in our countries is our responsibility, at least in part. As senior scientists, we have probably tried to improve things, and might have been unsuccessful in most of our attempts. Nevertheless, we must continue promoting a transition to a better education, research, and job environment for our younger colleagues. Some might step aside thinking that this must be solved by future upcoming colleagues. I disagree. We must invest more efforts towards this improvement because none will do it for us.

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APPENDIX

List of publications dealing with type material of several collections. Some institutions did not generate a published catalogue, such that their data bases must be consulted.

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