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Communication

The Study of Species in the Era of Biodiversity: A Tale of Stupidity

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Abstract: Research policies ensuing from the Convention on Biological Diversity made huge funds available to study biodiversity. These were mostly dedicated to projects aimed at providing services to taxonomy via information and technology, or to develop "modern", *i.e.*, molecular, approaches to taxonomy. Traditional taxonomy was overly neglected and is in serious distress all over the world. It is argued that both novel and traditional ways to study biodiversity are essential and that the demise of traditional taxonomy (based on phenotypes) in the era of biodiversity is the result of an unwise policy, mainly fostered by portions of the scientific community that aim at taking total advantage of the funds dedicated to the study of biodiversity.

Keywords: biodiversity; traditional taxonomy; molecular taxonomy; information and technology; research policies

1. On a Mission from God

The most popular definitions of biodiversity range from genetic to population, species, community, habitat, ecosystem, and landscape diversity. Species diversity, however, does have a pivotal role in the study and perception of biodiversity. The key question that triggered concern about biodiversity was: *How many species are there on our planet?* As shown by the animal paintings witnessing the first traces of human culture, this question was probably our very first curiosity, eliciting the rise of science.

It is suggestive that, in the Bible (Genesis, 1, 18), God gives just one job to Adam [1]: to name animals: *Now Jehovah God was forming from the ground every wild beast of the field and every flying creature of the heavens, and he began bringing them to the man to see what he would call each one;*

and whatever the man would call it, each living soul, that was its name. To name something means to acquire knowledge about it; hence, the Bible tells that God wants us to be knowledgeable! The Bible, after asking us to make the inventory of biodiversity by giving names to species, even hints at the law of priority, the foundation of taxonomic nomenclature: *whatever the man would call it, each living soul, that was its name.* The discipline aimed at naming species, *i.e.*, taxonomy, is the only science that obeys the wills of the Creator, as Darwin [2] used to call the hypothethical entity that created the universe: the study of biological diversity, thus, is a mission from God!

2. Species Diversity and Conservation

The estimated number of living species ranges between 10 and 15 million, but just two million have been named and the answer to the basic question on the number of species inhabiting the planet is very far from being answered (see [3] for estimates of future discovery trends). Furthermore, a name is just a label: knowing it does not imply that we really know about the named species. Once a species is named and it phenotype described, we should know about its variability and its life cycle, define its ecological niche, understand its role within communities and ecosystems. For the greatest majority of the described species, however, we know just the name, and how the adults look like. Our ignorance is enormous both in terms of *what are* the species and of *what they do* [4].

The exploration of biodiversity was a primordial urge for our species, in most cases stemming from simple curiosity, but in 1992 the Rio de Janeiro Convention on Biological Diversity agreed that we are leading species to extinction and habitats to destruction, and that some measures had to be taken. Man, in this vision, is part of Nature and cannot survive without it: if we destroy Nature, we destroy the premises for our very existence. After the Rio Convention, the exploration of biodiversity became more imperative than ever, since we cannot defend or manage something if we do not know it. It is clear, however, that we cannot wait to know all species and everything about each one of them before we can do something to preserve biodiversity. Action must be rapid because man-induced degradation of nature is rapid.

3. Our Well-Being and the Well-Being of the Rest of Nature

If we consider man instead of Nature, and we look at the way we started to cure our health problems, it is evident that we tried to find remedies even before we knew how our body is made and how it functions. We tried herbs, and rituals, magic words and magic potions: we were concerned about bleeding and how to stop it even before knowing that blood circulates in our body. And nobody dreamt saying: do nothing until we know everything about how we are made and how we function. We performed medicine long before knowing that we were made of cells. In parallel, though, we continued (and still continue) to study our body, and perfected our practices according to the new knowledge, as soon as it became available. We are still exploring our body and probably we will never know everything about ourselves. The invention of remedies and the exploration of our body proceeded in parallel. The results are rather good, in terms of improved care of our well being, and this way of tackling the problem of the health of our body is probably the best one also to approach the problem of the health of the rest of nature.

Our ignorance about Nature is still enormous, but this is just what science is all about: its aim is to reduce ignorance [5]. One and a half hundred years ago Darwin published *The Origin of Species* and, since then, our way of seeing the world changed radically. The basic principles governing life have been cleared, even though many mysteries remain: the main one is the process that led non-living matter to become alive. The discovery of DNA induced scientists to presume that, as phrased by the editor in chief of Nature [6]: Life is chemistry. Of course chemistry is not what biology is all about, but Maddox's permanence at the head of the most influential scientific journal for 22 years paved the way to the triumph of biochemistry and, then, of molecular biology. Once known the "secret" of DNA, we presumed to have revealed all mysteries of life. Genome exploration became the Holy Grail of biological knowledge; most efforts in the life sciences were focused on this aspect and on related ones.

4. The Decline of Taxonomy in the Era of Biodiversity

The stupidity of the title refers to the dismissal of taxonomy when this science was so obviously vital for the targets of the Rio Convention on Biological Diversity. Nobody expected that ALL efforts had to be dedicated to the fulfilment of our divine mission, but it still seems unbelievable that the mission could have been so neglected, in spite of the Rio Convention that opened the era of biodiversity. Of course it was and still is extremely important to explore the intricacies of molecular biology, but putting all eggs in one basket is proverbially unwise. Why, thus, against all odds, traditional taxonomy, based on phenotypes, is in such distress?

Both the public and the decision makers, if asked about biological diversity, think about species. And species, for them, are clearly phenotypes. So, it is obvious that the knowledge of species should be a stringent priority for the countries that signed the Rio Convention. As a matter of fact, huge amounts of money were and still are devoted to the exploration of biodiversity, but it was the scientific community that decided how to use them, through advisory committees made of scientists (representing the scientific community) that recommend measures to politicians and functionaires.

Politicians asked the scientific community to face the problem of biodiversity conservation and the outcome is that taxonomy is almost extinct [7,8]. I used the word stupidity, but maybe there are other words to define how the matter was dealt with by both decision makers and their advisors.

5. ISI and Traditional Taxonomy

The Institute for Scientific Information (ISI) was founded in 1960 and, since then, it has sold information to scientists, the generators of scientific knowledge. Scientists, in fact, cannot devote all of their time consulting thousands of scientific journals to be up to date in their field, since they would have no time for practiced research. Indexing all articles from all journals so to allow to extract the ones that might be of interest for a particular scientist is a precious service, and scientific institutions are willing to pay for it. ISI was not the first to sell scientific information, however: since 1864, for instance, the Zoological Record gathers all the articles and books published on animals in a given year, dividing them by phylum and indexing them through a multitude of entries, first of all the names of new species. Long before the advent of ISI, there were journals doing this also for botany and for mathematics. These sciences, thus, were not a fruitful market for ISI, since the niche of information providers was filled already and it would have been a waste of time trying to sell what was already available from other sources.

Covering all scientific journals, furthermore, is expensive. ISI, thus, ranked them according to their citations in the scientific literature, calculating their Impact Factor (IF). If the papers of a journal receive almost no citations within two years after publication, the journal has no or very low impact, and it is not worth while being covered. ISI, thus, chose what to cover and, automatically, the rest was considered as having no scientific impact (according to the criteria designed by ISI itself). It is somehow not surprising that the journals of Museums (the core of taxonomic literature) did not receive an Impact Factor. The information they contain was given by the Zoological Record and by other bibliographic repertoires dedicated to taxonomy, and so their deliberate omission did not damage the scientific community in terms of information availability. Novel sciences, like biochemistry and molecular biology, did not have such services, and so they became the main customers of ISI which, however, was presumed to cover all sciences in an equal way.

The situation is not strange at all, in terms of commercial policies. ISI is not a charity and it had to take care of own business. However, the way of ranking journals (with the original sin of the omission of taxonomic ones) for the internal purposes of ISI went over its original scope and became in use by the scientific community to rank the performances of scientists [9].

ISI, however, elaborated also other indexes, besides the Impact Factor. The Cited Half Life (CHL), for instance, tells for how long the average article of a journal continues to be cited. It is not surprising that most of the journals with high IF do have low CHL, and *vice-versa*. The law of priority prevents any paper containing the description of a species from being forgotten: its CHL is infinite. Infinite, for ISI, is >10 years. The scientists that started to use the ISI standards to evaluate scientific performances disregarded the CHL and used only the IF. Strange enough, their tribunes had high IF and low CHL, so they enhanced what was favourable to them, disregarding other indexes.

Taxonomists remained silent while this game started being played. They did not even know what ISI repertoires were, since these contained a negligible part of the information they needed, so why care about them? The basic science of diversity (traditional taxonomy), however, started to be evaluated, like all other sciences, according to the performances of its practitioners: in terms of IF. And their IF was usually, and still is, very low. Publishing monographs, furthermore, leads to zero IF, since books are not covered in these evaluations. A 600-page monograph like the one produced by Bouillon *et al*. [10], for instance, has no value in terms of Impact Factor, since the Memoirs of the National Museum of Natural History of Paris are not covered by the Web of Science! And all citations to it that appear in non-ISI journals do not count.

Hence, when scientific careers became boosted by researchers' IF, traditional taxonomy resulted in a scientific suicide. This led to its rapid disappearance from Universities, and the discipline became confined to Museums. The exclusion from the capacity building system of science (Universities), however, was fatal for the discipline that, however, became revived by molecular taxonomy.

6. The Grinding Frenzy and the PEET

Taxonomy, in fact, regained some IF respectability when it turned molecular. Instead of inspecting phenotypes, it became popular to investigate diversity at a molecular level; after all, phenotypes are specified by genotypes. So organisms started to be ground, their bodies were not looked at much and attention was focused on their molecules. A new question was: what portions of the molecular information were to compare? The list comprises enzymes, histones, aminoacids, whole genotypes by DNA hybridization, sequenced portions of RNA and of DNA, either nuclear or mithocondrial or ribosomal. In the beginning, it seemed that the molecular approach would have solved the problem of recognizing biodiversity in an unequivocal way. As suggested by the editor in chief of Nature, chemistry was the solution. Influential publishers, thus, launched journals dedicated to molecular taxonomy and systematics, with hints to phylogeny. These journals, issued by industrial publishers, received their Impact Factor very rapidly, and "real" taxonomists had to be molecular. Counting the hair in the back of beetles became a dull activity, cool taxonomy being involved in counting stripes in electrophoretic probes, or triplets of C A G T in sequencing experiments. Machines extract information that can be read only by other machines: scientists have just to grind the organisms and put them in their machines, following complex protocols, and then, with complex algorithms, computers build phylogenetic trees. The problem, however, was not miraculously solved. It happened that machines gave different answers about the same question, according to the molecules that were being studied. As Darwin elegantly argued, all living and extinct beings are united into one grand system by complex, radiating, and circuitous lines of affinity. Hence, for instance, there should be just one right phylogeny of the metazoa, but every approach gives a different one, the last one being the definitive one, until a new one is elaborated, by using another tool. The last one, by the time of the writing of this article, is by Paps *et al*. [11] who lamented, however, that these phylogenetic studies tend to increase the number of analysed genes rather than the number of considered species.

Furthermore, before putting a living being in a grinder, one has to guess what it is by inspecting a phenotype, and give it a name. Molecular taxonomists, however, know phenotypes in a rather primordial way. So we might end up having very precise sequences, deposited in international data bases, that are referred to nominal species that might have been identified in an incorrect way (and sometimes even the sequences are incorrect) [12]. The knowledge behind the provided information might be rather poor.

Molecular taxonomy is an essential aspect of taxonomy, but it does not solve all problems. We need to know both phenotypes and genotypes. The so-called central dogma of biology, postulating a one-way flow of information from genotype to phenotype, suggested a logical primacy in investigating genotypes, but epigenetics is showing that the so-called dogma is not a universal law [13].

In the USA, the country that started these trends, some illuminated scientists convinced the National Science Foundation that the dismissal of traditional taxonomy had been a stupid move (stupidity again). The country was almost deprived of taxonomists (the few remaining ones being old and confined to Museums) and young graduate students were not willing to pursue a career in a suicidal discipline. To revive taxonomy, NSF launched the Partnership for Enhancing Expertise in Taxonomy. The need of such initiative was due to the undeniable fact that traditional taxonomists had disappeared from the USA scientific community, and that molecular taxonomy was not enough [7]. The rest of the world is behind the USA of about 10 to 20 years, so the process of taxonomy dismissal is still on course in many countries that, unfortunately, are not learning from the mistakes of the USA and are destroying their expertise in taxonomy, to follow a false modernity that is only linked to the power of some scientific lobby. The disgraces of taxonomy, however, are not limited to the abuse of the Impact Factor in ranking disciplines and scientists. There is much more.

7. Services to Taxonomy: Information Is Not Knowledge

With the advent of Information Technology, and after the Rio Convention, it became obvious that all the things we know about the millions of species we have described so far must be ordered in some way, so to make them easily accessible to the scientific community. In the past, this was done through monographs, but this became unfashionable due to the zero IF of monographic work: diversity had to be informatized.

Of course, just as with the molecular approach, this is the rigth thing to do: it would be extremely stupid not to use the opportunities offered by information technology. Lots of the money dedicated to the exploration of biodiversity, thus, were dedicated to the informatization of biodiversity information.

Huge projects were launched: the Global Biodiversity Information Facility, the European Network of Biodiversity Information, Lifewatch, the Census of Marine Life, the European Register of Marine Species, Diversitas, the Tree of Life, the list might go on so to fill one page [8]. Almost every name means millions of either euros or dollars.

The logic behind all these projects is that information is there and it has to be made available. A very useful deed indeed, but what about knowledge? We know the names of two million species, and the estimate is that they are ten to fifteen millions. So, it is right to have the information about the two millions we know already, but we should dedicate some more resources to the rest of the unknown portion of diversity, the majority of it.

Paradoxically, however, after the share dedicated to molecular approaches and to information and technology enterprises, very few resources remained to go in the field, collect organisms, bring them to labs and study their phenotypes, to describe new species, produce revisions and compile monographs. Only very limited portions of biodiversity continue to be explored in a strategic way, like that of the Antarctic or of the deep sea, for reasons linked to commercial or political treaties and for the power of some scientific lobbies.

8. Decision Makers and Wrong Decisions

Decision makers, following the directives of the Rio Convention, decided to dedicate enormous resources to the study of biological diversity, but taxonomists received a ridiculous share of them. The lion’s share went to molecular and computational scientists who pretended to have the solution to the problem of biodiversity exploration. They do have some solution, but theirs are not the solutions. The approach must be multidisciplinary, and must include traditional taxonomy. In a Catch 22 situation, however, since traditional taxonomists are almost extinct, due to their low IF, there are not enough of them in powerful advisory committees to foster a policy to enhance taxonomy!

After decades of wrong decisions, furthermore, decision makers must defend own behaviour and are reluctant to admit their mistakes (with the exception of NSF). So the story continues. Now the magic solution is the barcoding of life [14]. Every species is identified by a genetic fingerprint, the barcode, and then one has just to read the barcode in each sample and the list of species comes out at the press of a button. Very nice indeed! But how to decide that that barcode identifies that species? Specimens have to be collected, identified, and then barcoded. The identification of the first barcoded specimen, however, has to be made by a human being, based on the morphology of the phenotype. Are we sure that, without trained taxonomists, the barcoded specimens will have been identified properly in the first place? And then, once we have barcoded what we know, how do we think to find what we do not know? The barcode concept is very helpful for identification and is leading to the discovery of many sibling species, but taxonomy is not identification. And we will always need taxonomists to name the new species, to clear the synonimies, *etc*. The barcoding of life is a strong help to identification but, without integration with traditional taxonomy, it will be probably a poor tool [15,16]. Of course, however, this technologically advanced "solution" to the problem of species identification is attracting lots of funding. It is much more "scientific" to identify specimens with machines than doing it by simply looking at them!

9. Another Face of Diversity

Functional diversity is rather limited, if compared with morphological diversity. The same elements (e.g., nucleotides or biochemical pathways) can be assembled by nature so to yield to much different structures that, anyway, are based on indentical principles and perform similar functions.

The genetic specifications of very complex achievements of evolution, like animal photoreceptors, are coded for by the same sequences (PAX genes) that strongly suggest monophyly [17]. This unity in diversity might lead to the conclusion that basic functions can be studied in model organisms and that the results are then applicable to the rest of nature. We do not need to check if all organisms are coded by DNA: the organization of living matter is based on a single type of information and this is a biological law. At a certain level of complexity, however, things become more intricate, and the uniformity of nature is not so universal anymore. The unity at the base of the organization of living matter is counterbalanced by a great diversity at the species level: not all species are the same.

It is a universal law of nature, for instance, that multicellular animals are born, grow, reproduce, and then die due to ageing (if not killed by starvation, predators, or pathogens). Some hydrozoans, however, can reach the adult medusa stage, spawn and then, instead of dying, de-differentiate their adult cells and re-differentiate them in the cells of the larval polyp, and these will re-assemble a polyp colony, performing ontogeny reversal [18]. The universal law of ageing is not valid for some metazoan species, whose study might yield some more hints about why and how animals become old, or why and how their cells can change their fate.

An exceptional organism, found by chance during the exploration of biodiversity, can lead to the understanding of the rules that it can break. Such discoveries cannot be predicted in standard projects.

Model organisms are chosen just for their exceptional features, such as gigantic chromosomes, or fixed number of cells, or huge neurons. Another important feature of model organisms is their thriving under laboratory conditions, so to be readily available for experimentation. The organisms that are easily kept in the laboratory, however, are not so many: the rest of biodiversity, especially animals, is difficult to rear. Experimental organisms, thus, are exceptional under many respects, and we are inferring generalities from exceptions. The case of ontogeny reversal in some Hydrozoa teaches us that the diversity of functions might be unexpectedly higher than we presume, having based our generalities on a very limited portion of diversity.

The exploration of genetic diversity showed that, with a limited number of genes, nature can construct much different organisms. Genetics is not all what diversity is about, epigenetics playing a fundamental role in determining the way organisms are built and function [19]. This, of course, does not mean that genes are not important, it only suggests that there are no shortcuts to the understanding of diversity: the logical primacy of molecular approaches is injustified. Knowledge of the alphabet, grammar, syntax, and the availability of a dictionary are necessary for the understanding of literature, but they are not sufficient. They simply are not literature. The uniformity of the rules leads to a great diversity in the results of their application. Reducing the diversity of the outcomes of the application of the rules to the uniformity of the rules themselves is simply dull! Music is not just the notes, literature is not just the words, and organisms are not just their molecules, even if music is made of notes, literature of words, and organisms of molecules! Life is not only chemistry! Otherwise biology would make no sense and chemistry would be enough to understand life (stupidity again).

10. Modern Taxonomy

Adam's godly task is not accomplished yet, and we have to carry it out with all the modern tools that technology makes available. We have many new species to find, and this will happen by exploring the world where we did not look enough, mainly the oceans. We have to study diversity in all its facets, from phenotypes to genotypes, ecological niches, life cycles, populations, communities. So to know, for every species, all the things that our curiosity urges us to know. Maybe it is not possible to have these tasks accomplished by a single person; the study of diversity is multidisciplinary and some work will be carried out by morphologists, some by molecular biologists, some by ecologists. They will work together to gain as much knowledge as possible about the diversity of life. Then, we will have to understand how these species assemble with each other and make communities and ecosystems function, how they form ecological landscapes, how they react to our impact, how we can use them in a sustainable way, how can we preserve them. All this knowledge will have to be translated into bits of information that will have to be made available by information technology platforms.

All these disciplines must collaborate to acquire a single vision of the grand picture of life. By now they are competing for resources, and we must shift from a competition scenario to a cooperation scenario, since the winning approaches have no logical supremacy over the neglected ones.

11. Predictive Science

For some scientists, science is to be predictive, and the general public expect it to be so. Scientists extract information from the world, elaborate it, and tell what will happen, performing predictions that will help society in planning the best practices for our well being. This idyllic view of the world is hampered by the inherent unpredictability of non linear systems [20]. Some predictions are very easily made, however, but we do not want to know about them. Since our planet is finite, for instance, it is easy to predict that nothing can grow to the infinite: infinite growth in a finite system is simply impossible, but economists expect continuous (*i.e.*, infinite) growth, without considering that our growth occurs at the expenses (degrowth) of the rest of diversity. It is very easy to predict that this will lead to collapse of ecological systems. This prediction is being made since centuries, from Malthus to Marx, but evidently we care only about the predictions we like and disregard those that we do not like.

Stupidity takes its toll again, since we based, and still base, our society on the paradigm of continuous (*i.e.*, infinite) economic growth, a rather infantile expectation that is impacting much on the biological diversity of the planet.

12. Back to the Bible

At the beginning of our evolution, our ancestors did not have to work to get what they needed: in a way, the biblical story of the Garden of Eden depicts our initial condition of hunters and gatherers. John Paul II once wrote that, for him (a rather authoritative interpreter of the Bible) the forbidden fruit represents a limit to the use of the Garden of Eden. We went over that limit and were expelled from the Garden, condemned to work to get what we need. To work to get own food is agriculture: the expulsion from the Garden of Eden depicts the passage from hunting and gathering to agriculture. Agriculture was developed when we had overexploited natural resources and we had to increase artificially the yield of nature but, to enhance production, we further destroyed diversity [9]. This happened because we obejed another divine command: go and multiply. The fitness of an individual is measured by the size of its progeny, by the efficiency in perpetuating its genotype in future generations: so the tendency to multiply is not only biblical, it is a key biological trait. However, it is impossible to increase own fitness (go and multiply) without breaking the limitats in the consumption of natural resources (the resouces of the Garden). All growths do have a limit, even ours!

These considerations apply well to terrestrial environments, whereas in the oceans we are still hunters and gatherers. Natural populations, in fact, are almost gone in terrestrial ecosystems, whereas they are still relatively healthy in the oceans, so to withstand industrial exploitation by fisheries. This is not going to last for a long time, though, and we have already impoverished the last Eden (the World Ocean) so much that we are shifting from fisheries to aquaculture as we did on land long time ago, passing from hunting and gathering to agriculture. This is happening for a very simple reason, the natural populations of marine species are overexploited and do not provide sufficient goods for our well being. With aquaculture, however, we further impoverish the seas, since we rear mostly carnivorous species and we feed them with smaller fish that are drawn from natural populations: we are scratching the bottom of the barrel of nature [21]. Furthermore, we obtain fish with extremely destructive tools, that destroy not only non-target species such as marine mammals and reptiles, but also the very habitats of the fish we use as a resource. Habitat destruction is probably the most pervasive threat to biological diversity but, especially in the marine realm, our knowledge of habitats is still in its infancy and even an agreed-upon way of naming marine habitats is wanting, this leading to unfocused conservation policies [22].

The only way to preserve nature is to release it from our pressure. This can be achieved by rationalising our use of its resources, but our first concern should take into serious consideration to disobey “go and multiply”: degrowth to a sustainable size of our populations is our only hope. We will go back to Eden when we will learn to regulate our pressure so to live in harmony with the rest of nature. The state of biological diversity is the first and most important indication of the state of nature, this is recognized by both the Rio Convention about Biological Diversity, and the Bible. When the multiple facets of our culture, from science to religion, converge in showing a way to save our species, we should be able to transform information into knowledge and use knowledge to obtain wisdom. The demise of taxonomy in the Era of Biodiversity is surely not a product of wisdom.

13. The Faults of Taxonomists

Traditional taxonomists succumbed to other members of the scientific community in the competition for the use of the resources dedicated to the exploration of biological diversity, often not being even aware of their existence. This happened because they did not understand the issue of the evaluation of scientific production and did not press to consider also the Citation Half Life in ranking scientists' performances, enforcing proper evaluation of revisionary and monographic work. Taxonomists did not apply much for funds but were eager to contribute, almost for free, to rich projects that exploited their knowledge in molecular- and information-and-technology-based enterprises. No research institution would hire scientists that do not bring research money and that work for free to the projects of other scientists! Taxonomists did not elbow to enter high-level advisory boards and did not raise their voice when the policy of biodiversity research was built with the advice of physicists, geochemists, molecular biologists, agronomists, modeling ecologists, engineers, economists, but not with theirs! Traditional and molecular taxonomists, with very few exceptions, worked in separation from each other, weakening a potentially strong alliance.

The study of biodiversity cannot proceed further without the contribution of integrative taxonomy and these obstacles will have to be removed [23]. Taxonomists must stop working for free, denouncing, in the meantime, the faults of current scientific policies and proposing wiser ways to use the resources dedicated to implement biodiversity research.

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