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Experimental Zoology and the Concept of *Milieu*: The Role of Marine Laboratories at the Turn of the 19th Century

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Abstract:
This paper explores the evolution of zoology during the *Belle Époque*, a time marked by the transformation of this discipline toward an experimental approach. By focusing on marine stations, the paper examines how these infrastructures enabled the study of marine organisms in their natural environment, illustrating this shift through the example of the Arago Laboratory and its founder, Henri de Lacaze-Duthiers. The analysis addresses the epistemic functions of marine laboratories, their contribution to contemporary epistemological reflections, and the impact of the concept of *milieu* in this context.

Keywords: Belle Époque; Historical epistemology; Marine zoology; Maritime laboratories; Philosophy of science and technology

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Introduction

The *Belle Époque*, spanning from the late 19th century to the onset of World War I, was a time of significant transformation in Europe marked by numerous scientific and technological innovations. This paper follows the evolution of zoology, a discipline that gradually shifted from a purely descriptive approach to adopting an experimental method. This change is largely attributed to the establishment of marine stations, designed to facilitate the study of marine organisms in their natural environment. Through the example of the Arago Laboratory and its founder, Henri de Lacaze-Duthiers, we will analyze the importance of integrating the marine environment into zoological research and the epistemological implications of this practice. Finally, we will explore how these marine laboratories influenced contemporary epistemological reflections and transformed the understanding of zoology.

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Historical Context and Transformation of Zoology

In zoology, the 18th century can be considered as the era of the systemization of nature (Larrère and Larrère 1997, 74). This period saw an increasing interest in the study of marine zoology. The great exploratory circumnavigations, coupled with a changing perception of the marine imagination (Michelet 1875 [1861]), gradually contributed to a significant evolution of knowledge about the aquatic world. The ocean and sea entered a new, less fantastic and more utilitarian paradigm (Corbin 1988; 1995).

Although these expeditions commenced at the beginning of the 16th century, notably with Fernão de Magalhães (1519-1522), García Jofré de Loayza (1525-1536), Francis Drake (1577-1580) and Olivier Van Noort (1598-1601), those having a direct link with naturalist study only appeared in the 18th century. The great circumnavigations, such as those of James Cook (1728-1779) and Louis-Antoine de Bougainville (1729-1811) brought many scholars on board with them. The scholars collected, studied and brought back unknown species which then accumulated in museums. The oceanographer Michel Glémarec thus places the beginning of the era of oceanography from 1758, with the publication of the tenth and final edition of Systema Naturae by Carl von Linné (1707-1778) (Glémarec 2007).

Before the 19th century, naturalist methods in zoology focused primarily on collecting, description, and classification of species. Naturalists of this era, such as Linnaeus and Georges-Louis Leclerc Buffon (1707-1788), focused on the identification and taxonomy of organisms, establishing classification systems to organize knowledge about species diversity. These naturalists primarily used specimens collected during maritime expeditions, often kept in cabinets of curiosities or museums for study and cataloging.

Classification methods were based on detailed morphological observations, but they were limited by the great degradation of specimens due to the long journeys and preservation in alcohol. Naturalists also relied on external and internal characteristics, mainly visible to the naked eye. Living beings were only studied in a deceased and deteriorated state, limiting zoology to a science of classification.

These methods were largely descriptive and did not provide an understanding of the underlying biological processes or interactions between species and their environment. Zoology then lacked experimental approaches to explore the physiological and behavioral mechanisms of marine organisms. It is also from this perspective that Claude Bernard (1813-1878), leader of the French School of Physiology, maintained in the second half of the 19th century that zoology should not and could not become an experimental science. According to him, it had to remain descriptive, just like mineralogy or astronomy (Debray-Ritzen 1992, 133-147).

Disconnection from the natural environment was another major limitation. Specimens were often studied outside of their natural habitat, in conditions that did not reflect their living environments. This approach isolated species from their environment, preventing researchers from fully understanding the complex relationships and adaptations specific to the marine environment. Thus, throughout the 18th century, marine zoology remained a science mainly of classification, not yet experimental, limited by descriptive methods and a disconnection from the natural environment.

Louis Ferdinand de Marsilli (1658-1730) is often recognized as the father of modern oceanography. Margaret Deacon describes his work, *A Physical History of the Sea*, as the first work devoted entirely to marine science, with particular attention to biology (Deacon 1997). Jean-Marie Pérès, by comparing contemporary classifications with Marsili's observations, underlines "the originality and accuracy of the observations, but more particularly of the approach" of the latter (Pérès 1968, 369-376). Between 1681 and 1704, the Count of Marsili served in the armies of Emperor Leopold I and began his marine studies when his unit was stationed near the coast. His research is mainly concentrated between Cassis and Marseille, where he examines the topography of the seabed, the physicochemical properties of water,

water movements, vegetation, invertebrates, and more particularly red coral. In his book, Marsili describes the challenges inherent in studying the marine environment: "Several experienced people, as far as the sea is concerned, to whom I communicated my design, imagine this methodical demonstration to be either impossible or at least extremely difficult; based on the difficulty of being able to directly penetrate underwater, to recognize what was necessary" (Marsili 1725, 1)[2].

This text highlights the obstacles encountered by Marsili. Sea observation, to be effective, requires complete integration of the marine environment. It is not simply an external, static gaze, but a dynamic movement seeking contact. Marsili understood that the real difficulty lies in the need to change environment to observe the sea, making this integration particularly delicate. As Josquin Debaz points out, "for Marsili, the interest lies precisely in the study of a *milieu* that is so inaccessible, which seems so different but which is in fact the continuity of the terrestrial environment on a geological level" (Debaz 2005, 62). Thus, there is geological continuity as well as a break between different environments. This idea is frequently present in Marsili's writings, implicitly integrating the notion of *milieu* as a condition of existence for organisms. He explains thus: "All Sea Plants are rootless; not being necessary for them to receive vertically from the place where they stop, their food [...] the food insinuates itself there by all the lateral parts in the same way as it is done to terrestrials by the perpendicular roots" (Marsili 1725, 54).

Marsili notes here that marine flora feeds through "all lateral parts", unlike terrestrial plants which feed exclusively through roots. The marine environment then becomes a nurturing element, enveloping and surrounding, influencing from all sides. Debaz also observes that "at Marsili, the sea is far from being a desert, and the difference between terrestrial plants and marine plants lies in the environment which contains the food and the seeds of the plant" (Debaz 2005, 63).

Marine zoology, through its study of aquatic animals in an opaque environment, makes the concept of an environment of interaction particularly evident, emphasizing the importance of relationships between organisms and their environment. The zoologist Frédéric Houssay (1860-1920) summarized this interest by asserting that knowledge of oceanic faunas reveals the need to link animal forms to the conditions of their *milieu*.

If, in an even more general way, a thousand differences in details produce a thousand particular adaptations on land as well as in the waters, it is nevertheless true that above all, the knowledge of the faunas of the Ocean makes it manifest to the spirit the necessity which links animal forms to the conditions of their *milieu* (Houssay 1893, 168).

Through Marsili's work, we observe a close link between the notions of element, *milieu* and in *situ* observation. It is regrettable that the fifth part of his *Physical History of the Sea*, dedicated to marine zoology, was never published. It nevertheless remains crucial to remember this intention in order to understand the interdependence and co-development of oceanography and zoology.

Jules-César Savigny (1777-1851) made the same observation when he accompanied Napoléon Bonaparte (1761-1821) to Egypt at the end of the 18th century, with the aim of studying invertebrates. It documents the difficulties encountered when studying coral. He asserts that the study of the dead polyp is certainly simple but sterile (Savigny 1809-1813). The difficulties presented by integrating the living environment of marine organisms reveal the limits of descriptive zoology.

Savigny thus underlines the epistemic limits of maritime expeditions, particularly with regard to zoological study and animal classification. He saw the need to study animals in their living environment, implying a permanent installation of research at his place of study. If the political upheavals of the early 19th century prevented the development of a true local

[2] All the quotations in this paper have been translated from French to English by myself.

zoology, the end of the Napoleonic wars gave Europe a peace favorable to the construction of these practices (Debaz 2005, 74).

This idea is reinforced by the work of Lazzaro Spallanzani (1729-1799) and Georges Cuvier (1769-1832), who also undertook field studies in the late 18th and early 19th centuries. Spallanzani, by exploring the Gulf of Genoa and establishing a laboratory at Portovenere in 1783, laid the foundations of marine zoology. This laboratory, although not having lasted over time, can be considered the first marine zoology laboratory in the world. Likewise, Georges Cuvier (1769-1832), by studying marine fauna on the Normandy coasts between 1788 and 1795, greatly contributed to animal classification (Debaz 2005). In addition to the first field work, there was that of Alcide Charles Victor Marie Dessalines d'Orbigny (1802-1857), a former naval surgeon with a passion for natural history, who settled in 1815 in Esnandes, near La Rochelle, with the objective of founding the first census work on the zoology of the French coasts.

Finally, the expeditions of Jean-Victor Audouin (1797-1841) and Henri Milne-Edwards (1800-1885) in the Chausey Islands, between 1826 and 1829, were decisive. By studying crustaceans directly in their natural environment, they not only collected valuable data but also highlighted the need for local and ongoing study. Their determination to flee Parisian universities to devote themselves to field investigation marked a turning point in the way of approaching zoology, by making the study of the environment a central element for understanding the interactions and adaptation of organisms in their *milieu*[3]. They emphasize the importance of a local investigation, arguing that the French territory, rich in biodiversity, is largely ignored by scientists. In his *Entomological Journal*, Audouin explains that their goal is to study crustaceans from an anatomical and physiological perspective, highlighting the need to observe animals in their natural habitat for a more in-depth understanding of their behaviors and development (Théodorides 1966).

Audouin and Edwards plead for the study of the French coasts. They argue that distant travel, while valuable, should not overshadow the importance of local explorations. In their official version, Audouin and Edward oppose the usefulness of local expeditions to that of distant journeys, in particular by relying on patriotic arguments and national valorization.

> The usefulness of distant travel is widely accepted; well-informed governments compete amongst themselves in these noble enterprises and are applauded for their efforts. As we understand that the greater the quantity and variety of information collected, the easier it will be to overcome generalizations in science. Natural history is more especially indebted for its progress to these scientific expeditions; but it would be unfortunate if the desire to observe and bring together foreign objects made us neglect our own soil; because it can provide treasures of this kind no less precious than those that we seek from great distances, and we must admit that, far from having exhausted them, we have at most only noted their existence. (Audouin and Milne-Edwards 1834, 1)

A naturalist in the beginning of the 19th century had to "undertake a real journey to study the animals of the sea" and "the first precise knowledge on the organization of lower animals was published with titles such as: Expedition to the coasts of Sicily of M. H. Milne-Edwards or A Summer in the Balearic Islands by M. Lacaze-Duthiers, etc." (Houssay 1893, 169). Naturalists undertook arduous, long and expensive journeys. They went to study the

[3] Maritime expeditions certainly extended far beyond cities, however the collections and discoveries always returned with them, often to be displayed in natural history museums; the locus of knowledge remained fixed and urban. Furthermore, almost all naturalists were trained in medicine. The specialization in zoology only emerged in the 19th century, notably thanks to the creation of specific zoology programs and degrees.

organisms far from French territory when all they had to do was bend down to pick them (Castanier 1891). The approach of Audouin and Edwards therefore recommends a field approach considering the direct observation of living species in their natural environment. This refocusing on the local and the in situ study of living beings lay the foundations of a new scientific methodology focused on the systematization and specialization of zoological research. Also, it is no longer just a question of describing and classifying animal species but of studying them in their living state:

> Were it possible to describe them, these descriptions would teach nothing about their habits, their mode of reproduction and their development, in a word about all the most interesting parts of their history. It is therefore not in the midst of collections and in the silence of the office that one can undertake similar work; to carry it out properly, one must travel to the places where these species inhabit, and observe them in their state of life. (Audouin 1834, 2)

These two naturalists are considered the creators of coastal biology in France[4]. In 1826 they established a research protocol to study the marine fauna of the French coasts. Aware of the immense diversity of these regions, they concentrated on specific places and fixed their work on the ground, thus beginning a natural history of the coast of France. Their methodical and localized approach allows them to systematize the study of marine species and reduce dependence on random harvests. They call for networking efforts to complete their work and are considering collaboration with the inhabitants of the French coasts to make their research more exhaustive.

Their expeditions, carried out between 1826 and 1829, led to the creation of a new discipline, bionomics, consisting of the study of the relationships of living beings with their environment and with each other. They thus describe the topographical distribution of marine invertebrates in their horizontal and vertical distribution. They identify four distinct zones along the Breton and Normandy coasts, depending on the tides and the species present. Bionomic distribution system which will be used until the end of the 19th century. Their epistemological contribution lies in the idea that species distribution is not random, but reflects specific adaptations to local environmental conditions.

Their method brings zoology closer to geology, recognizing the epistemic reciprocity between the two disciplines. In 1904, Julien Thoulet (1843-1936) confirmed this intuition, affirming that geology would be transformed by zoological discoveries on the relationships between animals and their environments. The reciprocity between these two disciplines is innovative in that it creates an integrated approach: zoological discoveries inform geology, and geology offers essential contextualization tools for understanding species distribution and adaptation. This methodology marks a turning point for zoology which becomes explanatory and dynamic, laying the foundations of a science of life deeply anchored in the study of natural environments. Audouin and Edwards eventually published books and articles on the morphology and anatomy of marine crustaceans, realizing their ambition to document the French coastline.

This methodology marks the beginning of a new era for zoology, where knowledge is built through an active and continuous presence in the field. This illustrates the effort of

[4] H. M. Edwards and J. V. Audouin are considered the founders of coastal biology in France (1823-1826), particularly based on their expeditions along the coasts of Brittany, Normandy, and the Channel Islands, where they primarily studied marine invertebrates. Through their expeditions, Edwards and Audouin also established the discipline known as "bionomics" by describing the topographical distribution of marine invertebrates in their horizontal and vertical distribution.

naturalists to fully integrate into their study environment, thus going beyond the limits of simple distanced observation.

Finally, Jean Louis Armand de Quatrefages de Bréau (1810-1892) is a key figure in the transformation of zoology in the 19th century, particularly through his explorations of the Normandy and Breton coasts detailed in his *Memories of a Naturalist* (1853). He criticizes the spirit of grandeur and the quest for distant horizons which neglect local realities. Quatrefages illustrates this idea with his own experiences in Granville and in the Chausey archipelago. It embodies this transition, where field research becomes essential to grasp the complexity of living systems and establish a new epistemology based on direct contact and careful observation of nature.

There is therefore a clear desire for localization, specialization and description of national coasts, evoking a form of epistemological humility: knowledge must start from a center and be deployed methodically from there; to know a little, but surely, is already to know a lot, as Lacaze-Duthiers would later say.[5] Beyond this epistemological humility and this national revalorization, the study of the French coasts necessarily includes the examination of all the beings that develop there in their natural environment. Localization does not simply represent the passage from one object of study to another; it does not consist of "looking at something else" or "studying a new object". This epistemological localization transforms the very notion of the object of natural sciences; in the context of zoology, it concerns living beings evolving in their environment. Zoology is moving from the study of animal remains in universities to the study of living animals in their natural environments. As oceanographer Patrick Geistdoerfer points out, "Life now distinguishes living bodies from inanimate bodies, whereas, until the end of the 18th century, it did not exist as a concept separate from living beings" (Geistdoerfer 2015, 68).

Although certain scientists embarked on distant expeditions enriched museums with collections of organisms, or others studied a coast locally and in depth, this remained an exception. Thus, marine zoology could only enter the path of rapid progress when permanent, well-equipped laboratories, installed on the very site of exploration, had opened their doors to all researchers.

The Founding of Maritime Laboratories

The second half of the 19th century saw the appearance of numerous maritime stations, first in Europe with Ostend (1843) and Concarneau (1854), in connection with the first fish farming works, then in the rest of the world. France is at the heart of this transformation of the zoological approach, seeing the emergence of a dozen maritime stations on its coast between 1872 and 1899. The main function of these observatories is to study living beings in their living environment.

It is necessary to mention the impact of the publication of *The Origin of Species* (1859) by Charles Darwin, which will have a significant impact on the development of maritime stations. The vast majority of these will have the primary purpose of "proving" the theory of evolution, in particular by looking for forms of primitive life also called "living fossils", that is to say organisms presenting ancestral characteristics. It is the marine world that offers the most subjects of study. In 1972, the diver and zoologist Pierre Drach affirmed that "those who

[5] It would be relevant to clarify the use of the term "epistemology", which here sometimes seems to be confused with "methodology". By "epistemology", we mean the theoretical (but also practical) foundations of scientific knowledge, including reflection on the validity and limits of the methods used. In the context of epistemological localization, this refers not only to a way of producing knowledge (methodology), but also to a reassessment of the criteria of scientificity which values direct contact with the natural environment as a condition for the validity of knowledge.

created the first stations [...] had a clear vision of the fantastic diversity of animal life in the seas" (Drach 1972, 571). While only a third of the clades are represented in terrestrial fauna, all are present in the oceans. It is no longer only external characteristics (Linnaeus), nor anatomical notions (Cuvier) that now guide classifiers. From the second half of the 19th century, the main interest focused on the sequence of beings, starting from current forms and going back to the most primitive forms of evolution.

This is the case of the emblematic Naples station (1873) considered the Mecca of zoologists (Whitman 1883). However, this reason is not unique and the example I am going to use demonstrates this. Indeed, certain fixists contribute to the transition from descriptive zoology to experimental zoology by insisting on the need for a local study that integrates the environment. According to the historian of science Jean-Louis Fisher, The founding of maritime stations responds to two main objectives: to develop a new direction for fundamental research in biology and to exploit marine resources (Fischer 2002). At the end of the 19th century, stations such as those of Sébastopol, Naples, Roscoff and Banyuls-sur-mer became nerve centers for marine biology in Europe.

From now on, I will analyze the context of the appearance of maritime stations through the example of the Banyuls-sur-mer station (1881) and its founder, Henri de Lacaze-Duthiers. Founder of the Oceanological Observatories of Roscoff (1872) and Banyuls-sur-Mer (1881), as well as of the journal *Archives of Experimental and General Zoology*, Lacaze-Duthiers left his mark on the history of zoology.

Image 1: Lacaze-Duthiers drawing coral in front of the Arago Laboratory
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By following the work of his predecessors, he completed this naturalist movement towards the coasts and the integration of living environments. Zoology not being established, between the movement of expeditions and the immobility of abstract studies, he will give it an anchor and a local dimension. His vision of science, focused on experimentation and direct observation, led to the creation of networks of maritime stations that strengthened the study of the relationships between species and their environment.

Henri de Lacaze-Duthiers made significant advances in zoology, notably through his work on marine invertebrates, whose functioning he elucidated in over 250 publications (Jessus 2023). Lacaze-Duthiers' methodology involved setting up maritime stations at strategic coastal sites to allow observation of organisms in their natural environment. On an epistemological level, this is based on the belief that the validity of zoological knowledge is enhanced through in situ observation, as it allows for a better understanding of the specific interactions between organisms and their environment. He focused on groups such as mollusks, ascidians, and corals, using a comprehensive approach that included the study of the life cycle, anatomy, physiology, and natural environment of these animals, emphasizing the importance of observing living animals, often in their natural habitat. Lacaze-Duthiers also carried out numerous expeditions along the French and Mediterranean coasts, as well as in North Africa, which resulted in exhaustive monographs on species such as Bonellia viridis, Dentalium entalis, and corals. These works provide detailed descriptions and were among the first to analyze embryonic and larval development, thus contributing to taxonomy and the understanding of relationships between species (Jessus *et al*. 2021). Furthermore, he challenged some established concepts, such as Cuvier's classification, by demonstrating that the study of larvae could reveal relationships that were not apparent in adult forms. He also contributed to debates on the origin of vertebrates, particularly through his study of ascidians, though he was initially hesitant to consider them as ancestors of vertebrates.

Lacaze-Duthiers' work continues to contribute significantly to contemporary scientific discussions. His comprehensive approach to studying marine invertebrates, emphasizing the observation of living animals in their natural environment, aligns well with current ecological and evolutionary perspectives. His exploration of evolutionary relationships, particularly regarding ascidians as potential ancestors of vertebrates, remains a reference point in debates on the origins of major animal groups (Jessus and Laudet 2023). Moreover, his detailed monographs on species such as Bonellia, Dentalium, and corals are still valuable for biologists, providing foundational knowledge for the taxonomy and developmental biology of marine invertebrates (Jessus 2023).

The Arago Laboratory, founded in 1881 by Félix Joseph Henri de Lacaze-Duthiers on the bay of Banyuls-sur-mer, followed the example of the Roscoff laboratory created ten years earlier in Brittany. This establishment aimed to study living organisms in their natural environment. The tide at Roscoff uncovers vast beaches filled with great faunal wealth, offering ideal conditions for naturalist studies. The island of Batz protects the coast from the swell, allowing exceptional development of living organisms, making Roscoff an ideal zoological location. Also, high ocean tides allow zoologists to take their own objects of study from the shore which is teeming with life (Brien 1952). In 1972, during the centenary of the Roscoff Station, Louis Cabioch (1933-2023) evoked the "prophetic views of the founder of the Biological Station". He writes that the Roscoff region appears as the very favorable meeting point of complementary faunal domains. If we add to this the great diversity of the nature of the seabed within a radius of 10 miles, where pebbles, sand and mud follow one another, we understand the origin of the extreme richness of the fauna and the we can only admire the accuracy of the choice made by Lacaze-Duthiers (Cabioch 1972, 594).

However, although this location offers many virtues, certain conditions, particularly in winter, render the research work laborious. Indeed, when October comes, in Roscoff, rain is as frequent as daylight is rare. Microscope work becomes tedious and difficult. Indeed, it was not until 1879 that Thomas Edison (1847-1931) produced the first incandescent lamp. Until diffuse and homogeneous light was available, observations depended on daylight, which, in a climate as harsh as that of Brittany, posed a problem. It was in the face of this obstacle encountered by Lacaze-Duthiers that the idea of building a second maritime station in the south of France was born. A. de Quatrefages already mentioned, in 1854, the difficult climatic conditions of Brittany and Normandy (Quatrefages 1854, 68). Later, in a letter to Lacaze-Duthiers, Yves Delage (1854-1920) expressed himself about Breton weather and the negative impact it had on research:

> For more than eight days I have been biting my nails impatiently waiting for a clear day to do this injection and this dissection which are very meticulous. But the weather is terrible: it rains continuously. Several times I tried this injection and I always failed because at the decisive moment the rain beat against the windows and took away the little daylight I had. Other times I succeeded in the injection, but missed the dissection for the same reason. It would take me three or four days and a few good-sized animals to completely finish off these two types. (Delage 1879)[6]

Lacaze-Duthiers often returns to the working conditions brought about by the climate and thus explains the reasons for the creation of the Arago Laboratory:

> We can say it, Roscoff enjoys a climate predestined for studies; in the middle of summer, it's spring, and we never experience the irritation of hot climates. But in winter, mists, winds, rains, humid days making the strike inclement and the work very difficult due to the lack of light, force the workers to emigrate to the land of the sun. This is why I thought of giving a counterpart, for the winter, to the Roscoff station, and that the Banyuls station was created. (Lacaze-Duthiers 1888, 369)

This climate's advantage is to allow optimal working conditions "even at the height of summer" (Lacaze-Duthiers 1895, 2), and that it "is reminiscent of a beautiful warm day and temperate in spring" (Lacaze-Duthiers 1895, 2). Once again, Lacaze-Duthiers chose a very particular locality conducive to the study of marine organisms. Indeed, the environment of Banyuls-sur-mer contains an incredible marine wealth over 2000 meters of elevation, going to the bottom of the canyons 30 miles out to sea (Frioul and Laudet 2019, 64).

Discussions and negotiations were first initiated in Port-Vendres, but it was ultimately in Banyuls-sur-mer, a few kilometers further south, that this idea came to fruition. Port-Vendres was initially chosen for its location, but the financial and material offers proved insufficient to establish a laboratory worthy of the name. In 1880, the commune of Banyuls-sur-mer, wishing to build a laboratory and noting the slowness and timidity of financial offers from the neighboring village, seized the opportunity. The municipal council of Banyuls-sur-mer votes for a subsidy of 12,000 francs, the acquisition of a location and an annuity of 500 francs for twenty years, an annuity which would later be regretted and described as a "cursed annuity" by some Banyulencs (Lacaze-Duthiers 1894, 36).

Apart from official offers, the villagers of Banyuls-sur-mer organized a "spontaneous subscription" allowing the future founder to obtain a boat equipped with fishing gear worth 3,000 francs. Lacaze-Duthiers often speaks of the need to study in "nature itself", isolated from human and worldly contingencies, yet his scientific practice shows a constant interweaving with local actors, whether fishermen, rentiers or local authorities. This contradiction illustrates the tension inherent in 19th century experimental science, between the ideal of scientific autonomy and the reality of its social and material dependence.

[6] Delage, Yves. "Lettre à Lacaze-Duthiers, Roscoff, le 2 juin 1879". *Archives de l'Observatoire Océanologique de Banyuls-sur-mer*.

It was thanks to these generous offers, brought by the villagers and the mayor at the time, Thomas Pascal, that Lacaze-Duthiers chose to settle in Banyuls-sur-mer. The latter does not fail to recall these facts each time the municipality opposes the requests of the maritime station or refuses to pay the annual rent. Lacaze-Duthiers therefore considers that it is erroneous, even dishonest, to claim that Banyuls-sur-mer made sacrifices by responding to his requests. We also find in the reports of the Academy of Sciences and in the report of the general councilor and deputy, Mr. Escanyé, the idea according to which the community of Banyuls-sur-mer forced the hand of Lacaze-Duthiers (Lacaze-Duthiers 1881).

The profound divergence between the two environments hosting maritime laboratories allows their complementarity. Roscoff is favorable in summer thanks to its temperate climate, while Banyuls-sur-mer allows research to continue during winter. The geographic and biological complementarity of these two stations enriches experimental zoological research and shows its local character. Although the two stations are designed according to a relatively similar plan, it was necessary to adapt to the natural conditions of the two localities. Thus, they complement each other precisely through the natural differences they offer.

Lacaze-Duthiers, by emphasizing the necessary adaptation of its stations to their respective environments, participates in an epistemological revolution by anchoring scientific knowledge in specific material and environmental contexts. Indeed, this practical approach marks a break with previous conceptions. The way of studying animals, of listing them and reproducing them in bestiaries shows a total carelessness regarding the adaptation of knowledge to the environments from which it draws its sources. The need for a permanent station for a local study is not limited to the simple construction of a building. It is essential that naturalists establish themselves in this environment. Lacaze-Duthiers attaches great importance to the accommodation capacity of its stations to accommodate not only researchers but also student interns. He firmly believes that field is the best teacher. He draws this idea from his own experience and his rejection of traditional academic education, which he found too theoretical and abstract. He thought that the youth of schools and faculties should be put in immediate contact with nature (Lacaze-Duthiers 1864, 342).

Lacaze-Duthiers' approach revolutionizes zoological learning by combining theoretical and practical knowledge in the field. At Roscoff, students and researchers work together, learning directly from their observations and experiences of the strike. It is not only a question of integrating the natural environment studied, but also the social environment of the localities:

> As far as I am concerned, he said, I have never failed to draw great benefit from my relations with even the most ignorant practice. It is to a Spanish fisherman that I owe having found and studied the true purple; it was an oyster farmer who taught me how we could usefully use a small marine snail to oppose the invasion of oyster beds by algae. [...] I must humbly admit that he is a practitioner of sables d'Olonne which proved to me the usefulness of this distinction. (Lacaze-Duthiers 1864, 342)

Frédéric Houssay summarizes well the educational interest of this new approach: "By following the flow, the young naturalist sees discoveries swarming under his feet. [...] The moving edge of the flow is thus the best school and is recommended for beginners who want to learn about marine zoology, and who, forced through circumstances, learn with joy a host of essential things – odious if they must be retained by 'bookish' memory alone" (Houssay 1893, 180).

Lacaze-Duthiers is opposed to the strict distinction between research observatories and those dedicated to education. Housing therefore constitutes a determining factor in this new research pedagogy, and Lacaze-Duthiers is fully aware of this. Regarding accommodation, Banyuls-sur-Mer will first serve as a place for experimentation and comparison with its sister resort. Indeed, despite the generous donations from the municipality and residents, a lack of financial means is felt, making it impossible to develop housing in the same way as in Roscoff. Lacaze-Duthiers then transforms this financial constraint into an opportunity for experimentation.

He plans to compare a station welcoming students with a station exclusively organized around research. This idea was inspired by observations of foreign scientists who came to Roscoff, who considered teaching and research as incompatible. These underline the divergence of objectives: while zoologists work with a view to research and discovery, most students focus solely on passing exams. Isn't this precisely what Lacaze-Duthiers wants to reform? The zoologist Louis Agassiz (1807-1873), visiting the Oceanological Observatory of Banyuls-sur-mer, had entered a remark in the laboratory registers in which he distinguished two main categories of maritime stations. For him, there are observatories which exclusively provide the means of work and original research and those which aim to provide zoological education to students. Lacaze-Duthiers combines the lack of means and the observations of foreign scientists to experiment with the two conditions and have a station offering accommodation as well as a station without housing (Lacaze-Duthiers 1898). Finally, he retains a unanimous need from this experience. All the naturalists who came to stay in Roscoff and went to Banyuls-sur-mer to continue their work during the winter regretted not living near their objects of study. It then becomes obvious that habitable marine stations are becoming one of the most powerful means to promote progress in zoology (Lacaze-Duthiers 1898).

In 1872, six to eight scientists could work in Roscoff, in August 1887, there were twenty-five researchers, including fifteen housed in the laboratory. Housing is a central point of this new experimental approach. It is not only about bringing the researcher closer to their object of study, but also and above all about involving them in the same environment. The rooms are equipped with small aquariums, glass vases, nets, preservative liquids, microscopes, scalpels and other tools necessary for fishing and zoological study. Naturalists go down from their rooms directly to the sea when the tide is low, so they can choose their own samples (Lacaze-Duthiers 1873).

Thus, the need to accommodate researchers and students so that they can literally establish themselves in the soil that they share with their object of study is recognized as a means of promoting the progress of French zoology, and even of reforming it. Lacaze-Duthiers considers that "nothing, during a long period of work, can replace living in the laboratory, alongside one's experiments" (Lacaze-Duthiers 1895, 5). This is how the Arago laboratory will finally adopt the Roscoff organization, allowing permanent habitation.

As the observatory evolves and the use of new technologies becomes more complex, Lacaze-Duthiers understands the importance of extending this idea of housing to all essential members of the station. He thus recognized that it was essential to provide housing for the mechanic, who also had to live near his machines and his workshop (Lacaze-Duthiers 1895).

Image 2: The mechanic Joseph David [1893]
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This illustrates how localization calls for a fixation of all functions within the observatory. The habitation represents a true transformation of zoology, both epistemological and practical. This embodies the need to consider knowledge as inseparable from the researcher's integration into the study environment. The evolution of zoology in the second part of the 19th century follows this formula by showing that knowledge is constructed through a process of integration and localization.

The free provision of infrastructure in the Roscoff and Banyuls-sur-mer resorts is a central aspect of Lacaze-Duthiers' approach. Unlike other European and Anglo-Saxon stations where access is paid, this free access attracts many researchers and students. Indeed, as one can imagine, the equipment used and, in general, all the means made available to researchers and students have a cost. This cost is entirely covered by the maritime stations of Roscoff and Banyuls-sur-mer. However, one only has to look at other European countries or in England to see that this practice is not common in the rest of the zoological world. For example, the Naples station, founded by Anthon Dohrn (1840-1909) in 1873 and considered a model for all zoological stations in the world, operates in a much more liberal manner, with a system of rental of work tables and rooms by the month or year, as well as the possibility of hiring assistants. Lacaze-Duthiers sees this free provision as a way to free science from socio-economic constraints, allowing zoological research to fully flourish.

Constraint is a central theme in Lacaze-Duthiers' work. Indeed, its maritime stations are the product of a desire to free ourselves from constraint. He considers that zoological work requires a real burden for a student and even for many professors (Lacaze-Duthiers 1895, 7). This is why the question of free access plays an important role for the founder of the two stations.

In England, several people make the same observation. Francis Arthur Bather (1863-1934), professor at the British Museum, was among those who visited Roscoff. In 1894, he published a text comparing the Roscoff station to that of Plymouth in England, located on a similar meridian. It highlights the difference in policy regarding the economic management of the two observatories. This management directly influences the influx of scientists into these stations: although the Plymouth station is better equipped than that of Roscoff, it nevertheless attracts fewer researchers. The first reason, according to Bather, is cost.

The high cost of rental influences the attraction of researchers who find themselves, for the most part, unable to carry out their research due to insufficient resources. In Roscoff, there is no financial obligation imposed on naturalists who have received hospitality. Everyone is free to give what they want, and this money (always given anonymously) is returned to the fund of each of the laboratories, to then be shared and distributed among the sailors and staff (Lacaze-Duthiers 1894).

A final example of Lacaze-Duthiers' epistemological vision is found in the absence of aesthetic considerations. Thus he says that "it is neither the columns, nor the large perspectives, nor the inscriptions in large gold letters, which make carry out good and solid work" (Lacaze-Duthiers 1895, 12). In the absence of sculptures and ornaments, the first building which resembles a barracks offers "as many things as possible useful to the research and needs of the workers" (Lacaze-Duthiers 1895, 12). By comparing the aquarium of Banyuls-sur-mer to that of Naples, Frédéric Houssay shows "the exclusively scientific concern" (Houssay 1893, 182) of the Côte Vermeille station. So he says that the impression provided by the Banyuls aquarium cannot be compared to that felt in Naples. There, everything is arranged to seduce and charm the tourist in love with art more than zoology: here everything is combined for the workers; and the visitors, because they come nevertheless enjoy a rare spectacle, even if it is not arranged for them (Houssay 1893, 182).

Towards a Relational Epistemology

Lacaze-Duthiers' approach, combining housing, land and free accommodation, transformed not only teaching and research methods in zoology, but also the social and economic landscape of the surrounding communities. Its stations become places of dynamic interaction between science and society. Lacaze-Duthiers' positivist vision is based on an "independence" conception of science, distinct from social and economic influences. We could thus speak of a realistic empiricism, in order to designate this idea of an external reality which is revealed through an empirical and experimental practice of science. This notion of scientific purity, separated from financial questions and luxury, guides the establishment of the Roscoff and Banyuls-sur-mer stations, which are free and solely dedicated to research and teaching. This free access attracts zoologists for obvious economic reasons. Thus, this particular vision of science creates a structure influencing and shaping the network of relationships of the actors in the discipline. Epistemological and economic reasons are therefore intrinsically linked and exist only in a system of interdependent relationships.

If Roscoff benefited from significant state aid, the Banyuls-sur-mer station was built with funds from private initiative (Lacaze-Duthiers 1894). The government only took charge of the station, accepted ownership of it and agreed to provide for its maintenance and the expenses necessary for the studies after a serious examination of the buildings by the academy's architect. from Montpellier in 1882.

The first building, located in the bay of Fontaulé, south of the village, has a square shape and resembles a barracks. It is installed on the rocky edge of the promontory, the materials for the foundations being extracted from this same stone. The building has a first floor with work offices and an unfinished attic. The ground floor houses a large room intended to become an aquarium, where researchers store fishing equipment, and a small temporary room for the keeper. The laboratory is separated from the neighboring house by a two-meter corridor wide, essential for access. It is in this state that the Arago Laboratory, at the request of Lacaze-Duthiers, is accepted by the Minister of Public Education, thus becoming an observatory of the French State.

Image 3: First building of the Arago laboratory [1882]
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Image 4: Expansion work at the Arago laboratory (Lacaze-Duthiers on the right) [1893]
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The construction of the laboratory integrates with its environment, adapting to the physical environment of the bay of Fontaulé and the social environment of the village of Banyuls-sur-mer. Lacaze-Duthiers describes this adaptation as a fierce struggle to establish the means of subsistence of the observatory, sorting out the positive elements of the environment and overcoming the obstacles hindering the development of a pure science, freed from all external constraints. The founder frequently emphasizes the idea of transformation and attraction that his work brings to the village of Banyuls-sur-mer.

At the time mentioned by Lacaze-Duthiers, the bay of Fontaulé was desert and difficult to access, requiring fording the Banyuls river, the Ballorye. However, the situation changed with the construction of a footbridge by the Ponts et Chaussées, thus facilitating passage at all times. The installation of the laboratory transformed the region, leading to the construction of infrastructure such as a wharf and stairs leading to Grosse Island. The presence of the laboratory has also stimulated real estate development, with villas and a bathing establishment, making this stretch of coastline a popular center of attraction for walkers.

The Sunday walks mentioned by Lacaze-Duthiers reflect a common orientation gradually adopted by the scientific actors and the inhabitants of the village. The Fontaulé thus becomes "the goal of the walk". Consequently, the initially abstract project of installing a laboratory in a predetermined environment materializes through a co-evolution between this observatory and its environment; whether natural, social or technical.

Image 5: Walk on Fontaulé of Banyuls-sur-mer [1900]
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The book by Isabelle Stengers and Ilya Prigogine entitled *The New Alliance* seeks to go beyond this common conception which presents science as a permanent evolution based on liberation from the constraints of society, prejudices and "lazy common sense". This "classical" epistemology presents the scientist as an ascetic who frees himself from social contingency; which represents the epistemology of Lacaze-Duthiers quite well.

Hence this conclusion that the scientific community should be protected in relation to the demands, needs and requirements of society. Scientific progress would constitute an autonomous legal process, which any "external" influence, any interest determined by the scientist's participation in other cultural or social activities, or by the need to obtain resources, could only disrupt, divert or delay. This ideal of abstraction, of withdrawal from the scientist, is often based on the evocation of what would be an essential element of the vocation of the "real" researcher: his desire to escape the vicissitudes of the world (Prigogine and Stengers 1979, 48).

Therefore a paradox is expressed in this double contradictory movement. On the one hand Lacaze-Duthiers seeks to free zoology from external constraints by making it autonomous, on the other hand he links it to networks increasing in complexity, mixing social, economic and technical conditions.

We then see the emergence of two notions of environment that it is essential to distinguish while understanding their intimate relationships in the context of maritime laboratories. On the one hand, there is the natural environment of marine organisms, that is to say the environment in which these living beings evolve and which became the very object of zoological research in the 19th century. The integration of this environment allows us to better understand the interactions and adaptations of species to their environment.

On the other hand, there is the human, economic and material environment of maritime laboratories. The organization of these laboratories involves a complex interaction with a technical-social network, made up of the infrastructure, economic resources, and human relations necessary for the construction and maintenance of these stations. This environment is essential to support research activities and to create a framework conducive to scientific exploration. Taking these two environments into account is crucial to understanding the evolution of experimental zoology. While the study of marine organisms in their natural environment allows an in-depth understanding of biological processes, the integration of the laboratory into its human and material environment guarantees the sustainability and effectiveness of research. Although necessary for a rigorous epistemological analysis, it is obvious that these two environments intersect and shape a common environment.

During a session at the Academy of Sciences, Lacaze-Duthiers received a donation of 50,000 francs from Prince Roland, allowing the construction of a motorboat in 1893, named "the Roland". This boat replaces the sail, considered insufficient and too dependent on weather conditions for zoology research. The steam engine offers new stability and independence, facilitating the dredging work necessary to study marine animals, particularly in the Mediterranean where tides are absent. Indeed, as Frédéric Houssay explains when speaking of Banyuls-sur-mer, as there is no tide, the majority of the animals studied must be collected by dredging. To flirt, you need very good weather: dead calm is ideal for this operation; an unrealizable ideal, since then the sailing boat cannot leave the port. There is no need to dwell at length after this overview on the violent desire for a steam boat that a director of Mediterranean stations can imagine (Houssay 1893, 183).

The Roland was not the first introduction of steam to Banyuls-sur-mer. From 1887, a steam engine replaced the self-propelled mill, operating a rotary pump to regularly supply the aquarium and the experimentation tanks. This technical innovation is crucial for reproducing the living conditions of the species studied. In the early days of the formation of the Roscoff station, the pump which supplied the water was operated manually (Lacaze-Duthiers 1891). The stability of these conditions is ensured by sophisticated technical systems, such as the network of pumps and tanks, guaranteeing a constant environment despite external hazards.

The reliance on technical systems to sustain life in aquariums demonstrates that zoological research relies on a complex technological infrastructure. In the event of a malfunction, such as the destruction of the mill by a mistral blow, life in the aquariums is directly threatened (Lacaze-Duthiers 1895). The reproduction of vital conditions relies on mechanisms, ranging from the simple operation of a self-propelled mill to the use of a rotary pump governed by the laws of thermodynamics. Thus, life is recreated from a technical network. The apparent stability of living species is therefore maintained through continuous adaptation and the constant use of techniques allowing them to reproduce their conditions of existence.

Thus, steam engines not only improved navigation by making it more free and autonomous, freeing zoologists from the vagaries of the wind and sea currents. They also make it possible to stabilize the living conditions of aquariums, i.e. the object of study of the naturalist. There is therefore an empowerment which occurs through the complexity of the zoology network. Freedom of maneuver is conditioned by technical integration into the environment. The autonomy of the Arago Laboratory is achieved through the progressive integration of technical elements essential to its operation. The steamboat, although beneficial, also brings its share of constraints such as maintenance and repairs. This requires the creation of a workshop to meet the needs of steam engines, thus contributing to the formation of a self-sustaining network.

According to the theory of individuation by Gilbert Simondon (1924-1989), the Arago Laboratory evolves into a system of complex relationships where each technical element becomes an integral part of a network, rather than simple tools serving a theoretical end. In fact, it is about the constitution of a common environment which engages objects as subjects, through technical mediation.

The Arago Laboratory does not superimpose itself on intact nature nor distort a primitive natural environment. Lacaze-Duthiers did not impose his project on the commune of Banyuls-sur-mer; rather, he participated in a compromise, an equilibrium in which laboratory and environment mutually transform each other. The station does not just observe the environment, it is an integral part of it. It is not simply a structure placed on the promontory after the plans have been finalized. For example, the use of Fontaulé stone to build the first walls of the station shows that construction does not destroy the natural landscape but actively transforms it. As Serge Moscovici (1925-2014) says, "the natural environment is not defeated, diminished by techniques, but modified by another natural environment into which it is integrated" (Moscovici 1968, 40).

The example of the Arago Laboratory shows that a maritime station is distinguished by its technical ensemble designed to study the natural environment in which it is located. This set integrates the specific requirements of the environment it explores, thus creating an interaction between the scientific tool and the object of study. This situation makes it impossible to design an abstract technical system, adaptable to any natural environment. Indeed, if this technical set is specifically invented for a particular environment, then the objective study of this environment is closely linked to the relationships and local conditions which have shaped this set.

This dynamic underlines that the study of the natural environment cannot be done outside of the local context. For example, the networks that form maritime stations, although they may appear similar, are in reality strongly influenced by their respective localities. In Banyuls-sur-mer, the scientific infrastructure depends on collaboration with local fishermen, while in Roscoff, researchers organize themselves autonomously to collect their specimens due to the distinct geographical conditions.

Image 6: Fishing boats on the beach at Banyuls-sur-mer (or Catalan boats) [before 1882]
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In fact, the operation of the Banyuls-sur-mer station is closer to that of the Naples station. The same animal collection processes developed due to the low tides of the Mediterranean. The same needs were met by the same equipment (Houssay 1893).

We therefore find the same type of organization achieved while the two stations develop under separate managements. Conversely, the Roscoff and Banyuls stations were organized differently, although they were both managed by Lacaze-Duthiers (Houssay 1893). This demonstrates that technical, social, and ecological networks develop in a unique way depending on local specificities and the composition of environments. Thus, it is impossible to dissociate an individual, a technical ensemble and even scientific knowledge from the environment in which they evolve, because they interact and transform each other. Knowledge, far from being abstract entities, is rooted in a networked reality. This interaction between technical elements and the environment studied leads to an understanding of reality that is embodied and relational, and not a simple theoretical abstraction. This implies that all scientific knowledge, at least from experimentation, is the product of a complex network of local, historical and material relationships.

Finally, the analysis of maritime laboratories reveals an interesting contradiction between Lacaze-Duthiers' realistic vision and the relational reality of networking. By realism I mean here the idea that there is an independent nature which is the subject of science. While scientists sought to establish objective and universal facts, their practices revealed a dependence on a complex network of actors, instruments and institutional contexts. This networking of scientific activities has shown that the production of knowledge is a collective and distributed process, where interactions between the various elements of the network play a determining role. The analysis of the evolution of the Arago Laboratory highlights this tension between the empirical-realist vision of Lacaze-Duthiers and a relational reality, highlighting the importance of considering the sciences not only as knowledge-producing disciplines, but also as social and relational activities modifying the environment.

Conclusion

The maritime laboratories of the *Belle Époque* not only revolutionized marine zoology by transforming it into an experimental science, but also left a structural legacy. Much more than theories or even scientific results, the networking of marine zoology has created the conditions of possibility for a study of organisms in their living environment.

Lacaze-Duthiers' work illustrates the crucial role of infrastructures and networks in scientific development. Its maritime stations and its journal made it possible to structure experimental zoology and promote an integrated approach to zoological research. Through these epistemic structures, zoology has played a crucial role in the conceptualization of the environment, by highlighting the study of the relationships between living beings and their environment, and by contributing to a new localized and contextual scientific approach. My analysis revealed that the zoological study of organisms in their environment co-evolves with the environment itself. The transformation of zoology from a descriptive to an experimental approach illustrates this process. The concept of environment has become central in this zoological revolution, reflecting the epistemic function of maritime stations. The Arago Laboratory study showed that knowing living things involves transforming one's environment, highlighting a performative knowledge that is not limited to an abstract vision of the world but a concrete and integrated position.

Science historian Jürgen Renn notes that "infrastructure serves as the backbone for the transmission of knowledge systems, guaranteeing their long-term continuity" (Renn 2022, 48). This is exactly what maritime laboratories are. The evolution of zoology during the second half of the 19th century reveals the true conditions of possibility of contemporary natural sciences. It is no longer a question, as in the 18th century, of listing living organisms based on morphological criteria disconnected from their environment. It becomes necessary to study the environment itself and the relationships that operate there. The conditions for knowledge of living things therefore become material and are organized in networks through maritime stations which are like the "organs [...] with which contemporary science perceives the phenomena of marine life" (Houssay 1893, 170). Zoology becomes experimental and integrates the environments it studies. In doing so, it in turn participates in the transformation of the environment.

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