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The "Eels" of South America: Mid-18th-Century Dutch Contributions to the Theory of Animal Electricity

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Abstract. During the mid-18th century, when electricity was coming into its own, natural philosophers began to entertain the possibility that electricity is the mysterious nerve force. Their attention was first drawn to several species of strongly electric fish, namely torpedoes, a type of African catfish, and a South American "eels." This was because their effects felt like those of discharging Leyden jars and could be transmitted along known conductors of electricity. Moreover, their actions could not be adequately explained by popular mechanical theories. Many of the early documents supportive of the hypothesis of animal electricity were associated with the Dutch colonies in South America. This article presents and examines those documents, and shows how Dutch scientists on both sides of the Atlantic conducted experiments and communicated with each other in the 1750s and 1760s. It reveals the important roles played by inquisitive physicians and lovers of nature in South America, and by natural philosophers and collectors of exotic specimens in the Netherlands—learned men who began to make a credible case for animal electricity in some exciting places at a pivotal moment in time.

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It is worth speaking here of the Gymnotus,
and particularly of the American Torpedo.
Nobody, unless if instructed by the experiment,
could imagine that, by simple contact, this fish
could produce the same shock as that caused
by electric fire.

Trans. from David Hieronimus Gaubius (1758)[1]

Introduction

Electric fish are one of the wonders of the natural world, stunning prey and protecting themselves in ways that for centuries seemed to defy rational explanation. Fascinating for the numbing effects they could have on other fish and even people, even without direct contact, these unusual creatures figured prominently in two of the most important scientific advancements of the modern era—one in physics and the other in physiology.

In the field of physics, they led Alessandro Volta to the pile, "the most wonderful instrument that men have ever invented, with no exception, not even the telescope and the steam engine," as French physicist Louis Arago said in the 1831 *éloge* he gave for Volta at the Académie des Sciences in Paris.[2] In his published letter of March 20, 1800, in which he described his new battery to Joseph Banks, President of the Royal Society of London, Volta called his new invention an *organe électrique artificiel*. He explained that its form was similar "to the *natural electric organ* of the torpedo and of the trembling eel."[3]

Volta had earlier accepted the notion that some fish are electrical, and as an inventor he had been inspired by the structural and functional characteristics of their electric organs, which had been studied in the 1770s by individuals he knew and respected at the Royal Society of

[1] Gaubius, 1758, Preface to volume III of Seba, 1734–1765, second page, unnumbered.

[2] Arago, 1854, vol. I, pp. 219–220.

[3] Volta, 1800. p. 400.

London. These men included natural philosopher John Walsh, anatomist John Hunter, and fellow physicist Henry Cavendish. The idea of interposing humid material between the bimetallic discs Volta had stacked in columns stemmed directly from what he had learned from them about the electrical organs of these fish.

The second landmark scientific achievement that can be traced to electric fish research in the 18th century is the idea that the nervous system functions electrically. In 1791, Luigi Galvani argued in his *Commentarius* on electric forces in animals that electricity is not just a property of a few unusual fish, but a force that could also explain human nerve and muscle physiology.[4] Galvani's own experiments were primarily on frogs, but they too were stimulated by previous experiments suggesting the electrical nature of the fish shocks, especially those conducted by Walsh, who in 1776 drew a spark from a South American "eel" that had survived the voyage to London.[5]

Books and articles have been written about the death of "animal spirits" late in the 18th century, and how the electric fish research of Walsh and his colleagues at the Royal Society of London inspired Volta to his battery and Galvani to his revolutionary physiology.[6] Yet much less has been said about the observations and experiments on electric fish that preceded Walsh, and specifically the important roles played by the Dutch in South America and the Netherlands in the middle of the century. The primary aim of this article is to provide new information on this pivotal and extremely important phase of earlier electric fish research. The material we shall present also sheds light on the nature of 18th-century science, the excitement caused by these fish, and how scientists and collectors of biological specimens communicated with each other in Holland and the Dutch colonies, and with colleagues elsewhere in the world, during this time.

The Mechanical Setting

During the first half of the 18th century, it was generally assumed that the effects produced by those fish we would now regard as strongly

[4] Galvani, 1791.

[5] Galvani envisioned a neuromuscular system that would function like a physicist's Leyden jar, an early capacitor with wires (the nerve fibers) allowing for the communication between the internal and external part of the muscle fiber, the ultimate source of the 'electric fluid' being the brain. Walsh envisioned the Leyden jar model in order to account for the discharge of the torpedo.

[6] Walsh, 1773. See Piccolino and Bresadola, 2002, 2003a; for further reading see: Pancaldi, 1990; Piccolino and Bresadola, 2003.

electrical involved rapid muscle contractions or mechanics. This view, which was largely based on the perceived trembling movements associated with their actions, emerged with some Italian followers of Galileo in the second half of the previous century.[7] These investigators focused on reinterpreting natural phenomena previously attributed to occult or metaphysical forces, and on avoiding terms they viewed as meaningless, including virtues, qualities, and affections. This was one of the main aspects of the cultural program explicitly expounded by Galileo in his main works, and particularly in his *Saggiatore* and *Dialogo sopra i due massimi sistemi del mondo*.[8]

In 1671, Francesco Redi raised the possibility that the sea torpedo he was studying in Italy might produce its numbing effects by mechanical actions.[9] Seven years later, Stefano Lorenzini (1678) conceived that its numbing effects could be due to the violent mechanical emission of a multitude of minute corpuscles that could penetrate the hand or arm of the experimenter, and would interfere with nerve conduction. Giovanni Alfonso Borelli, in a posthumous work published in 1680–1681 (his *De motu animalium*), also invoked a mechanic explanation, albeit one that did not imply any kind of corpuscular emission.[10] Borelli's hypothesis was based on a percussive-concussive action, like that felt when receiving a sharp blow to the elbow.

French naturalist René-Antoine Ferchault de Réaumur presented another variation of the mechanical theory, which he presented at the Paris Académie des Sciences in 1714, after conducting a series of experiments on torpedoes at La Rochelle, where he was born.[11] He wrote that the torpedo's upper surface, normally flat or even concave in a resting state, becomes convex at the moment of the shock. He provided an anatomical description of the specialized organs responsible for the shock, and ascribed the cause to the elastic actions of the minute muscular fibers composing these organs, which he compared to minute "mechanical springs" (*ressorts*). Numbness due to nerve compression, he explained, was a consequence of these violent mechanical actions.

[7] For a discussion on the possible reasons of the mechanical interpretation of fish shock, see Piccolino, 2005.

[8] Galilei, 1623, 1632.

[9] Redi, 1671; Redi's description of the torpedo is on pp. 47–55, and the mechanical hypothesis is alluded to on p. 54.

[10] Borelli, 1680–1681; Borelli discussion of the torpedo's shock is on pp. 441–442 of the second volume of his work.

[11] See Réaumur, 1717.

Réaumur's variation of the mechanical doctrine became widely accepted by naturalists, physicists, and others interested in these fish.

The 18th Century and Electricity

Réaumur's mechanical theory of the torpedo's powers drew a large following in the first half of the 18th century. With time, however, attention began to shift to other natural forces. Electricity in particular began to dominate the literature as an explanation for a wide variety of phenomena.[12] This was a consequence of many factors, including new discoveries, improved technologies, and theoretical advances. Additionally, there were some spectacular successes, including experiments showing the electrical nature of lightning.

The clear distinction that could be made between conductive and non-conductive bodies, and the demonstration that electricity could travel along a long metal wire at a very fast speed, were of particular importance. And on the technological side, in addition to the construction of new and powerful friction-type electrical machines and atypical electric generators (such as Alessandro Volta's "electrophore"), the invention of the Leyden jar (Figure 1) in the 1740s was of tremendous importance for researchers. The Leyden jar functioned as a primitive electrical capacitor and was invented independently by Ewald Georg von Kleist in Pomerania and by three experimental philosophers in the Dutch town of Leiden: Pieter van Musschenbroek and two collaborators, Jean Nicolas Sébastien Allamand and Andreas Cuneus.

Musschenbroek was well known in scientific circles and he wrote in a colorful way about how the jar accidentally came into being in a letter to Réaumur, then his correspondent at the Académie des Sciences and the organization's perpetual secretary. Because Leyden jars could be charged by machines or by simple friction, they could be taken into situations previously not considered fit for electrical experiments. This made it relatively easy to compare the discharges produced by fish that could cause numbness with electricity, even in locations where there were no well equipped *cabinets de physique*, some far from the shores of civilized Europe. It is not by chance that the association of the fish shocks with an electrical force occurred soon after the Leyden jar became universally adopted as an electrical tool (see below).

With the development of electric science, there was, moreover, an interest in the possible therapeutic effects of electricity. During the middle of the 18th century, the "electric fluid" was administered in

[12] Heilbron, 1979.

Figure 1. Leyden jar. (Courtesy of the Museum Boerhaave, Leiden, The Netherlands.).

various ways to treat a variety of diseases. Early on, electrical medicine was viewed as a kind of panacea by some people, although doubts soon emerged about the efficacy of the electric treatments, at least for some disorders, such as palsies of long duration.[13]

The possible involvement of electricity in nervous function and muscle excitability also began to be debated at this time,[14] as the theory of ''animal spirits'' began to wane. In the classical system of Galen, animal spirits were supposed to flow through the hollow nerves to produce motions and generate sensations. This basic idea underwent many modifications over the years, and one view was that the animal spirits made muscles stiffen by inflating their fibers. This view was slowly abandoned during the course of the seventeenth century, and in post-Cartesian science the prevailing idea was that animal spirits were fluids

[13] Bertucci, 2007; Finger, 2006; Rowbottom and Susskind, 1984.

[14] See Duchesneau, 1982; Piccolino and Bresadola, 2003.

that could produce muscle contractions by chemical processes akin to fermentation.[15]

The possibility that nervous conduction could imply an electric agency was alluded to in a hypothetical way by Newton at about the same time as Réaumur was proposing his mechanical theory to account for the torpedo's benumbing actions. In the *Scholium generale* added to the second edition of the *Principia*, and in the *Queries* 22–24 of the second edition of th *Opticks*, Newton raised the possibility that nerve actions might be a consequence of vibratory or elastic movements of an æthereal medium penetrating the solid parts of nerves. This medium was thought to be similar to that involved in electric and magnetic phenomena.[16]

In 1733, Newton's suggestion led Stephen Hales to propose in a direct way that nervous conduction might be based on electrical processes.[17] The possible electric nature of the animal spirits had a number of supporters in Bologna during Galvani's youthful years, although it was strongly criticized by those who accepted Albrecht von Haller's doctrine of "irritability." According to Haller, whose theory dates from the 1750s, muscles possess an intrinsic capability to contract in response to physiological or experimental stimuli (or "irritability"). Nerves bring about muscle contractions by putting this internal capability into action, but they are not the effective agents of the contraction, as generally assumed by the supporters of the "neuro-electric" theory.[18]

Haller and his followers, including Felice Fontana and Marc'Antonio Caldani in Bologna, raised various objections to the idea that the nerves may trigger muscle contractions by releasing an electrical force. They pointed to the presumed impossibility of an internal electric disequilibrium required to move an electric fluid down the nerve fibers. They argued that the presence of conductive humors inside animal tissues would dissipate any electrical disequilibrium generated internally. Moreover, and for a similar reason, an electric flow would not be restricted to specific groups of nerve fibers (as required by the physiological needs), thus

[15] See Walker, 1937; Home 1970; Clower, 1998; Ochs, 2004.

[16] Newton, 1713, 1718.

[17] Hales, 1733.

[18] Neuro-electric (or (or nerveo-electric) fluid (or force) were expressions recurrent in the literature of the second half of the 18th century, particularly in the context of the controversy between the supporters of Haller's theory of irritability and those who conceived an involvement of electricity in nervous conduction (see Piccolino and Bresadola, 2003). See also: von Haller, 1756–1760; Cavazza, 1997; Duchesneau, 1982.

leading to unwanted functional consequences (as, for instance, moving the entire foot when one wished to move just one of the toes). Another difficulty came from the different effects of nerve ligature on the propagation of nerve signals, compared to electric conduction along nerve tissue: electric conduction persisted, whereas nerve signal propagation was blocked, as evidenced by the loss of movement or sensation.[19]

These objections of Haller and his followers also applied to the supposition that the benumbing actions of a few fish, including the torpedo, could be due to internal electricity. Thus, it is no wonder that Haller adopted the mechanical theory of fish shock proposed by Réaumur, and dealt directly with this subject in the chapter devoted to movement and muscular contraction in his *Elementa physiologiae* (see below). To think that fish could deliver electric shocks seemed to defy the known laws of physics. It was akin to thinking that an electric device, such as a Leyden jar, could remain charged after being immersed in water!

The Family of Electric Fish

When the Leyden jar appeared on the scene, sea torpedoes were the best known of the three different types of fish capable of numbing prey or even an experimenter's hand. The Greeks and Romans, including Aristotle and Galen, wrote about these flat rays with disk-like bodies and small tails, and they began to be beautifully illustrated in European texts in the 1500s (e.g., in the books of Belon, Rondelet, Salviani, Gessner, and Aldrovandi).[20]

A second benumbing fish with a long history is an African silurus, and its image can be found on Ancient Egyptian tombs. This catfish is capable of delivering shocks up to 300 V (the shocks of common torpedoes are only about 50 V). Sometimes called the Nile catfish, although it inhabits other rivers too, it was often referred to with the same terminology as the saltwater torpedo, namely *narke* in Greek and *torpedo* in Latin. This

[19] Cavazza, 1997; Fabri, 1757; von Haller, 1757–1768; see also Caldani, Marc'Antonio Leopoldo. 1757. *Sur l'insensibilité et l'irritabilité de Mr. Haller. Seconde lettre de Mr. Marc Antoine Caldani*, in van Haller, 1756–1760 (ed), vol. III, pp. 343–490; Laghi, Tommaso. 1757. *Cl. Viro D. Cesareo Pozzi [epistola]*, as referred to in Fabri, 1757, vol. II, pp. 110–116 and Fontana, Felice, 1757. *Dissertation épistolaire […] adressée au r.p. Urbain Tosetti*, in von Haller (ed.) 1756–1760, vol. III, pp. 157–243.

[20] See also: Kellaway, 1946; Wu, 1984; Whittaker, 1992; Moller, 1995; Debru, 1966; Copenhaver, 1991.

generic terminology occasionally limited a clear identification of the species and triggered confusions in the older literature.

New descriptions of this river fish appeared in the Western literature at the beginning of the seventeenth century, when Portuguese missionaries encountered them in Africa, most notably in Ethiopia. Antonio Fernandes, Pedro Paez, and Manoel de Almeida described them in their letters or manuscripts. In 1615 Nicolao Godinho,[21] mentioned Fernandes' report of the African ‘‘torpedo’’ and subsequent writers cited their writings.[22] Although the nature of the discharge was not addressed, the recurrent indication was that this fish moved just before its numbing actions were felt, the very observation that would later give rise to mechanical theories, which stood in contrast to the ancient notion of a released poison or some occult quality.

The so-called electric ‘‘eel’’ was the third type of electric fish known to 18th-century naturalists and philosophers. It was of special interest because its discharges felt so much stronger than those of the other fish (at 600 V, they are twice as strong as the electric catfish). It would be this fish that would play the pivotal role in bringing fish electricity to the fore in the middle of the 18th century, and in opening minds to the broader concept of animal electricity.

These ‘‘eels’’ reside in the murky river waters of equatorial of South America. (They are not really eels but members of the knifefish family: We shall continue to use the term ‘‘eels,’’ however, because they were often called congers or eels in the 18th century.) Feared by the Indians of the Guianas and in neighboring regions, their powerful discharges are strong enough to ward off even large animals, such as horses and mules that would wade into their rivers and streams.

The earliest descriptions of these eels date from the 1500s, and they came from Spanish administrators and missionaries in equatorial South America.[23] These men did not, however, engage in systematic experiments. Late in the next century, they were described in vivid detail in *Oroonoko; or, The royal slave,* a popular novel by Aphra Behn, an Englishwoman who had visited Surinam.[24]

At about the same time, the French astronomer Jean Richer, who had visited Cayenne (now the capital of French Guiana) in the 1670s, wrote the following about these eels:

[21] Godinho, 1615, pp. 67–68.

[22] For example, Tellez, 1660; Ludolf, 1681. A modern collection of the texts of the Jesuits in Ethiopia has been published by Camillo Beccari, 1903–1917.

[23] De Asúa, 2008.

[24] Behn, 1688/2000.

> I was even more surprised to see a three to four foot fish, similar to an eel, as fat as a leg, which the fishermen call a conger, that by simple touch with a finger or the tip of a stick, so numbs the arm and that part of the body closest to it that one remains about 15 minutes without being able to move. … I was witness to this effect and I felt it, having touched the fish with my finger one day when I met up with some savages….[25]

Charles-Marie de La Condamine, the internationally known physicist and explorer, also encountered these eels. Although his 1745 description of the effects of their shocks was even briefer than Richer's, he also brought up the transmissibility of the shock through a stick (*un baton*). But like those before him, he did not mention electricity, only the "mystery of a hidden spring"—the very terminology used by Réaumur, who had studied less powerful sea torpedoes.[26]

These eel-like fish are now classified as *Electrophorus electricus*.[27] In 1766, the Swedish taxonomist Linnaeus had classified them as *Gymnotus electricus*. For Linneaus, this was a fitting name, given the electrical experiments that had recently been performed on them, and the conclusions that were now being drawn from the largely Dutch material that we shall now examine in detail.

A First Mention of Fish Electricity?

With the great interest in electricity that prevailed in the middle of the 18th century, fish capable of delivering what felt like electrical shocks excited the curiosity of experimental natural philosophers. Some of these men were well educated, whereas others were enthused amateurs. Everyone seemed to want to know more about these fish and their discharges.

What could well be the first published mention of fish electricity appeared in 1749, in a letter sent to a general culture magazine, *The*

[25] Richer, 1679, pp. 70–71. For more on Richer's scientific expedition to equatorial America, see Olmstead, 1942.

[26] La Condamine, 1745, pp. 157–158. For more on La Condamine's journey to equatorial America, see McConnell, 1991.

[27] These eels are confused with other electric fish in some 18th-century publications, including Marcus Elieser Bloch's (1786–1787) monumental work on the natural history of foreign fish. Such confusions, however, began earlier. In 1681, Hiob Ludolf referred readers to the African torpedo section in a book published by a Portuguese Jesuit, Nicolao Godinho, in 1615. Ludolf then directed his readers to what he thought must be the same fish in a book by Barlæus (Kaspar van Baerle) on Brazil!.

student or Oxford monthly miscellany.[28] Its author, Dale Ingram, was an English surgeon practicing in London. Ingram had lived in Surinam—"a colony once belonging to the English, but exchanged with the *Dutch* some years since for *New York*"—where he had personally experienced the pain and numbness caused by the local river eels. His attention to these fish was stimulated by a report published in 1748 by Richard Walter, the chaplain of an English expeditionary force commanded by George Anson against the Spanish in the New World. Walter had obtained a saltwater torpedo from a bay in Mexico, and he wrote that the ray's shock could be felt "through a walking cane," although in a more attenuated way than when touched directly.[29]

In his letter dealing with the eels, Ingram noted that its discharge could be transmitted through a metallic body but not a (dry) stick, unless it had a metallic component in it. And in the conclusion of his letter, he used the phrase "electric energy or spring" to describe the force responsible for the fish shock.

In the period from 1750 to 1770, Ingram's report was translated and presented several times in German periodicals, including in the *Hannoverische gelehrte Anzeigen* and the *Physikalische Belustigungen*.[30] Notably, what can be regarded as his rather ambiguous phrase about electrical energy or spring was translated as *elektrischer Kraft und Wirkung,* meaning "electric force and effect" in these publications.

The Dutch Step Forth

Dutchmen were in a particularly privileged position when it came to associating these South American eels with electricity. There were several reasons for this. One was that their physicists, led by Musschenbroek and his associates, were making important discoveries in the science and technology of electricity. A second was that their scientists and collectors of *naturalia* had a great interest in zoology and the money and means to obtain coveted exotic specimens.[31] And a third was that these eels were common in the rivers of the Guianas, where they had

[28] Ingram, 1750a, pp. 49–52.

[29] Walter's account of Anson's voyage was a bestseller, with an astonishing number of editions in several languages. It contributed in an important way to reviving interest in electric fish during the mid-18th century. The description of the torpedo can be found on p. 266 of the ninth English edition of 1756.

[30] See Ingram, 1750b, 1770.

[31] See Müsch, 2005.

established colonies for commercial (e.g., sugar cane and other crops) and strategic reasons.[32]

Given these facts, it is not surprising that some learned Dutchmen would set their sights on the powerful eels of South America soon after the discovery of the Leyden jar and the publication of Ingram's report, which stemmed from his visit to Surinam. Nor should it come as a surprise that the first important Dutch contribution from the region would involve one of Leiden's leading physicists, Jean Allamand.

Storm van 's Gravesande and Jean Allamand

Born in Switzerland and trained for the ministry, Jean Nicolas Sébastien Allamand (Figure 2) had moved to the Netherlands in 1738. He became a professor of philosophy in Franeker (Friesland) in 1747 and was awarded a position in Leiden 2 years later.[33] He was the first professor in the Netherlands to lecture on natural history and owned an important cabinet of *naturalia* that he enjoyed showing to visitors. Allamand also taught philosophy and experimental physics and, working alongside Musschenbroek, was a co-discoverer of the Leyden jar.

Interested in the powerful eels for multiple reasons,[34] Allamand attempted to acquire a dried specimen for his collection, while also wishing to obtain more information about living eels. Hence, he contacted Laurens Storm van 's Gravesande (1704–1775), who was then in Essequibo, one of the three settlements (the others being Demerara and Berbice) west of Surinam in what was then Dutch Guiana. His contact initially served as secretary and bookkeeper for the Dutch West-Indische Compagnie in the Essequibo Colony, founded in 1616, and was now

[32] The Dutch began to establish settlements in the 'Wild Coast,' meaning the Guiana area, at the end of the 16th century. Some were destroyed several times, first by the Spaniards and later by the English and French. Only after the end of the War of the Spanish Succession (1702–1713) did it become possible to restore and extend the plantations. In particular, between 1742 and 1772, when Storm van's Gravesande was commander, the colony reached a certain level of prosperity. In this era, the public plantations of Demerara, initiated by 's Gravesande, gradually outnumbered the 140 plantations of Essequibo. The number of plantations in Surinam that had been conquered and later exchanged for New-Netherlands by the peace treaties of Breda (1667) and Westminster (1674) was 400 in 1750 and 500 in 1790. See Den Heijer, 2002, for more on this history.

[33] Suringar, 1867, pp. 265–284; Lindeboom, 1984.

[34] In addition to what was just stated, Allamand knew what Richer had written about the South American eels that seemed to have even greater benumbing characteristics than the saltwater torpedoes found off the coasts of southern Europe. He specifically mentioned Richer (but not La Condamine) in his 1756 publication on the eels.

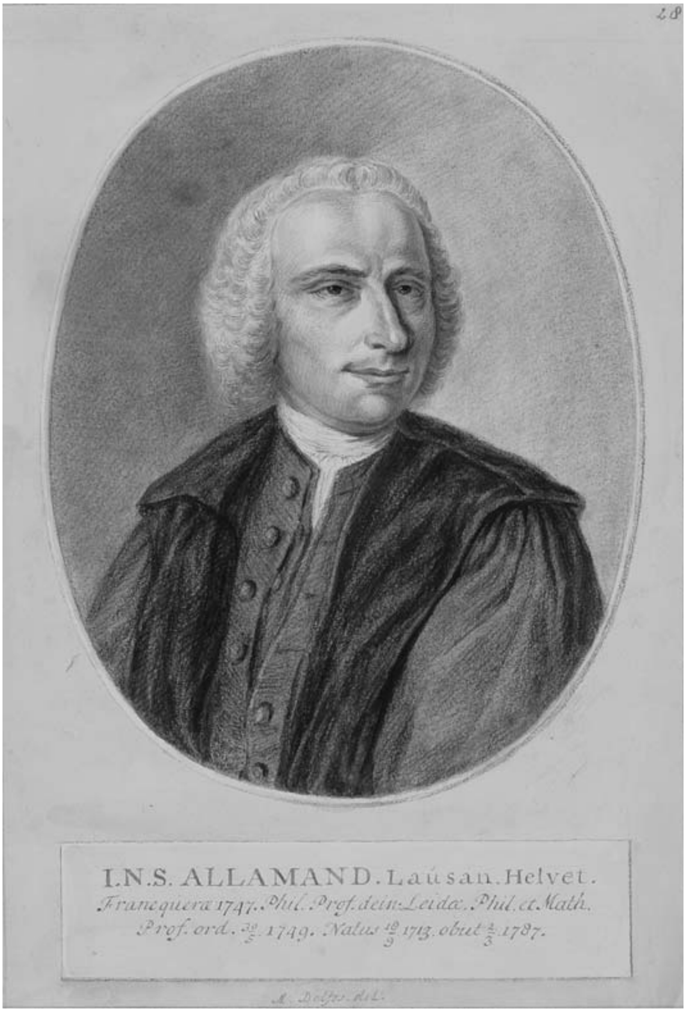

Figure 2. Jean Nicolas Sébastien (Jan Nicolaas Sebastiaan) Allamand (1713–1787). (Courtesy of the Leids Historisch Museum, Leiden, The Netherlands.).

governing it (from 1742 to 1772).[35] After the Demerara region was opened to free settlement, he was also made *Directeur-Generaal* of that territory.

An energetic and enlightened man, Laurens Storm van ‘s Gravesande was an ideal person to comply with Allamand’s request. He enjoyed studying the wonders of the region and knew Allamand’s family. In fact, Allamand had earlier been entrusted with the education of the two sons of Willem Jacob van’s Gravesande, Laurens’ uncle and a professor of astronomy and mathematics at Leiden.

[35] See Villiers, 1920.

Laurens Storm van 's Gravesande referred to Allamand as his "good friend" in his informative return letter, which was composed in French. Upon reading it, Allamand translated it into Dutch and published it after adding his own commentary. It appeared in 1756 under Allamand's name in the journal of a new scientific society in Haarlem (1752), the *Verhandelingen uitgegeeven door de Hollandsche Maatschappye der Weetenschappen te Haarlem*.[36]

The entire article, here translated into English for the first time, begins:

> Almost two years have past since I received a fish from Mr. 's Gravesande, general director of the *Volksplanting* of Issequebo; a fish that the inhabitants of the place consider a kind a eel; although basically it is a fish, called Gymnoti by Artedi and *Carapo* by Marcgraf. The gentleman to whom I have shown it, Professor Gaubius, has had a copperplate made of it, and also provided a description in the new volume of the large book by Seba, which will appear soon; thus I can be spared the trouble of describing it here. But what Mr. 's Gravesande has since written to me with respect to the effects of touching this fish is so peculiar that I do not doubt that people will receive this story with considerable satisfaction.
>
> When the gentleman sent it to me, he wrote that it was a kind of tremble fish,[37] the effect of which he had himself felt. This fish has, with respect to its form, nothing in common with the usual tremble fish, which is a kind of ray.
>
> I asked Mr. 's Gravesande to be so kind as to examine the situation from the start with accuracy, and to inform me of his observations with more details. I could not ask anyone more capable of giving me satisfaction in this matter than this gentleman since, when he is not engaged in the welfare of the Volksplanting, of which he is the manager, he passes his time becoming fully acquainted with everything remarkable that is brought forth from the areas where he stays.
>
> Examine how he answered me in a letter, dated Rio Issequebo the 22nd of the slaughtering season [November] 1754.

[36] Allamand, 1756, pp. 372–379. Allamand, became a member of the newly founded society in 1753. In the first volume of its journal, he published a paper medical electricity (Allamand, 1754). It had been sent to Gaubius, a member of the Haarlem Society since its conception, as a letter (see Note 43).

[37] "Trembling fish" is the literal translation of the Dutch term *sidder-vis*, which was synonymous with "torpedo" at the time.

With these words, Allamand presented his translation of the letter he had received from Guiana.

> "The experiment was done with an eel called a tremble fish, and what I had written to you about it in my previous letter is true. It produces the same effect as the electricity that I felt with you, while holding in a hand a bottle [Leyden jar] that was connected to an electrified tube by an iron wire. But what will surprise you more is that Mr. Charles Bolton of Barbados, who took two living fish upon his departure from here, found great interest to see and touch these fish at Barbados, and observed that several persons suffering from gouty pains in some limb were cured within two or three minutes after touching the tremble fish. This experiment has been repeated several times, but always with the same result.
>
> "If our skippers would have the slightest inclination to oblige, I would send you a few living [ones]; it is very easy to feed them with small crabs, which is their usual food. Mr. Bolton has ordered the person who replaces him [when away] to send one with each ship that leaves from here. This seems to me to be a natural rarity, worthy of examination in more detail.
>
> "If one touches the fish, it does not give off fire or sparks, similar to the apparatus for electricity. But for everything else it is the same; yes, even much stronger, because if the fish is big and lively, the shock produced by the animal will throw anyone who touches it to the ground, without exception, and one feels it throughout the whole body; all joints crack without leaving the slightest harm. All this happens in an instant.
>
> "However, here we have a certain Mr. van der Heiden, who dares to hold the fish in his hand and does not feel anything.
>
> "One sees very few of these eels in the river, but they are in all small creeks, and if one finds them, one may be certain that one will not see any fish within of eight or ten rods around it. They are good to eat: the Indians indulge others with it and they are considered a delicious snack; but if they are alive, they fear for it as for the devil."

Allamand provided this commentary:

> It appears from this story that there is good reason to give this fish the name tremble fish, considering that the effect upon touching it

does not differ from that of the common torpedo, other than it [the eel's shock] is much stronger.

The primary cause on which it [the shock] depends in the latter fish [torpedo] isn't a mystery anymore, since Mr. de Reaumur has provided a clear and neat explanation in the memoirs of the [French] Royal Academy of Sciences for the year 1714. It would be very useful to know whether this primary cause is the same in our Gymnotus. Dissection of the animal being the only means to teach this to us, I shall devote myself to it as soon as I have received another one, for which I have written, and which has been promised to me. I have not been able to dissect the one that has been sent to me, since it is a too valuable addition to the cabinet of our High Academy.

I take the opportunity to advise those who have properties in Issequebo or in the Berbices, where this same fish is found, to send for some living specimens, as they will very easily be granted the favor from the skippers of the vessels, who are dependent on them [the persons who have properties in the colonies.]. And the latter will be richly refunded for the care they will provide, since in Europe these fish retain the same feature that they have in America, notably of curing gouty pains; a quality that truly deserves to be examined, and which will probably be similar to that of the Electricity, which occasionally has been applied with good results for the cure of this disease, but mostly has not brought about any effect at all.

For the rest, this fish has been known for many years: Mr. Richer has seen them in Cayenne and even felt the numbness it may cause. Du Hamel speaks about it in his History of the Academy for the year 1677.[38] There is, he says, another fish, three or four feet long, not different from the Conger-eel or Sea-eel, which, when touched with the finger, yes even with the end of a stick, brings a trembling to the arm, and brings about a dizziness which he [richer] experienced himself.

Beyond all arguments, this fish, which was the subject of this story, is the same as our Gymnotus, the Figure of which indeed resembles that of the Conger-eel. It is true that its length is not more than of almost two feet, however, one has written me from America that some have been found that are twice as large.

[38] Actually for the year 1674.

Behind the Contents of Allamand's Article

In introducing 's Gravesande's letter, Allamand mentioned Seba and Gaubius. Albertus Seba, who died 20 years earlier, had been an Amsterdam chemist (pharmacist), a natural philosopher, and a member of numerous scientific societies (including the Royal Society of London). He also possessed one of the most important collections of *naturalia* of his epoch.

In 1734, Seba had started a monumental catalogue of his cabinets, one that would be enriched with 446 magnificent copper engravings. Peter Artedi, who was Linnaeus' teacher and is sometimes called the father of modern ichthyology, Frederick Ruysch, the famous anatomist, and Pieter van Musschenbroek helped with the project. But Artedi's accidental death in 1735[39] and Seba's own death the next year interrupted the project after the second volume was completed.

The third volume of Seba's *Thesaurus*, the one dealing with fish and other marine creatures, was finally published in 1758, thanks to the intervention of Gaubius, who incorporated a large amount of Artedi's material and included an image of Allamand's *gymnotus* with some text.[40] Gaubius included a good description of the external features of the eel, along with a beautiful image of it, in this volume, and he considered the "torpedo's virtue" as one of its constitutive characteristics. In this regard, he drew particularly from Laurens Storm's Gravesande's letter to Allamand, published 2 years earlier. Not to be overlooked, he stressed the particular significance of this fish in his Introduction to Volume 3, noting that it is capable of producing an effect "similar to the electric fire."

As for Laurens Storm van 's Gravesande raising the possibility that the eel's discharge may be electrical, it is important to note that he and Allamand had experienced the explosive discharge of a charged Leyden jar together, before he left for the New World. This is significant because it had long been recognized that things that feel the same are likely to be of the same nature, and because sensation was an important tool in the physiology and physics of the time. Thus, when Allamand read that the eel "produces the same effect" as a Leyden jar, this had to be of great interest to him. Similarly, knowing that the impact of a full-charged large Leyden jar could knock a person to the ground, as happened on several occasions

[39] He drowned in a canal of Amsterdam in 1735 after a dinner in Seba's house. He was 30 at the time.

[40] Seba, 1734–1765. This work was printed in two bilingual editions, Latin-Dutch and Latin-French.

to Benjamin Franklin,[41] he must have been excited to learn that "the shock produced by the animal will throw anyone who touches it to the ground, without exception, and one feels it throughout the whole body."[42]

In the same context, when Laurens Storm van 's Gravesande mentioned that the eel's discharge is could cure "gouty pains," the governor was again alluding to an important parallel between the discharges of these fish and what was now being claimed for man-made electricity. Allamand would have understood this, having just published a paper on medical electricity in the same journal as the one that would publish the new eel article.[43]

The statement about curing gout is also notable, because it strongly suggests that some European settlers in South America were turning to these fish to cure themselves, much as they might have been treated with a Leyden jar. In other words, the discharges were not just a native cure. This is because gout has always been a disease of the well to do. Even before the middle of the 18th century, this painful disorder was associated with eating copious amounts of meat and fish, and drinking large amounts of fortified wine (e.g., port, Madeira). Gout was, in short, a disease of the rich, not one associated with Indian or slave populations.[44]

The fact that these fish could be eaten without ill effects could also be related to electricity, at least by excluding another theoretical possibility. This observation made it highly unlikely that the eels might be utilizing a stored poison with numbing effects. During the second century, Galen had suggested that torpedoes might release a cold poison, and his theory was still garnering some attention, even with the advent of newer, mechanical explanations.

[41] Benjamin Franklin and Jan Ingenhousz both experienced serious electrical accidents that resulted in temporary loss of consciousness, buckling, and amnesia for the event. See Finger and Zaromb, 2006; Finger, 2006, pp. 109–113.

[42] In contrast to these much more powerful eels, French and Italian torpedoes typically do not produce effects that extend past the elbow, even when touched directly with the hands (see Piccolino, 2003a).

[43] In a 1754 paper that can be translated as, "Cure of a girl, suffering from a kind of stroke," Allamand wrote that clinical trials with electricity usually did not produce great medical benefits (Allamand, 1754; also see Bertholon, 1786, T. I, p. 511 and footnote 36). Nevertheless, he found an exception with a young girl suffering from *affectum paralytico-spasmodicum*, who, after an intense terror, displayed hemiparesis, fits, and aphasia. Following electrical treatments, her speech improved, but she was not as fluent as she had been before her illness. She showed more recovery of her other impaired functions.

[44] See Finger, 2006, pp. 276–293, for more on gout, its perceived causes, and its treatment in the 18th century.

In summary, Allamand learned that the tremble fish discharge is very much like one from an electrical device, including in its remarkable speed (“All this happens in an instant”). But he was also told about one difference: The fish “does not give off fire or sparks, similar to the apparatus for electricity.” Given this difference, the intellectual climate, and personal friendships involving Réaumur, Allamand opted to be cautious and polite in his conclusions, and he did not directly refute the mechanical theory of the French *savant*.[45] Thus, although Allamand concludes that the eel and the torpedo probably function in the same way, he does not state in so many words that both species are must be electrical. Instead, he writes that the Réaumur has “provided a clear and neat explanation” for the torpedo. He even calls for a careful dissection of an eel, stating that comparative anatomy will help clarify the picture.[46]

Allamand might have been wishing to verify the possible presence in the eel of muscles similar to those seen by Réaumur in the torpedo—muscles thought to have mechanical, spring-like actions. One is left wondering whether this politeness toward Réaumur and his mechanical theory could have stemmed from the fact that Allamand was so close to Musschenbroek, who in turn was a good friend of the French scientist. Réaumur was still living at this time and was highly esteemed by his Dutch academic colleagues, who still did not have an eel to dissect.

Gronov: Eels and the Collector

In 1758, 2 years after the article bearing Allamand’s name appeared, Laurens Theodore Gronov (Gronov or Gronovius), another eminent Dutchman, published his report on the eel (Gronov 1758).[47] Gronov was fascinated by natural history and was a collector of zoological specimens for his museum, which was a continuation of his father’s collection. He had a particular interest in fish, and he dedicated one of his more important publications, his *Museum ichthyologicum* (1754–1756), to a description of the fish in his personal collection. An updated description of the specimens from Gronov’s museum (including his eel)

[45] Réaumur, 1717, pp. 344–360.

[46] Allamand was probably wishing to verify the possible presence in the eel of muscles similar to those seen by Réaumur in the torpedo—muscles thought to have mechanical, spring-like actions.

[47] Laurens Gronov belonged to an important family of German origin, whose most eminent member had been Johann Friedrich Gronov, one of the greatest classical scholars of his epoch. Laurens’ father, Jan Frederik was an eminent collector of naturalia and a famous botanist.

appeared in his *Zoophylacium*, a magnificently illustrated volume published posthumously in 1763–1764.

With his interest in fish, and with physicists and naturalists becoming increasingly focused on the electrical world, Gronov set his sights on the strange eels in South America. Then, after also corresponding with Laurens Storm's Gravesande,[48] he published a memoir in a Dutch serial publication that contained scientific pieces from Europe and the Americas, the *Uitgezogte verhandelingen*.[49] Gronov's paper had been written in Latin but was translated into Dutch at the time of publication, probably by Gronov himself.

Uitgezogte verhandelingen was indeed a fitting place for what Gronov had to say about these eels in 1758, because the editors of this publication focused on both electricity and natural history. In the first volume, which appeared in 1757, we find, among other things, a translation of three letters by Franklin on electricity. Two of them were addressed to Peter Collinson (who in 1763 would sponsor Gronov's election to the Royal Society of London, and would be the dedicatee of the *Zoophylacium*). The first volume also contained a translation of an account of Abbé Nollet's *Letters on electricity,* which appeared in the *Philosophical Transactions of the Royal Society* in 1753. Among the memoirs on natural history of the *Uitgezogte Verhandelingen*, there was also a description of a Dutch fish written by Laurent Gronov's father (Jan Frederik), which had originally been published in a Swedish journal, the *Acta Upsalica*.

Gronov's paper opens with a description of the external shape of the fish, which is based on a specimen that he had imported for his collection. This specimen was illustrated in his memoir and later in his *Zoophylacium*. He describes the numerous openings on the skin, seemingly pores which allow the fish to emit the slimy substance that covers its body, and remarks that they could also be a way ''by which… the electric action of this fish comes out.'' Gronov did not dissect his eel

[48] Gronov did not mention his contact's name in his published letter, but it became clear 20 years later (see Garn, 1778, p. 19).

[49] His memoir was published in a serial publication in Dutch containing various scientific memoirs from different European countries and America (*Uitgezogte verhandelingen uit de nieuwste werken van de societeiten der wetenschappen in Europa en van andere geleerde mannen*). It appeared in the form of a letter to the editor, Cornelis Nozeman, who was a Dutch clergyman in Haarlem and later in Moordrecht near Rotterdam. Nozeman translated selected papers from proceedings of European societies and published them in *Uitgezogte Verhandelingen* (''Selected Treatises'').

to learn more, wishing to preserve his prize specimen intact for his cabinet[50] (Figure 3).

Most of Gronov's text involves answers to 25 questions that he had asked his correspondent in the New World. Many relate to the nature of the intense shocks and the known properties of electricity. He informs his readers:

(1) A person who is in water can be put in serious danger of being drowned by the shock of the eel.
(2) Every person, of any age and constitution, is affected by the eel without exceptions, although the sensitivity can be different among different individuals.
(3) There is no notable difference in the shock produced by the fish in different meteorological conditions, or when it is put in a stone tub or a wooden barrel.
(4) The shock is felt by touching the fish in any part of his body even though it is especially severe when touching particular zones (as for instance the belly or the tail).
(5) There is no part of the fish that can be touched without feeling the shock.
(6) The shock is felt particularly when the fish is moving; when the fish is kept in water inside a *Corjaar*,[51] a person touching the water can feel the trembling or numbing sensation produced by a freely moving eel even when the fish is at the distance of fifteen feet or more.
(7) The shock is felt even when the hand is covered by oil or wax.
(8) The shock is felt also by touching the fish with a wooden tool, particularly when the wood is very hard, even though its intensity is smaller than with a direct contact.
(9) If a piece of metal (iron, copper, silver, lead, tin etc.) is inserted in the sticks, and if a person keeps in his hand the wooden part while touching the fish with metallic extremity, then the sensation is stronger than that felt with only the wooden stick.

He concludes his communication by stating that the shocks can be useful in medicine; that "various accurate surgeons" have told him that they restore function when the nerves are blocked by obstructions. He specifically mentions the medical use of an eel shipped to Barbados, as related by Mr Bolton, and refers interested readers to Allamand's (1756) article.

[50] Some of Gronov's specimens are still conserved at the Natural History Museum of London (see Gronov 1781, 1854; Wheeler, 1958).

[51] A long boat typical of the natives of the region.

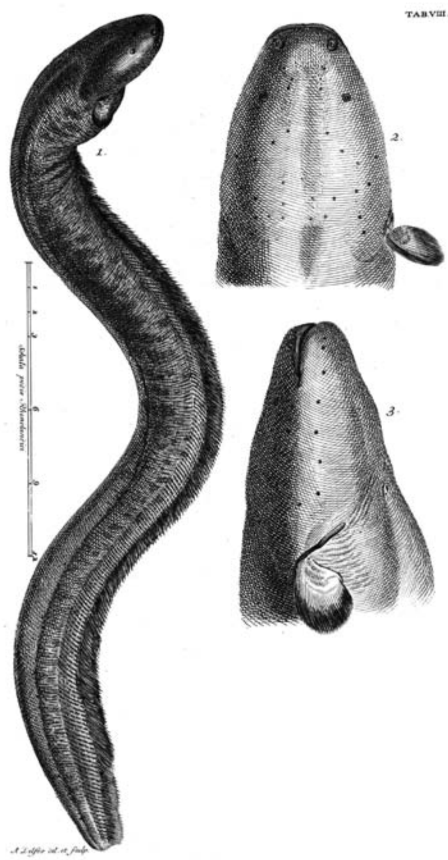

Figure 3. Laurent Theodore Gronov's illustration of an electric eel, first published in 1758 in the *Uitgezogte verhandelingen* and afterwards reproduced in the first fasciculus of his *Zoophylacium*.

Although Gronov's report is intriguing, he is more the collector of natural specimens than a skilled investigator capable of unraveling the mystery of an intriguing physiological phenomenon. He does not show a clear awareness of the laws of electric conduction, and of the role of metals in favoring the flow of electricity in a circuit. When he mentions experimenting with different metals, they are not used alone and are inserted into a wooden rod. The latter procedure was not in line with the physics of the day, although it was also used by Ingram, whose paper Gronov might have read (possibly in German translation).

Two years after both this article and the third volume of Seba's *Thesaurus* appeared, Gronov's article came out in its original language, Latin. This was a language more widely known to members of the

Enlightenment's "Republic of the Letters." Interestingly, the phrase *Elektrikaale werktuigen* (Dutch for electric apparatus), used for the production of the electricity that might have come through holes in the eel's skin, became *motus tremuli* (Latin for trembling motion). This change could imply several things: that Gronov was still open to mechanical explanations; that he thought the fish's electricity was the result of a mechanical action; or that the decision to use *Elektrikaale werktuigen* in the Dutch version came from the editor's desk.

In 1763, the matter seemed settled for Gronov. In the first fasciculus of his *Zoophylacium*, he unequivocally wrote about an "electric force" (*vim electricam*). Moreover, not only does he apply this explanation to the eel, he extends it to sea torpedoes as well.

In retrospect, Gronov would have had additional reasons to feel confident about fish electricity by 1763.[52] For one thing, Pieter van Musschenbroek had just come out with a new book, one favoring specialized fish electricity. Additionally, another important letter pointing to eel electricity had appeared in the same Haarlem journal that had published the letter from Storm van 's Gravesande to Allamand 6 years earlier.[53]

Pieter van Musschenbroek

Although not contributing directly to electric eel research, Pieter van Musschenbroek played more than a technical role (e.g., the invention of the Leyden jar) in helping these fish seem electrical. Musschenbroek, who attended lectures by Newton in the 1710s, was a Professor of Mathematics in Leiden since 1739, having succeeded Willem Jacob Storm van 's Gravesande (Laurens Storm's uncle). Highly respected at home and around the world, van Musschenbroek summarized what he knew about the eel in his *Introductio ad philosophiam naturalem*, published in 1762, a year after he died. In making the case for fish electricity, he referenced Allamand's (1756) paper although he relied even more heavily on Gronov's report.

Musschenbroek presented a detailed list of many of the characteristics of the eel's shocks. And when discussing these characteristics, he took a firmer stance about the fish being electrical than either Gronov or Allamand had taken. He concluded by asking himself (in a rather rhetoric way) if the effects of the sea torpedo might also depend on electricity.

[52] Gronov, 1763–1764, Fasc. I, p. 42.

[53] Van der Lott, 1762, pp. 87–94.

Musschenbroek succeeded in casting doubt about Réaumur's interpretation of the torpedo's action. Réaumur had died in 1757, and Musschenbroek attempted to justify his break with his late friend's theory in the kindest possible way. He wrote that electricity was little known and poorly understood when the French natural philosopher had come forth with his mechanical explanation. He seemed to imply that Réaumur would have changed his mind, if he would have lived long enough to see the newest findings.

Hence, Musschenbroek, an internationally recognized authority on electricity, not only presented the case for eel electricity but expanded the theory to the sea torpedo in a public way. His book was one of most important texts of physics of the time, as can be gleaned from the fact that it had French and English editions.

Frans Van der Lott

In 1762, the very year in which van Musschenbroek's book was published, Frans Van der Lott saw his own important letter from the New World published. Referred to in some texts as a Dutch surgeon and in others as a jurist (lawyer),[54] Van der Lott lived in Essequibo. He was probably an affluent man who pursued science in his leisure, as was common among gentlemen in the 18th century.[55] As might be expected, he also knew Storm van 's Gravesande.

Van der Lott's letter, when translated into English, bears the title, "Short Report on the Conger-Eel, or Tremble Fish; Drawn from a Letter from Frans Van der Lott, Dated Rio Essequebo, June 7th, 1761, Reported to the Society by One of its Members." The published report was not written in the first person. Rather, Allamand or another member of the Haarlem scientific society edited this letter prior to its publication. As with the Allamand (1756) publication, we here present a full translation of this fascinating letter for the first time.

This letter opens with a physical description of the eel and how it shocks its prey:

[54] Bancroft (1769) called him a surgeon, whereas the "Essequebo and Demerary Gazette" of 24 November 1804 referred to him as a lawyer.

[55] Benjamin Franklin best illustrates how even people with minimal education were drawn to the sciences and medicine during the Enlightenment. For more on how he made the transition from a skilled printer to a gentleman scientist who hoped to help suffering humanity, see Finger, 2006.

> The shock [or "drill"] fish, which is here called the Conger-eel, is very similar in form to an eel, except that the former has ears, resembling those of bats. He has to breathe above the water; and therefore forms bubbles on the water that quickly disappear.
>
> Two varieties may be found, identical in effects but not in power, the black one giving off stronger shocks than the red.
>
> Their sizes vary considerably; one may find them 1 to 5 feet long or longer. Their thickness is proportional to their length. But the longest exert the most power.
>
> They are eaten by many, Whites, Indians, and Negroes. Additionally, they have very bony backs and a fairly solid body, but are quite soft and slimy on the belly.
>
> They mainly stay near rocks and on stony bottoms, although they may also appear in creeks or river branches, but when this is the case few or no other fish are found there because, if a fish approaches too close, it will be immediately shocked to death. And if the Conger-eel itself is in a fyke[56] for a long period, it will die, because, as said before, it has to breathe above the water.

We now learn more about the nature of the shocks, which to Van der Lott can only be electrical:

> The author of this letter had done electrical experiments while in Middelburg in 1750.[57] Hence, he reports on experiments that he has undertaken with this fish, and concludes that the power of the fish corresponds with that of electricity, except that the fish does not produce sparks, such as may be observed in electric experiments, and in the case of electricity in very dry and clear weather. In experimenting with the power of this fish, however, water is necessary. In order to prove this he refers to the following experiments:
>
> I touched (he says) such a fish, lying in a tub with water, with a long iron rod, which shocked me enormously. But if I held the said iron rod in a dry cloth and touched the fish again, I did not feel the slightest shock. After wetting or even moistening a cloth, I again felt the stroke like before.

[56] Fyke (*fuik* in Dutch) is a circular net with a dead end into which fish can be caught.

[57] Middelburg is a Dutch city in the province Zeeland.

Although the shock also occurs on touching the fish with a *copper* wire, he supposes that not all copper will serve in this way, because he noticed different effects of different *copper* pieces (like a skimmer, a candlestick, etc.), in a way such that he did not feel anything at all in the one case and a violent shock in another. Using good English *tin*, it also shocks very powerfully, but if there is much lead underneath, the blow will be less. Using *gold*, one will feel it through the whole body; the same is true for *silver*, but less powerfully. Using *lead*, *tinplate*, *baked earth*, *bone*, *twig,* and *wax,* no effect is observed. The same is observed with *dry wood*, but it will have the power if the pores are permeated with water.

Further, the location where the fish is touched is of importance: The closer to the head, the more powerful the blow. Under the throat, the blow is enormous.

The author reports the following experiments, of which the first was carried out at the house and in the presence of Mr. Laurens Storm van 's Gravesande, Governor of the Colony.

When five persons held each other hand by hand, and the first touched the fish with the point of a sword that had a silver hilt, the blow was felt up to the fifth person, although less powerfully. It should be noted that the shocks in these experiments are not felt further up than the shoulder; that nothing is felt in the other arm or hand, even though the shock is felt by another person, who holds the latter's hand.

The second was performed at the plantation in the person of Mr. Adriaan Spoor, counselor and secretary there (who the author calls his dear patron). This gentleman, desirous of experiencing the power of this fish and being diffident to touch it himself, took the author (as he had done several times) to a certain Indian boat constructed from a hollow tree more than 26 feet long and 2.5 feet wide, put water in it until it was almost full, and then a Conger-eel. While the fish was in the front of the enclosure, the gentleman [spoor] put his hand in the water at the back, roughly 20 feet from the fish, thinking that the blow would not reach him there; then the author touched the fish, and the gentleman said that he felt a very considerable shock.

> If a hand is placed three or four inches above the water surface where, at that moment the fish forms a bubble when breathing, it will feel a considerable shock, which most certainly will be caused by the exhaled air.

Van der Lott now turns to the medical virtues of the fish, which he would have construed as being further evidence for electricity, because of parallel claims being made by physicians in Europe with their Leyden jars:

> And, the author tries to prove that this fish, with respect to its effects, is similar to Electricity by the following experiments:
>
> I held by their wings (he said) some chickens suffering from cramps of the tendons in their legs, leading to contraction of the claws in such a way that they could not walk and would die. I put the legs of one on the back of a Conger-eel that was lying in a tub of water. The chicken was so shocked that it started screeching in a most dreadful way. After this was repeated a second time, the chicken seemed to be fully recovered. And continuing [the same experiment] with the others, no more chickens died.
>
> An Indian (he continues) suffered from a Paralysis of the lower body. After he had taken several ineffective external and internal medications, I pressed a *Conger-eel* that had just been caught in the River, and hence was full of power, against his knees, as witnessed by several of my friends. Its shock was so powerful that two persons, who supported the patient on both sides by holding his arms, almost fell down with him. After I repeated this three times, the person, who had been carried over from a plantation, went back to his plantation completely recovered, without a stick or crutches, and without ever using anything else for it.
>
> Mr. Abraham van Doorn, ex-counselor of the same colony, had a Negro boy among his slaves with an estimated age 8 or 9 years. He suffered from obstruction of the nerves in such a way that his arms and legs were crooked. Each day, this gentleman threw the boy in a tub of water with a large Conger-eel of the black variety, which shocked the boy so powerfully that he crept out on all fours. And sometimes, when he was unable to do this, he had to be helped out, although the helper then received some of the shock. The result was that the boy recovered completely from his nervous disorder, but his accompanying malformation of the shinbones remained.

> Furthermore, the said gentleman (the author says) carried out the following two experiments:
>
> He likewise threw a slave boy, who suffered from a bad Fever into a tub with a Conger-eel. The boy was shocked in such a way that the gentleman was compelled to help him out of the water. But a few minutes afterwards, the Fever disappeared and did not recur.
>
> The second was on an Indian boy, who had suffered badly from several episodes of a Fever, and had himself shocked with a Conger-eel. The result was the same as in the previous case.
>
> The gentleman also says (the author continues) that when a slave complains of a bad headache, he has them put one of their hands on their head and the other on the fish, and that they will be helped immediately, without exception.

Frans van der Lott was unequivocal when he referred to the eel's discharges as electrical shocks. He showed that they could pass through a variety of known conductors of electricity (e.g., metals, people), but not through non-conductors. He even found that five individuals holding hands would feel the shock when they completed a circuit with the fish. Further, although a dry stick might not convey a shock, a wet one could do so. But like Storm van 's Gravesande, Van der Lott never detected a spark, which would have made his electrical conclusions even more substantiated and impressive.

As was true of his predecessors, Van der Lott was convinced that the eel's shocks could have wondrous healing effects, and therefore that they could be equated to the discharges of Leyden jars in the hands of skilled physicians. He went farther than others, however, when he did therapeutic experiments with his eels on sick animals, for which expectations, gullibility, hysteria, and other human factors would not enter the picture. Specifically, he shocked chickens suffering from leg "cramps"—which had caused such severe contractions that they could no longer walk—and claimed that they fully recovered.

Van der Lott also revealed that the eels were used more extensively with humans than had been indicated in previous publications from the New World. One of the cases he mentioned was an Indian with a paralysis, who "went back to his plantation completely recovered, without a stick or crutches, and without ever using anything else for it." Another was a young Negro slave, who "suffered from obstruction of the nerves in such a way that his arms and legs were crooked." Here too, complete recovery was reported, as was the outcome with other slaves, who suffered from headaches and fevers.

As noted, these wondrous effects were very much in accord with some of the claims being made by several practitioners with their electrical machines.[58] Nevertheless, a few luminaries, such as Benjamin Franklin and the Abbé Nollet, had their doubts about some of these wondrous claims and cures.[59] As for the use of slaves and to a lesser extent the local Indians as test subjects, this was common in the New World at this time.[60] Rather than subjecting each other to unproven and possibly dangerous or painful treatments, the European settlers and their physicians first tried things on those under their control.

The use of slaves in eel experiments can also be found in a book published in 1769 by Philippe Fermin, who was in Surinam from 1754 to 1762. Fermin wrote in French, but his book was printed in Amsterdam, and he spent most of his life in the Dutch town of Maastricht. He was involved in polemics on slavery, siding with those who advocated better treatment of slaves.[61]

While in Surinam, Fermin attempted to dissect an eel. With regard to its powers, he pointed to (in translation) "two strong muscles in the back and the breast," and used the words *mouvement* and *tressaillement* (the latter term meaning rapid, isolated jerk, not trembling) in this context. Thus, unlike Van der Lott, Fermin still seemed to be favoring a mechanical interpretation over an electrical one. How much he knew about what the Dutch in Essequibo and Leiden were now starting to think about eel electricity is unclear.[62]

[58] See Bertucci and Pancaldi, 2001, and particularly Bertucci, 2007.

[59] Franklin, like Nollet, was not convinced that medical electricity was helpful for treating palsies of long duration. He based his pessimism largely on his own clinical trials in Philadelphia. For more on Franklin's medical experiments with paralytics, see Finger, 2006, pp. 80–101.

[60] Delbourgo, 2006, pp. 186–187; Fermin, 1769, pp. 260–263. Another Dutchman who made an extensive use of slaves in his experiments on the electric eel was Godfried Willem Schilling (Schilling, 1770, 1772). Schilling supported the curious view that the loadstone deprived the eel of the power of giving the shock, this leading to a controversy with the Italian naturalist Lazzaro Spallanzani (see Piccolino, 2001; Piccolino and Bresadola, 2003).

[61] Fermin, 1770.

[62] See Fermin, 1769, pp. 260–263.

Impact

Together, 's Gravesande's communication (published by Allamand) and Van der Lott's letter, as well as the books and other writings of Gronov, Gaubius, and Van Musschenbroek, combined in a powerful way to suggest that the shocks of the South American eels are electrical, and by analogy, so are those of less exotic sea torpedoes and the more neglected Nile catfish. This conclusion was soon heard around the Western world. References to Allamand's and Van der Lott's journal articles, and to the other publications, spread with some rapidity in the journals and other publications of the epoch.[63]

The diffusion of the Dutch observations was particularly intense in German scientific and general culture magazines. The article bearing Allamand's name was translated and published several times. In 1756, it appeared in the *Nützliche Samlungen* of Hannover, and in 1768 and 1775 in the *Neues Hamburgisches Magazin,* a periodical that also translated Van der Lott's article.[64] Further, in 1760 it was included in a letter sent to *Der Arzt*, a weekly medical journal out of Hamburg.[65] There was also a stream of references to the eel papers in dictionaries of sciences, other cultural magazines, and textbooks of physiology and natural science, again most notably in Germany.[66]

Gronov's (1760) communication in Latin was also important for spreading the new doctrine, as was Linnaeus' mention of it in his *Systema naturae,* starting with the 12th edition of 1766.[67] As noted, it was in this edition the influential Swedish naturalist began to use the phrase *Gymnotus electricus* to designate the electric eel. These works, along with Gaubius' text in Seba's *Thesaurus*, were followed with particular interest both by collectors of biological specimens and naturalists. Additionally, Gronov's monumental *Museum Piscium* and *Zoophylacium* and Seba's *Thesaurus* were shelved in many important libraries, where they were avidly consulted. Gronov's section on the *Gymnotus*, for example, was frequently quoted in later treatises and compilations on fish.[68]

[63] Anonymous, 1762.

[64] Anonymous, 1756; Allamand, 1768, 1775; Van der Lott, 1775.

[65] The letter without a title and with just the signature St. B. S., was published on pp. 334–336 of the II part (Theile) of the XII issue (Auflage) of the periodical physician Johann August Unzer directed.

[66] See Martini, 1774, pp. 1–48; Jéhan, 1852, p. 815; Garn, 1778; and Treviranus, 1818, pp. 141, 184.

[67] Gronov, 1760; Linnaeus 1766, Vol. I, pt. I., pp. 427–427.

[68] See for instance Bloch, 1786–1787; Lacepède, 1798–1804; von Humboldt, 1811; Figuier, 1868.

The French at the *Académie Royale de Sciences* were slower to warm up to the possibility of eel electricity than the Germans, even though Musschenbroek communicated the new Dutch findings to his French correspondent, physicist Abbé Nollet. In the volume of the *Histoire de l'Académie* for the year 1760, Grand-Jean de Fouchy, the perpetual secretary, openly criticized Musschenbroek's conclusions. He maintained that the sealing wax used to intercept the fish shock might not have been a proper insulating body, because it was humid. Further, he questioned the experiments using metals, because metals could also transmit mechanic vibrations [*ébranlements*] or movements communicated by the fish. Fouchy even maintained that, "since there are two thousands leagues from here [i.e., Paris] to Surinam, the facts can be strongly altered during the journey"!.[69] Fouchy's reticence shows how difficult it was for French *académiciens* to discard the hypothesis of the illustrious Réaumur, whose ghost was obviously still attending Académie meetings, supposedly unwilling to abandon an old idea.

Notable Conversions

The changes triggered by the Dutch researchers can be more fully appreciated by examining different editions of some zoological treatises and compilations. They reveal that some of the most influential and respected scientists of the era underwent "electrical conversions." One especially notable person was Albrecht von Haller, whose physiology books were widely disseminated and used at universities around the world. In the last tome of his *Elementa physiologiae,* published in 1766, he quoted the writings of Allamand and Gronov, and concluded[70]:

> I admit, after the recent experiments made on the numbing eel [*anguilla stuporifera*], that without doubts it rather seems that an electric vapour comes out from the animal. Indeed the fish permeates with her poison also the water so that she numbs from distance, and kills the fish contained in the same barrel together with her.

This was a substantial change for this *savant*, who just few years earlier had been one of the fiercest opponents of the notion that electricity could play any role in animal physiology.

Charles Bonnet, the Swiss naturalist and philosopher, was a another very influential thinker of the Enlightenment to change his mind. Bonnet

[69] *Académie des Sciences*, 1761, p. 22.
[70] von Haller, 1757–1768.

was the author of *Contemplation de la nature,* one of the bestsellers of mid-18th-century science. This work, dedicated to Haller and Allamand, first appeared in 1764, after which it went through numerous French editions and was translated into many other languages.[71]

In the first edition of this book, Bonnet discussed the possible electrical nature of various physiological processes. He related electricity to the element fire (one of the four elements of antiquity), and showed awareness of its growing use in medicine, writing in his Preface:[72] "Could one suppose that a piece of Amber, which attracts a straw, might have led to the healing of a paralytic?" However, when mentioning the properties of the torpedo in the context of other strange fish, he does not make any reference to electricity. He writes:

> The *Torpedo* which so rapidly numbs the Hand that touches it, has not she a very remarkable method of provide to its conservation, and a great art to offer to the meditation of the Physicist?[73]

In the 1769 edition, we find the following footnote added:

> Raja, Torpedo. *Linn*. Mr. De Reaumur has given in the memoirs of the Academy of Sci. (Year 1714) an interesting description of this fish. The numbing effect that it causes seemed to be the effects of a very lively percussion, operated by a curious apparatus of muscles placed under the back of the animal.
>
> A fish of another genus present in the river of Surinam, and which has been described by Gronovius in the Memoirs of the Society of Haarlem, deserves some word here: It produces on those that touch it the effects of violent electricity, that is, it gives them a commotion similar to the experiment of Leyden. This effect occurs both if one touches it directly or if the contact is established through a rod of wood or metal; sometimes also by simply dipping the hand in the water in which the fish swims. No similar effect is felt if the fish is touched with a rod of wax.[74]

Bonnet was now warming to the idea of eel electricity. Moreover, even though he brought up Réaumur in his first paragraph, he concluded his footnote with a question suggesting that he believed that the

[71] Bonnet, 1764.
[72] Bonnet, 1764, p. xi.
[73] Bonnet, 1764, Tome II, p. 159.
[74] Bonnet, 1769, Tome II, p. 241.

torpedo must also be electrical. In his words: "Could one not also suppose a principle of Electricity in the torpedo?"

In the fourth edition of Bonnet's *Contemplation de la nature*,[75] there were more footnotes accompanying what was written about these fish. Here, the element fire is now the electrical fluid. An entire chapter is, in fact, in praise of electrical science in general, and more specifically with the great advancements that one could expect in both physiology and medicine from the experiments being made on electric fish.[76] He now writes:

> At present there is no more doubt that the subtle fluid that nerves transmit to the electric organs of the Torpedo and to those of the Eel of Surinam, is analogous to that which operates in the phenomena of electricity, and perhaps is just the same one. How this discovery appears to favour the opinion of Physicists who admit a great analogy between the nerve fluid or animal spirits and electric fluid![77]

London Connections

The ideas that more than just fish could be electrical, that the nerves might function by electricity, and that disorders of the nerves and muscles might be helped by electricity, stemmed largely from the progress that was being made in understanding electricity in the mid-18th century—and especially from what was being discovered about electric fish. In this context, the reports by 's Gravesande (Allamand), Van der Lott, and Gronov stand out as being particularly important. Although these natural philosophers focused on the South American eels, their conclusions, based on simple experiments, also seemed applicable to the torpedo and African (Nile) catfish.

At the same time as the last edition of Bonnet's *Contemplation de la nature* was disseminating, Europeans were also being informed about the landmark experiments of John Walsh. Guided by Benjamin Franklin, Walsh first conducted electrical experiments on torpedoes caught off the coast of La Rochelle (in 1772) and published his findings favoring torpedinal electricity in 1773. He then devoted his attention to an electric eel that had survived the voyage from the New World to London. At the same time, fellow member of the Royal Society, John

[75] *The Contemplation de la nature* was included in the 7th tome of the collected works on natural history, which was published in Neuchâtel in 1781. See Bonnet, 1779–1783.

[76] Ch. XIII of Part V of Tome VII.

[77] Bonnet, 1781, pp. 262–263.

Hunter, studied the anatomy of these fish and masterfully illustrated the electrical organs of sea torpedo[78] and electric eel.[79]

With his captive eel, Walsh was able to accomplish something in London that neither Laurens Storm van 's Gravesande nor Frans van der Lott had been able to achieve in Guiana. In 1776, he was able to perceive a spark at the time of the eel's discharge.[80] The ability to produce a spark was considered a fundamental criterion for something to be electrical in 18th century science, and with his reproducible spark before amazed onlookers from the Royal Society, the thought that some fish might be electrical found many more supporters. Henry Cavendish's physics and artificial models of the electric organ provided important new information that helped others to understand the nature of the fish discharges, adding to the excitement now generated in London and spreading around the world.[81]

Despite of the importance of Walsh's results, and of the systematic and methodic way in which he conducted his research, the roles played by the earlier Dutch investigators was not forgotten. Marcus Elieser Bloch, in his famous systematic description of fish that went through numerous editions in a variety of languages since its first publication in 1786, praised the importance of the work of 's Gravesande, Gronov, and Van der Lott. He wrote that they were the first to provide sure evidence of the electric nature of certain fish. In particular, when dealing with the electric eel, he wrote:

> Hunter considers Walsh as the discoverer of animal electricity: but since this author made his experiments at La Rochelle only in 1773, and on the other hand many years before *Gravesande* and other physicists have sufficiently proved by their experiences the electric property of our fish, one could not attribute to *Walsh* the honor of this discovery.[82]

There can be little doubt about the importance of Walsh's researches in making the idea of the fish electricity widely known and better accepted. Hence, some people might question Bloch's conclusion about 's Gravesande's priority.[83] Nevertheless, it cannot be contested that the Dutch research on the eels provided very important results, and at that it contributed to the new *Zeitgeist* favoring fish electricity.

[78] Hunter, 1773.

[79] Hunter, 1775.

[80] Piccolino and Bresadola, 2002; Piccolino, 2003a, b.

[81] Cavendish, 1776.

[82] Bloch, 1786–1787, 1st part, p. 243.

[83] See Piccolino, 2003a; Piccolino and Bresadola, 2003.

It is moreover apparent that the Dutch experiments influenced Walsh, even though the English experimenter did not provide direct references to the Dutch in his published manuscripts. Walsh did, however, mention John Bancroft in his 1773 torpedo paper. Bancroft had been an American member of the Royal Society of London and he was very close to Franklin.[84] He lived in Guiana before joining Franklin in London, and he had recently published a book on Guiana.[85] This book had a lengthy section on his experiments and observations on the eels, in which he argued that their discharges are unquestionably electrical. Bancroft knew Van der Lott personally and cited his publication in this chapter. Franklin and his associates read this book, and both he and Walsh were so impressed that they nominated Bancroft for membership in the Royal Society.

In addition, Franklin, who was foremost among electrical scientists at the time, and had helped Walsh plan his torpedo experiments, read Musschenbroek’s publications and even visited him in Holland. Franklin also corresponded with Allamand and many other natural philosophers with ties to the Netherlands, as did his colleagues at the Royal Society of London.

One of Franklin’s colleagues and a close friend was John Pringle, then President of the Royal Society.[86] Pringle not only knew what the Dutch had done, but singled out and praised the contributions of Laurens Storm’s Gravesande, Allamand, and Van der Lott in a lengthy, published oration (which was translated in various languages). This speech was given when Walsh received the 1774 Copley Medal for his electrical experiments on sea torpedoes.[87]

Thus, as can be seen, there were communications between Walsh and Franklin in London and the leading Dutch experimental natural philosophers. Some of the information transfer was direct and some was indirect. The newest information about these fish was communicated between organizations and individuals in different countries, allowing natural philosophers in different places, such as London and Leiden, to keep abreast of the latest discoveries and to plan new experiments. As a consequence of these various communication paths, and by being in contact with Bancroft, Walsh would have known about the Dutch achievements before he started his own fish experiments.

84 Finger, 2006, 2009.

85 Bancroft, 1769.

86 Finger, 2006.

87 Pringle, 1775.

Connections with Galvani and Volta

In similar ways, with publications and personal communications, Luigi Galvani in Bologna also learned about the successful experiments on electric fish.[88] In 1791, Galvani promoted the idea that nervous conduction is electrical, and he did this in a way that drew attention both from people who tended to agree with him and some notable critics.[89]

Galvani, started his experiments on the effect of electricity on muscle contraction in 1780, 3 years after Walsh's experiments on the eel became known in Italy. In 1786 (the year of the publication of Bloch' work praising 's Gravesande), he was able to obtain a contraction by simply connecting the nerve and a muscle of a frog leg with a metallic conductor without any obvious source of external electricity. This experiment was a crucial step in Galvani's path to his theory that there is intrinsic electricity in nerves and muscles. Galvani named this intrinsic electricity "animal electricity," using an expression that Walsh had used when describing his experiments at La Rochelle in 1772.[90]

Galvani (1791) went on to conclude that animal electricity is responsible for nerve conduction. He thought that it accumulates inside nerve and muscle fibers, and envisioned these organs as minute, animate Leyden jars, with the nerves being its wires.[91] The Leyden jar image further connects Galvani's theoretical endeavor to Walsh, who used a similar metaphor for torpedinal electricity, and, to Leyden, and thus to the Dutch natural philosophers, collectors, and amateurs. All helped contribute to the historical and cultural background, on which Galvani based his frog experiments and drew his landmark theoretical conclusions.

Although more than two centuries of electrophysiological studies have shown how insightful Galvani had been about the electrical nature of nerve signals, Alessandro Volta assailed his experiments and conclusions. Volta believed that Galvani's "animal electricity" derived instead from the metals used to establish the connections between nerve and muscles. But although he argued against frog electricity, Volta never questioned specialized fish electricity. In a letter penned in 1782 to a French lady, Mme Le Noir de Nanteuil, Volta wrote:

[88] Bresadola, 1998; Piccolino and Bresadola, 2003.

[89] Hodgkin, 1964; Piccolino, 2003b. It was not until 1952 that a full understanding of the complex electric mechanisms underlying the generation and propagation of nervous impulse was reached, as a result of the research on the squid axon carried out by Alan L. Hodgkin and Andrew F. Huxley (see Hodgkin, 1964; Piccolino, 2003b; Piccolino and Bresadola 2003).

[90] Piccolino, 2003a; 2006.

[91] Piccolino, 1998, 2006, 2008; Piccolino and Bresadola, 2003.

> In order that we may be entitled to speak of *animal electricity,* we must find a kind of electricity essentially linked with life itself, and inherent in some of the functions of animal economy. Now, does such electricity really exist? Yes, it has been discovered in the *Torpedo* and in the electric eel of Surinam, that the Naturalists, following Linnaeus call *Gymnotus electricus*....[92]

Hence, 10 years before starting the experiments leading him to the invention of the electric battery, Volta accepted specialized fish electricity. He was especially impressed by the experiment in which Walsh drew a spark from his eel, as he explicitly wrote in his letter to Mme Lenoir de Nanteuil. But in the same letter, he also recognized the significant role played the Dutch, and particularly of 's Gravesande and Musschenbroek who, "feeling the inadequacy of all the simple mechanic explanations, and perceiving a great resemblance between the commotion of the fish and that of the Leyden jar, thought that the two phenomena might be of the same species, and produced by the same cause, i.e., by electricity."[93]

Among the other factors that contributed to Volta's acceptance of fish electricity, we find John Hunter's careful anatomical descriptions of the specialized organs present in these fish,[94] but absent in animals incapable of giving electric shocks. Additionally, fellow physicist Henry Cavendish (1776) had worked out the physics of the discharge and supported his theoretical findings with working models. Cavendish's theoretical elaborations on the parameters contributing to the intensity of fish shock were in accord with Volta's theory of the importance of both the quantity of charge and its "*tension*" (i.e., electric potential in modern terminology) as the fundamental parameters in the electric phenomena.

Indeed, it was on the basis of what these Englishmen did, which had been triggered by the Dutch experiments that Volta came forth with his battery using stacks of disks of different metals. As noted earlier, this was his *organe électrique artificiel,* so named because it was based on, and closely resembled, the impressive electric organs of certain fish. It must be added, however, that in contrast to Walsh, Cavendish, and others, Volta, after inventing the battery, steadfastly refused to accept

92 Volta, 1918, p. 9.

93 Volta, 1918.

94 Hunter, 1773, 1775.

the model of the Leyden jar (i.e., of a capacitor effect) when explaining fish electricity. Instead, he put forward a new model, which opened the path to the development of modern electrochemistry.[95]

Why the Dutch?

In the period in which Allamand, Gronov, and Van der Lott were reporting on fish electricity, a few others were also starting to think about animal electricity. One such person was the French botanist Michel Adanson, who published his *Histoire naturelle du Sénégal* a year after the Allamand report.[96] Adanson, writing in French (but in a book quickly translated into English), provided a short paragraph about a fish found in the Niger River that could produce an effect similar to "the electric commotion of the Leyden experiment." He noticed that, as was true of man-made electricity, "the shock of the fish was similarly communicated by a simple contact, with a stick or rod of iron five or six feet long, to such a point that one drops instantaneously all the things that he has kept in his hands."[97]

Adanson was undoubtedly studying the electric catfish, and his book reveals that, in the 1750s, the idea of fish electricity was on the minds of more than just a few learned people with ties to the Dutch colonies in the New World. Nevertheless, the Dutch clearly dominated this phase of electric fish research. Indeed, circumstances peculiar to the Netherlands in the mid-18th century allowed the Dutch to bring the concept of animal electricity to life. The invention of the Leyden jar, the tremendous interest in electrical phenomena shown by Dutch physicists, their emphasis on reproducible experiments, and the fact that they possessed colonies with inquisitive men trained in medicine, natural history, and physics all seemed to converge at this moment in time.

Although there may be a tendency to view the Dutch reports as showing how a few individuals conducted science in exotic locations, they also reveal much about how Dutch scientists were approaching nature in the mid-18th century. Much of what occurred in the New World was stimulated by inquiries or publications from the homeland, and the parties involved in the dynamic interchange of information were

[95] Heilbron, 1978; Pancaldi, 1990; Piccolino, 2000; Piccolino and Bresadola, 2003.

[96] Adanson, 1757.

[97] Adanson, 1757, p. 135.

exceptionally knowledgeable and well connected. In this context, it is worth looking at the three towns in the Netherlands that figured prominently in what transpired in the 1750s and 1760s.

One such place was Leiden, which had become one of the largest cities in Holland in the 17th century. It was the location of one of the most important universities at the time and a center of great cultural and research activity, particularly in the sciences and medicine. Allamand, Gaubius, and Musschenbroek were all professors in Leiden, and Gronov, although not an academic, was a member of the town's elite scientific community. Each of these individuals had extensive international connections and was member of important foreign scientific societies, such as the Royal Society of London and the French Académie des Sciences.

Haarlem was a second town of importance. The *Hollandsche Maatschappye der Weetenschappen,* or Dutch Society of Sciences and Humanities, was founded here in 1752.[98] Its initial membership list included Gaubius and Musschenbroek, with Allamand joining 1 year

[98] This was much later than in the surrounding countries, and several causes for this have been suggested. In the first half of the 18th century, the natural sciences in the Republic became quite popular, and gradually the balance between university and extra-academic science practice shifted to the latter. Important natural scientists of the stature of Willem Storm van 's Gravesande and Pieter van Musschenbroek became scarce and scientific societies were founded, the first in 1752 (whereas the Royal Society was founded in 1662 and the *Académie des Sciences* in 1666; in Italy academies had been present since the 15th and 16th centuries). In other countries, initiatives to found great academies had been taken by the national government or ministers. Even if a particular initiative had been taken, the monarch imprinted a new character on it. In the Dutch republic, lacking powerful central authority, the cities or local regents were unable to raise funds for such national societies. Moreover, an important part of the establishment and especially reformed clergymen raised objections against natural theology and the natural sciences inspired by it (Van Berkel, 1985, p. 85). But around the middle of the century, the climate changed and scientific societies came to be founded (1752: *Hollandsche Maatschappij der Wetenschappen*). These societies were more similar to French regional societies than to the great national academies, such as those of England and France. In addition to the natural sciences, the promotion of the arts was pursued.

The Hollandsche Maatschappij would be an example for several other societies, not only in its purposes, but also with respect to its organization, being composed of 'directors' (mainly local dignitaries providing financial means) and members, who often were scientists. Society activities consisted mainly of organizing competitions, publishing proceedings, building collections, and inviting lecturers. Following the foundation of the *Zeeuwse genootschap* (1868), the number of Dutch societies increased even more (Van Berkel, 1985, pp. 69–97). For more information on Dutch scientific societies, see Visser, 1970, and Buursma, 1978.

later and Gronovius 9 years later. The young organization's foreign associates included many greats in science and medicine, four whom had already been mentioned in this article: John Pringle (England), Albrecht von Haller (Germany/Switzerland), Alessandro Volta (Italy), and Charles Bonnet (Switzerland).[99] Scientific societies were starting to flourish throughout Holland at this time. In addition to stimulating research endeavors, these societies promoted scientific communication by personal relationships (at both local and international levels) and by printing scientific papers. As we have seen, the letter from Storm van 's Gravesande that Allamand edited and commented on, and the published piece based on Van der Lott's letter, appeared in the fledgling journal of Haarlem's new scientific society.

The third important Dutch center for the intellectual activities was Amsterdam, where the aforementioned *Uitgezogte verhandelingen* began publication in 1757. In line with the growing attention of the *Grand siècle* in scientific culture, this periodical promoted the circulation of scientific information at an international level, going beyond the narrower limits of academic culture. It was an ideal periodical for collectors, which is why Gronov chose it for his 1758 publication.

Amsterdam also became the leading European center for obtaining exotic specimens at the end of the seventeenth century. Obsessed with exotic fish and animals, and having the money needed to fill their cabinets, Dutch collectors took advantage of the situation. Not surprisingly, it was in Amsterdam that pharmacist Albertus Seba assembled one of the most important collections of rare and exotic *naturalia* of the era.[100] Seba asked people in distant ports to ship him specimens, occasionally bought items from ship captains and sailors, and was

[99] Also see Anonymous, 1902, and Bierens de Haan, 1952.

[100] Encyclopedic collections, like those of Seba, were popular in these days. But the obsession with collecting had already started in the 16th century. An early example of a natural history cabinet is that shown on an engraving in Naples apothecary Ferrante Imperato's (1550-1625) *Dell'Historia Naturale* (Naples 1599). They were referred to as *Kunstkammern*, *Wunderkammern*, '*Cabinets of Curiosities*,' or '*Cabinets of Wonders*' and some later evolved into museums. Naturalists, physicians, rulers, aristocrats, and members of royalty, including Peter the Great of Russia and Frederick III of Denmark, were involved in collecting Nature's curiosities. The objects that were included would nowadays belong to natural history, archaeology, geology, ethnology, etc., but for them it was a kind of theatre of the world. Such collections probably played a role in the changing view of natural history from static to dynamic (Bredekamp, 1995). For studies of the natural collections in the Europe of the time, see Olmi, 1992; Impey and MacGregor, 2001; and Bredekamp, 1995.

willing to trade medicines for specimens with the sailors that stopped here.[101,102]

The openness of the Dutch to visitors to their colonies, and to botanical and zoological exports from these lands, was also important. This openness can be contrasted to Spanish, who controlled what is now Venezuela, where electric eels can also be found. Unlike the Dutch, the Spanish virtually closed off their colonies to foreigners, so European scientists and naturalists did not have easy access to their exotica in the 18th century. The Latin neologism created to refer to exotic items coming from the New World reflects the importance of the Dutch, as opposed to the Spanish, in this domain. The word for such imports was *Surinamensia*.[103]

As can be imagined, the publication of magnificent books, including those of Seba and Gronov, demanded considerable time and money. These publications served many purposes, including increasing the value of their personal collections. The presence of skilful artists and an advanced typographic industry in Amsterdam added to this city's appeal to collectors, some of whose magnificent cabinets would serve as the foundations for modern museums.

[101] Pharmacists, including Seba, were naturally inclined to collect natural objects, particularly plants, but also animals and especially snakes, in order to prepare remedies and potions. For Seba, the world was a vast field from which to collect the plants and animals that God, in His providential goodness, had created for suffering humanity and human utility. Seba's collection, as portrayed in the *Thesaurus*, was aimed at presenting an encyclopedic portrait of the three domains of Nature: plants, animals, and minerals. Collecting various objects from the natural and artificial world, in order to recreate a symbolic reproduction of the entire world in the restricted space of a cabinet, had been a favorite leisure of the upper classes since the Renaissance. What was obtained was classified with criteria that still owed much to the wondrous and to aesthetics. But it was becoming increasingly different from the rather chaotic assembly of objects typical of the *Wunderkammern* of the Renaissance and Baroque, in which natural specimens (mostly of the singular and monstrous genre) were combined with handicrafts, so as to create fascinating but bizarre pictures, often with esoteric symbolisms.

[102] It is not by chance that Carl Linnaeus visited Holland in 1735 and spent considerable time in the nearby summer residence of rich Amsterdam banker, George Clifford (to whom he had been introduced by physician Herman Boerhaave). Clifford's estate included a *Hortus botanicus*, and Linnaeus described it in his book *Hortus Cliffortianus*, which formed an important basis for his subsequent works. He had recently concluded that the diversity of plants and animals had become so large that a better classification system was needed. During his stay, he became acquainted with Seba and with Jan Frederik Gronovius, Laurens Theodor's father, to whom he showed the manuscript of a new work, his *Systema naturae*, published in Leyden in 1735.

[103] See for instance Sundius, 1749.

Thus, although the Golden Age (17th century) in the Netherlands had already closed, the Dutch Republic during the middle of the 18th century was still a very special place for science and scientists. Its international connections, economics, political and cultural features, ties to exotic lands, and flourishing scientific and medical communities provided the fertile conditions that helped people view the discharges of certain fish in a new way, namely as electrical.

These various factors intertwined in ways that can at times be difficult to imagine and impossible to disentangle. For instance, the academician-physicist Allamand possessed an important collection of *naturalia,* whereas Seba and Gronov, two internationally known collectors, were also reputed scholars. The personages mentioned above also belonged to some of the same scientific institutions, held important public and political posts, and had networks of international correspondents. And a common value uniting all of them, was a drive to understand Nature's deepest secrets.

It is somewhat surprising that, in spite of their importance in the path leading to the discovery of the electric nature of the nervous system and the invention of the electric battery, the early Dutch publications are so rarely cited in books or journal articles today.[104] It is simplistic to think that this gap is due to the fact that these contributions appeared solely in Dutch and in somewhat obscure Dutch journals, rather than in major French, German, or English scientific periodicals. This is because these contributions were not just written in Dutch and, more importantly, because many were translated in full or in abridged formats and were published and cited in non-Dutch texts. Further, as we have emphasized, the lines of communication were wide open during the Enlightenment, with exciting new findings and ideas being exchanged with correspondents outside the Netherlands, including in France, Germany, and England.

Since so little has been written about the early Dutch achievements with electric fish the mistaken impression might be that the Dutch endeavors were relatively unimportant. A somewhat similar neglect occurred in the case of the Walsh's achievements with the eel, which were unknown to Faraday only about half a century later. Neglect seems to be the fate of any human achievement in the absence of accessible documents and writings by historians.

By providing the first complete English translations of two of the most important texts of what we would like to think of as the "Dutch

[104] See for instance Vijselaar, 2001, pp. 40–70 and Roberts, 1999, pp. 680–714, although the latter paper is dealing with electricity generated by machines. Brazier, 1984 and Kipnis, 1986, pp. 107–142 only provide the references but these are inaccurate.

path to fish electricity," we hope to have resurrected an inadequately referenced scientific achievement of great importance. Although John Walsh deserves the credit for his landmark experiment of spark production from an electric eel in 1776, the groundwork for this achievement began to be laid in the 1750s, when Storm van 's Gravesande penned a note from Guiana to his physicist-friend Jean Allamand in the Netherlands. With this letter and other exchanges of information, and with follow-up observations and additional discoveries by the Dutch and then the British, animal electricity began to be accepted. Many exciting developments emerged in this new *Zeitgeist*, among which were Galvani's revolutionary "neuro-electric" physiology and Volta's innovative battery, without question two of the most significant achievements of the scientific Enlightenment.

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