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Urodele limb and tail regeneration in early biological thought: an essay on scientific controversy and social change

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"The tails of lizards and of serpents, if they be cut off, will grow again"

(Aristotle, History of Animals, Book II, chap. 17, 508b 4-7)

Lizard tail regeneration thus appears in Aristotle's biological treatises; but then many organisms and phenomena, real and imaginary, appear intermingled in the early natural history literature. Two thousand years after Aristotle's comments on regeneration, in June and July of 1686, Melchisedech Thevenot treated the Paris Academy of Sciences to a demonstration of lizard tail regeneration (Roger, 1963). This event, a simple presentation with a subsequent cataloguing of observations, was characteristic of natural history of the period. But important context appeared subsequent to the demonstration as naturalists rehearsed for a transition to a hypothesis-driven exploration of nature. *Claude Perrault explained the regenerating lizard tail in a brief dissertation (1688) as analogous to the outgrowth of hair and feathers, taking origin from preformed, preexistent 'germes' which unfolded or 'developed' at need.*

Animal regeneration again received transient attention when the great French naturalist, René-Antoine Ferchault de Réaumur, presented the Paris Academy his classic work on crayfish claw regeneration (Réaumur, 1712). He also concluded that preformed, preexistent structure and the accompanying mystery of its origin remained the only reasonable interpretation. Placing generation and associated events beyond the realm of human understanding by invoking preexistent germs remained an acceptable conclusion at this juncture. Réaumur thus joined his predecessors and neatly positioned this additional example of animal regeneration among previously "known" phenomena, in effect removing it from critical analysis or question. His authority secured that interpretation.

Preformation versus epigenesis

Preformation constituted the most widely accepted explanation of the generation of complex animal form in the latter part of the seventeenth century (Roger, 1963). The somewhat familiar and generally favored representation was the 'emboîtement' model, in which successive generations of organisms were encapsulated one within the other. A concept in which each generation was preformed at the time of the creation accorded with the mechanical view of nature which emerged from Cartesian science; at the same time it preserved to God an active role. That concept received unambiguous and articulate philosophical justification in the widely read works of Nicolas Malebranche (1638-1715; see Malebranche, 1980) and Gottfried Wilhelm Leibniz (1646-1716). According to Hoffheimer (1982): "Belief in preexistence was doubtless further reinforced by contemporary theological notions of predestination; the maintenance of certain Calvinist or Augustinian doctrines by both the Jansenist Malebranche and Protestant Leibniz is not irrelevant to the ease with which both accepted a preexistence theory of generation." Roger (1980) also comments that: *"In the first half of the eighteenth century, natural history was written mainly for religious purposes," a consequence "of the theocentric atmosphere of the late seventeenth century."* Widespread commitment to preexistent preformation forms a critical component of the context in which the concept of animal regeneration was shaped.

Epigenetic theories, typically placed in opposition to preformation, gave nature greater play in the generation of complex bodies. Matter possessed of self-regulating dynamics or an autonomous but indeterminate 'force' comprised a central feature of epigenetic models. These concepts drew largely on the seventeenth century's progress in chemistry and physics, which relied heavily on yet-to-be-explained 'forces of attraction,' such as gravitation. In 1745 P-

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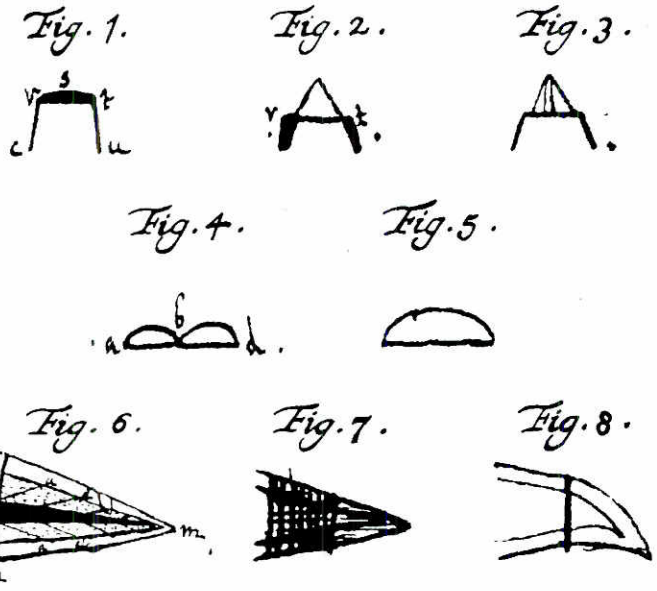

Fig. 1. Sketches abstracted from Spallanzani's 21 September, 1766, letter to Bonnet. *These are the first illustrations of salamander* **(Figs. 1-5)** *and tadpole* **(Figs. 6-8)** *tail regeneration. Mr. Philippe Monnier of the Bibliothèque Publique et Universitaire in Geneva kindly provided a photocopy of the letter from which this figure was prepared for an earlier publication (Dinsmore, 1991)*

L.M. de Maupertuis (1698-1759), the mathematician and naturalist, anonymously published his *Vénus physique*. He used the first 16 chapters to demonstrate how simple observations and common sense made the preformation model of generation untenable. He then floated his own epigenetic explanation of reproduction, a form of pangenesis, and asked: *"Why shouldn't a cohesive force, if it exists in Nature, have a role in the formation of animal bodies?"* (Maupertuis, 1966).

Nearly twenty years earlier Maupertuis had performed a series of studies on salamanders; hitherto, urodeles, though not unknown, had yet to receive serious investigation. Their reputation as deadly beasts may have diverted attention from them, despite their extraordinary regenerative abilities. In any event, Maupertuis marveled at the continuing belief by "modern Naturalists" that salamanders could tolerate fire and that they were extraordinarily venomous, able "to make an entire country perish" (Maupertuis, 1727). He published the results of his simple experiments debunking those beliefs. As a final observation, after opening several animals and observing their ovaries and eggs, he added prophetically: *"These animals seem quite appropriate to clarify the mystery of generation."*

Others went on to develop more fully elaborated ideas about the nature of the attractive forces suggested in the *Vénus physique*. Réaumur's successor at the Jardin du Roi, George-Louis Leclerc, comte de Buffon (1707-1788), discussed theories of generation with Maupertuis (Eddy, 1984). Not surprisingly, features of the epigenesis model that he subsequently proposed in the second volume of his *Histoire naturelle* (1749) bear great resemblance to those of Maupertuis: they both invoked Newtonian forces to account for both generation and embryonic development and criticized theories of preformation and preexistence. Buffon, however, based his epigenetic theory on 'organic molecules' and 'internal molds' as the only reasonable concept of generation. Like earlier theories of spontaneous generation, however, epigenesis met strong opposition on two major grounds: it accorded nature increased autonomy, a formative power independent of divine guidance referred to as materialism, and it also allowed for change, thereby challenging conventional dogma about the stability or constancy of nature and, by implication, of society.

As interesting as the earlier examples of animal regeneration may have seemed to some individuals, they aroused little lasting curiosity. They defied no fundamental credos, were analogized with 'already known' phenomena, and subsumed into extant views of nature, the preformation model dominating into the first half of the eighteenth century. All of that changed in 1740. *Abraham Trembley's (1710-1783) revolutionary discovery that bisecting a hydra resulted in the production of two complete animals — a novel means of animal reproduction — brought regeneration unmistakably into the realm of generation.* In so doing, animal regeneration became a central issue in the confrontation between the preformationist and the epigenetist world views. By the time Trembley had published his detailed account describing the range and depth of his investigations of hydra biology (Trembley, 1744; English trans., Lenhoff and Lenhoff, 1986), many naturalists throughout Europe had confirmed and extended his preliminary observations. Significantly, the issue of how to accommodate animal regeneration into contemporary ideas about the nature of animal generation and its philosophical implications began to escalate.

Among preformationists, the hydra was heralded as the juncture between the plant and animal Kingdoms in the great Chain of Being: "One could say that you have discovered the point of passage from plant to animal" (Bonnet to Trembley, 24 March, 1741 in Dawson, 1987). This latter concept gave structure to a number of world views during that period; indeed contemporary philosophers such as Leibniz and Malebranche had supposed the existence of these "zoophytes" in their hierarchical representations of nature and society. Why had not earlier observations on animal regeneration raised these issues? Trembley's incisive observation in the final pages of his 1744 *Mémoire* captures a constraining feature of the intellectual milieu:

> It is quite probable that were it not for a number of preconceptions that have gained currency, natural history would be more advanced than it presently is. This view holds especially true in regard to the multiplication of animals by sectioning. Had this process been presumed possible, it would long since have been a property recognized in a number of animals. In fact, everything seemed ripe for the making of this discovery.... Why then did we not...? The answer is that it was presumed impossible (Lenhoff and Lenhoff, 1986, p.186).

This, then, provides essential context in which the discovery of salamander regeneration became problematic. As with Trembley's enigmatic polyp (Dawson, 1987), urodele appendage regeneration was not supposed to happen either; that is, there was no *reason* at the time it was discovered to suppose or to hypothesize that these highly differentiated quadrupeds possessed that particular ability.

The beginnings of scientific interest in urodele regeneration

Though urodele regeneration may have been noticed earlier, it became a matter of scientific interest in the mid-1760's, when

Lazzaro Spallanzani (1729-1799), a professor of philosophy at the university in Modena, Italy, discovered that urodele tails could regenerate. Spallanzani had become interested in the issue of the nature of generation in 1761, when his former professor, Antonio Vallisneri (the younger), introduced him to the published microscopic studies of Buffon and John Turberville Needham (1713-1781). They had described what they interpreted as the spontaneous generation of 'animalcules' or microorganisms in various broths or infusions. Their observations had served as a basis for the development and support of epigenetic explanations of generation, though each man created his own particular explanatory mechanisms.

A need to see things for himself characterized Spallanzani's life, and the use of experiment, more heavily and consistently than most of his contemporaries, grounded his epistemology (Grmek, 1982). The naturalist's relationship with nature was in transition: changing from observation and description to interrogation (Grmek, 1982). Spallanzani's collected correspondence (Di Pietro, 1984) documents these events and relationships. Spallanzani represented the new naturalist's shift to prioritization of experiment, and animal regeneration soon became a target of his interrogations. He repeated Needham's experiments and ultimately rejected his interpretations in a study which he eventually published in 1765. Spallanzani became involved in and increasingly informed of the controversy between theories of epigenesis and preformation. This led to his reading Charles Bonnet's (1729-1793) philosophically-oriented *Considerations sur les corps organisés* (1762; typically referred to as the *Corps organisés*) and his *Contemplations de la nature* (1764). In them, Bonnet promoted development from preformed, preexistent germs as the only "sane" philosophical interpretation of generation or reproduction. Spallanzani responded again by repeating and then expanding on Bonnet's directive to employ worm regeneration as a powerful experimental tool. He initiated correspondence with Bonnet in 1765 (Dinsmore, 1991).

Unconstrained by Bonnet's emphasis on insects, Spallanzani went on to amputate some salamanders' tails and to observe their complete regeneration (announced in a letter to Bonnet, 18 November, 1765). Bonnet replied (27 December, 1765) with encouragement, though still emphasizing the importance of worm regeneration: "I cannot encourage you too much, Sir, to continue your experiments on earthworms." (The quotations in this paragraph and in the next two paragraphs from letters by Trembley, Bonnet, or Spallanzani were translated by the author from the originals in the Bibliothèque publique and universitaire, Geneva). Turning to Spallanzani's discovery of salamander tail regeneration, he pointed out that "these kinds of reproductions can furnish us some ideas about the manner in which growth takes place: this issue in the study of nature is one of the most obscure." He then directed Spallanzani to specific passages in both his *Corps organisés* and *Contemplation*, where, as noted above, he had persuasively developed the preformation framework in which generation and regeneration must, in his view, be interpreted. Though he told Spallanzani that his goal should be "to discover if these appendages [tails] originally exist in miniature within a germ or if they arise simply from the elongation of certain fibers," the authority and slant of his publications favoring preexistence and preformation had broad influence.

The following Spring Spallanzani informed Bonnet that he had just subjected more than two hundred salamanders to his regen-

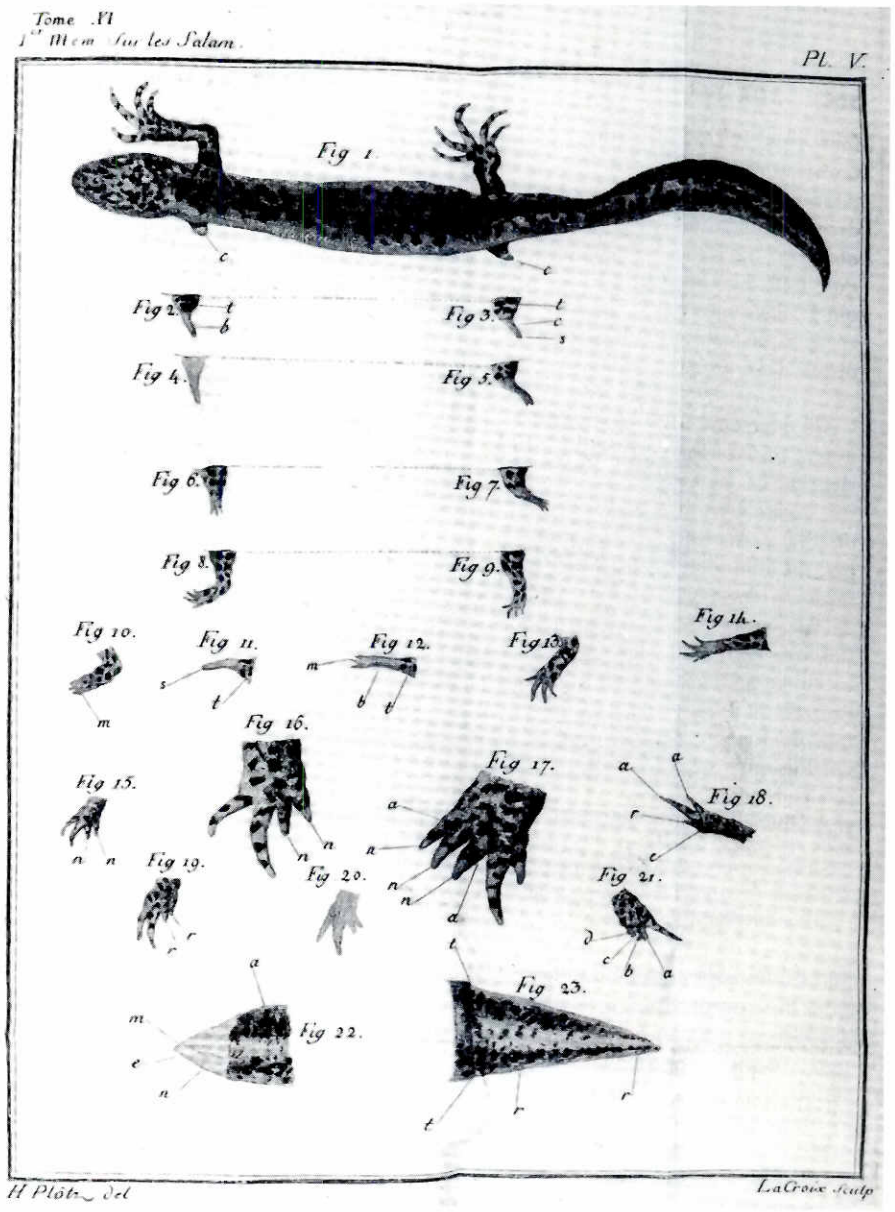

Fig. 2. Salamander limb and tail regeneration. *This illustration of both limb and tail regeneration accompanied Bonnet's first Mémoire on regeneration in aquatic salamanders. It appears in volume 11 of his Oeuvres d'histoire naturelle (Bonnet, 1779), p.109.*

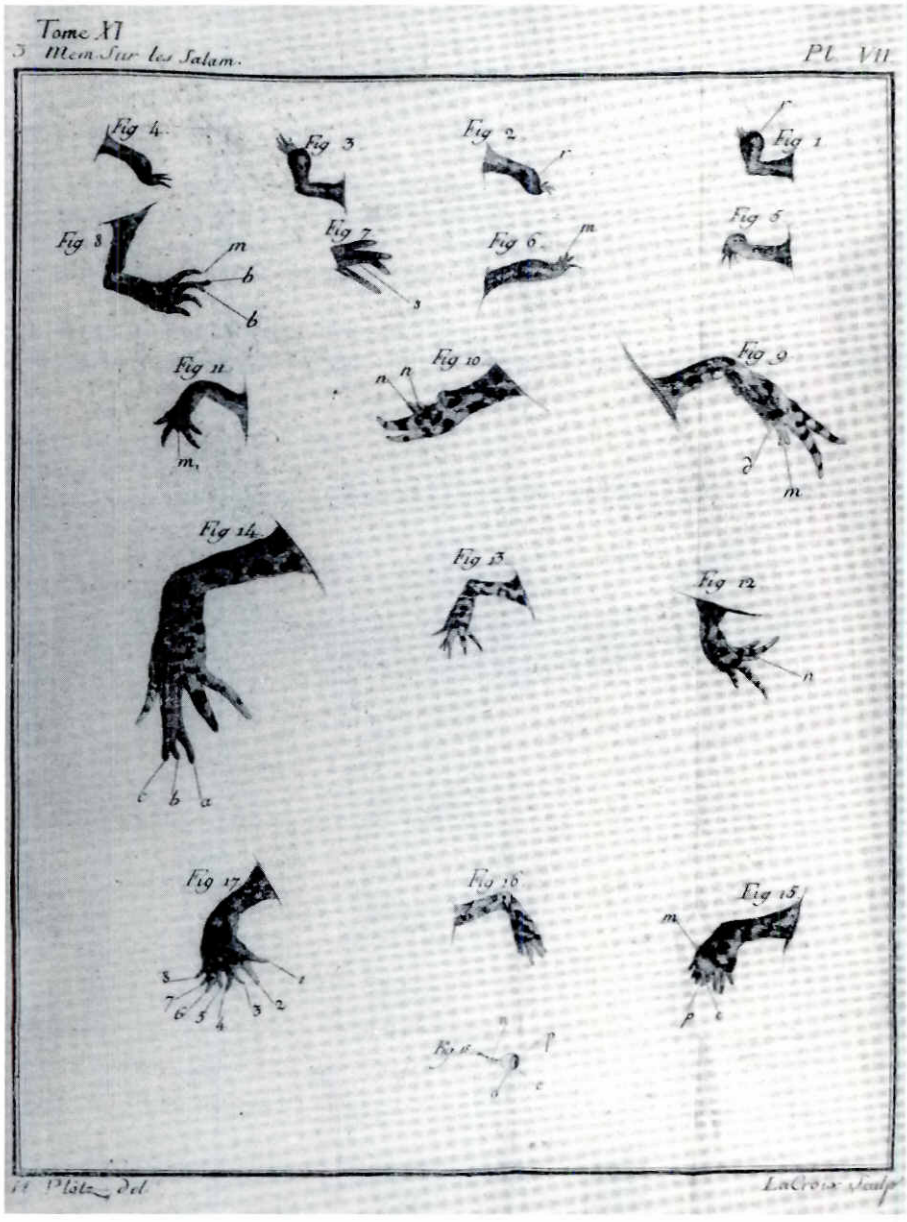

Fig. 3. Abnormal salamander limb regeneration. *Inserted at the end of Bonnet's third Mémoire (Bonnet, 1779-83, vol. 11, p. 179) on aquatic salamander regeneration, this illustration depicts deficient regenerates as well as supernumerary digits (in fact he used the term "doigt surnuméraire"). His attempts to explain their origin influenced his final thoughts on the preformed germ theory and also have a familiar ring to them.*

eration studies. He added that: "My principal objective is to observe whether the new production is an elongation of the old, or if it takes its origin from a small germ" (17 April, 1766), thus paraphrasing Bonnet. His preference was nevertheless clear when he concluded by stating that some of his most famous Italian colleagues, Morgagni among them, considered that Bonnet's arguments supporting preformation had completely refuted epigenesis, particularly as developed by Needham and Buffon.

Spallanzani later (21 September, 1766) provided Bonnet several pages of detailed description of his regeneration experiments, complete with illustrations of regenerating salamander tails (Fig. 1). But only after two years of various studies directed at discovering the nature of generation did Spallanzani finally test and observe urodele limb regeneration (again, announced in a letter to Bonnet, 6 June, 1767).

Spallanzani's salamander regeneration discoveries first appeared formally in a brief publication, written in Italian, entitled *Prodromo di un opera da imprimersi sopra la riproduzioni animali* (1768). He sent a copy to the Royal Society in London, where Matthew Maty, the Society's Secretary, published an English translation, An *Essay on Animal Reproductions*, the following year (Spallanzani, 1769). In the *Prodromo*, Spallanzani outlined his discoveries on the regenerative abilities of worms, snails, tadpole and salamander tails and limbs, and salamander jaws. Also included was a chapter devoted to his claim to have seen preformed tadpoles in unfertilized frog eggs, an explicit indication of his commitment to ovist preformation. Apologizing for the brevity of the work, he promised a more complete account to follow.

A simple announcement of urodele appendage regeneration would not have differentiated it from the earlier observations on lizard tail replacement, but this time regeneration had emerged into an intellectual framework characterized by Roger (1963) as a new scientific spirit. Its framing as an issue directly related to generation ("reproduction" as it was then broadly defined) entered it squarely into the preformation/epigenesis controversy, amplified by Bonnet in terms of preformed germs.

How did urodele regeneration become problematic?

Abraham Trembley's seminal observations on bisected hydra regeneration, confirmed in round worms by his cousin Charles Bonnet (Bonnet, 1745, part II), opened a new front for the preformation/epigenesis debate. Certain animals could be propagated from cuttings! From that point on, generation and regeneration became linked phenomena, but regeneration offered potentially greater experimental, or at least observational, access to mechanisms underlying these processes — if only for some of the lower organisms. But Trembley's discovery threw Bonnet's religiously based philosophy into confusion. He wrote to Trembley suggesting that it would not make the "Metaphysiciens" very happy and would "give rise to terrible difficulties" (Dawson, 1987, p. 206, 1 September, 1741, this author's translation from the French), particularly because of the problems it raised relative to the concept of animals' souls, an issue that haunted him well beyond his subsequent worm regeneration studies. Nearly thirty years later, he still recalled the shock of the discovery of hydra regeneration: "It overturned all of my ideas and ignited my brain, so to speak" (Savioz, 1948a). But insects, defined

at that time as any segmented organism (discussed in the Preface of Bonnet's 1745 *Traité*), did not yet fully elicit analogies with 'higher' organisms. He therefore assumed responsibility for reformulating the preformation model to accommodate insect regeneration. This he accomplished with his *Corps organisés* and his *Contemplations*. With the *Corps organisés* he "sought to bring that beautiful part of Natural History [i.e., the issue of generation] back to more philosophical principles" (Preface, p.v). In the second volume of the *Corps organisés* (p. 3) he explicitly invited his readers to perform new regeneration experiments on earthworms in order to perfect or complete the theory encompassing both regeneration and generation. He later confirmed that he wrote these volumes "to combat the various systems founded on Epigenesis, and in particular those of Mr.'s de Buffon and Needham" and at the same time "to develop/expand on the system of germes," (Savioz, 1948a). *Thus a preformation-preexistence bias permeated his presentation of the excitement found in exploring issues of generation and regeneration.*

His *Contemplations* took at least as vigorous a position in the context of preformed germes, while pressing the attack on opinions offered by Epigenetists, particularly Buffon. There he also drew another explicit relationship: "We know how much nonsense about the nature of the Soul arose at the time of the Discovery of the Polype. The Materialists had seized on it with avidity to shore up their preferred dogma." (Bonnet, 1764) Discourse on the problematic science of animal generation thus carried with it the emotional weight of religious opinion about the nature of the soul. It was these works which attracted Spallanzani to regeneration research and offers an explanation of how his discoveries became problematic.

Spallanzani's discovery of salamander tail and limb regeneration added fuel to the emotionally charged conflict over the fundamental nature of reproduction. Spallanzani explained the significance of his discovery in the *Prodromo*: "Now when the legs and tail of this animal are taken away, new vertebrae, new bones are produced; a phenomenon as wonderful, as it is hitherto unknown" (from Maty's 1769 English translation). Salamander regeneration became problematic when lizard tail regeneration and crayfish claw replacement had not because "the structure of these parts in the salamander is infinitely more complicated and refined" (Spallanzani, 1769). Bonnet, though, in Trembley's terms, held "a number of preconceptions" (Lenhoff and Lenhoff, 1986, p. 186) about generation and regeneration in higher forms like the quadrupeds. With regard to regeneration of salamander appendages, he undoubtedly, "presumed it impossible." (p. 186) And yet when Spallanzani relayed to him the news of its discovery, he almost immediately grasped it as an opportunity not just to look for his postulated 'germes' but to actually find them.

He reiterated Bonnet's own reasons for studying regeneration- to clarify the shrouded issues of generation- similarly couching them in terms of seeking the illusive preexistent germs. When he announced his discovery of salamander limb regeneration to Bonnet, the next paragraph in that letter (6 June, 1767) also declared: *"I pride myself in having found that the tadpole which becomes a frog preexists fertilization."* He then concluded emphatically: *"thus the unfertilized egg is the actual tadpole, and it therefore follows that the tadpole preexists fertilization"* (author's translation of letter in Bibliothèque publique and universitaire, Geneva). The juxtaposition of the discovery of salamander limb regeneration with his imagined preexistent tadpoles, both in correspondence with Bonnet and in the *Prodromo*, provides another inescapable demonstration of how urodele regeneration became problematic in terms of the controversy about the nature of generation.

A decade after Spallanzani had first told him of salamander regeneration, Bonnet grew tired of waiting for the details of that work to be published. Spallanzani's elaborate letters had furnished him all of the information he needed to repeat the studies (Di Pietro, 1984). Thirty years after having effectively left personal observations of nature, Bonnet returned to active investigation. From his renewed efforts he produced three Memoires on salamander limb and tail regeneration (Bonnet, 1779, vol. 11) establishing beyond doubt the validity of his Italian colleague's observations. In them he continued his struggle against the rising tide of epigenesis with successive accommodations in his theory of preformed germs.

Regeneration, preformation, and divine providence

Personal motivations and philosophical commitments play a large part in the history of urodele regeneration research. In the late seventeenth century, preformation theories arose largely in response to the dangers of epigenesis as they were perceived by the conservative intellectual establishment. Explanations of embryogenesis which incorporated the concept of preexistence since Creation "avoided the atheistic and materialistic implications of development by epigenesis" (Roe, 1981). Animal regeneration in general and urodele regeneration in particular presented uncomfortable contradictions to expectations of preformed, preexistent organisms. Abraham Trembley refused to engage in the polemics on how best to explain the mechanisms of generation and regeneration, but his cousin, Charles Bonnet, embraced the challenge and became the principal, and very articulate, naturalist-protagonist for the preformation concept.

Bonnet repeatedly named Buffon in his letters and his books as his principal epigenetist antagonist. He shared some of his most revealing personal thoughts with Albrecht von Haller (1708-1777), the noted physiologist-physician from Bern. The fact that, as a student of Boerhaave, Haller began as a preformationist and then converted to epigenesis upon learning of Trembley's polyp regeneration work must be inserted here. His return to preformation occurred after he began corresponding with Bonnet, and was probably a direct consequence of that relationship. Bonnet's influence on Haller may be discerned in the over 900 letters they exchanged before Haller's death in 1777. Sonntag (1983), who has transcribed them, concluded from their contents that Bonnet and Haller were *"joined from the start by the strong bond of their common Protestantism," grounded in Calvinism, which led to their being greatly "troubled by the spread of deistic and materialistic ideas."* From this perspective they portrayed those who refused to accept their views on the nature of generation and regeneration as being materialists, or atheists, although they themselves sought to explain generation in mechanistic terms.

In early correspondence (1754), Bonnet vigorously objected that Haller's recent explanation of the process of fracture repair would render "the Beautiful Theory of Germes ... tremendously problematic." He added that he had always believed that repair and reproduction necessarily implied preexistent fibers. He then warned Haller that "Mr.'s de Maupertuis & de Buffon could, in my opinion, assume the privilege of using your Experiments to provide support for their strange [epigenetic] hypothesis of the organic molecules" (16 August, 1754; in Sonntag, 1983). Several years later (August,

1761; in Sonntag, 1983), he wrote to Haller, accusing Buffon of *"a hidden design to weaken one of the most beautiful proofs of the existence of God."* This he inferred from Buffon's analysis of the origin of certain congenital defects or 'monsters' in which excess or deficiency in structure occurred. Several years earlier Haller had reviewed Buffon's *Histoire naturelle* and concluded that: "The doctrine of Mr. Buffon is less dangerous than that of Mr. Needham" (Sloan, 1981). But Buffon's ideas were linked to those of Maupertuis, in whose work Haller had initially found much to admire, as indicated in the first edition of his 1747 *Physiology* (Roe, 1981). Over time, though, Maupertuis had become Maupertuis, the Atheist President of the Berlin Academy (Bonnet to Haller, 18 September, 1759; in Sonntag, 1983). And by 1761, Haller was accusing Buffon of *"reasoning like an Atheist"* (5 October, 1761) with Bonnet concurring that Buffon "speaks like an Atheist" (22 December, 1761).

The issue of generation and regeneration for Bonnet and Haller was much more than just a scientific debate; they framed it largely in terms of whether or not ideas conformed to orthodox beliefs about divine providence. While hydra regeneration more easily blended with orthodoxy since the polyp occupied a middle realm between real animals and plants, *salamander appendage regeneration contradicted philosophical orthodoxy*. If the discoveries of hydra and worm regeneration presented difficulties, Bonnet reconciled them by simply stating that lower insects are different: "that unlike the larger animals... whose ovaries occupy a particular region, they are distributed throughout the body of an earthworm, of certain freshwater worms, of the polyp, etc. I have thus considered the body of these singular animals as a kind of universal ovary." (Bonnet, 1764, p. xxvii). He went on to decry the misuse of the discovery of the Polyp by materialists and skeptics who "had avidly seized upon it to shore up their preferred dogma." (p. xxvii) Warning others of the dangers of theorizing, he nevertheless ended the preface by advocating the preexistence of germs: "I'm inclined toward the Emboîtement [model of preexistence]." (p. xxvii)

In the text of his *Contemplations*, Bonnet ridiculed Buffon's organic molecules and "moule interieur" and the concept of epigenesis itself: "The greatest marvel would not be that such Molecules exist; but that an 18th century scientist had imagined them, that he then believed that he had seen them, and that he had brought them to light as very real Beings, of a singular order." Nevertheless, he continued to reserve the right to himself to believe in the reality of his 'beautiful germes.'

Bonnet returned to the same themes over a decade later with his first article on salamander limb regeneration (Bonnet, 1777; Fig. 2); eventually he devoted three *Mémoires* to the subject (Bonnet, 1779, vol. 11) and provided the final version of his be loved germ theory. In the concluding "Resultats Generaux" of his first salamander publication, he listed several consequences which "seem to me to flow directly from the facts." (Bonnet, 1777) He observed that unlike regeneration in polyps and worms, salamander regeneration "proceeds very slowly." This he attributed to the former being "very gelatinous, and having nothing bony, nor anything that becomes so." Salamanders, though, "are little quadrupeds, and like quadrupeds, they have bones invested with muscle and flesh." However, he maintained that: "All of these parts *preexist* (emphasis mine) well before their appearance in a gelatinous state." (Bonnet, 1777)

Bonnet's "second truth" concerned the "bouton animal," or limb blastema in today's terms. He asserted that the blastema "is the limb itself highly concentrated and greatly reduced in size." (Bonnet, 1777) It therefore followed that the "'bouton animal' is thus actually a real hand or a real foot already completely formed." He continued with "a third truth; it is that the limbs which replace those that were amputated, are not correctly viewed as being 'engendered,' but that they preexisted from the beginning... they only proceed to unfold themselves," having "preexisted in some germes." His "fifth result" is a summary statement about the nature of regeneration in salamanders, which also illustrates the evolution of his preformation theory: *"The bodies of Salamanders probably contain a multitude of germes of different orders"* (Bonnet, 1777) according to what kind of structure might need to regenerate. He had now moved away from an earlier preference for preformation by 'emboîtement', which could not readily accommodate salamander appendage regeneration (deficient and supernumerary regenerates, in particular; Fig. 3), to promoting a model assuming preformed but heterogeneous, reparative germs. Worm regeneration studies forced Bonnet to rethink his theory of preexistent germs, but his definitive ideas gelled only after he performed his salamander regeneration experiments (Savioz, 1948b).

The foregoing analysis presents a brief and necessarily selective sketch of some data about when, how and why urodele regeneration became the object of scientific interest. It does not pretend to be exhaustive nor does it claim to be definitive. Nevertheless, reflections on the role of urodele regeneration research in the unfolding of the preformation/epigenesis debate, in addition to their intrinsic interest, may prove instructive for their resonance with current scientific deliberations. Controversial contemporary issues such as the necessity of embryo research or the assumptions made about what aspects of behavioral neurobiology ought to be pursued come immediately to mind. Placement of scientific content knowledge into a theoretical framework may therefore reveal as much about the theorist as it does about relationships included in the theory. And it will be interesting to watch how current debates in urodele regeneration research are recounted in the decades to come.

Summary

Lazzaro Spallanzani (1729-1799) announced his discoveries of salamander tail and limb regeneration to Charles Bonnet (1729-1793) in the 1760's. The phenomenon soon became embroiled with the ongoing epigenesis/preformation controversy over the fundamental nature of generation. The concept of animal regeneration as a process linked to reproduction had emerged in 1740 with Abraham Trembley's (1710-1783) demonstration that a bisected hydra gives rise to two new, completely formed individuals. The discovery of urodele appendage regeneration revealed for the first time that a quadruped could regenerate and restore complex form, lizard tail regenerates having been recognized as only substitute structures. Moreover, regeneration of a quadruped appendage became problematic because it was not supposed to be possible, and because it conflicted with prevailing opinion about the nature of higher organisms. Why animal regeneration in general engendered conflict transcends biological concerns and touches on personal philosophical commitments. Preformation had been adopted into orthodox theology as a validation of predes-

tination and of the hierarchical structuring of man's relationships to nature and within society. Epigenetic interpretations of regeneration represented challenges to certain aspects of the extant social and political fabric in their extrapolation to ideas of what constituted natural order. Urodele regeneration as an integral part of the epigenesis/preformation debate therefore constituted a formative component of eighteenth century thought in a period of social and intellectual revolution.

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