Being Hydra

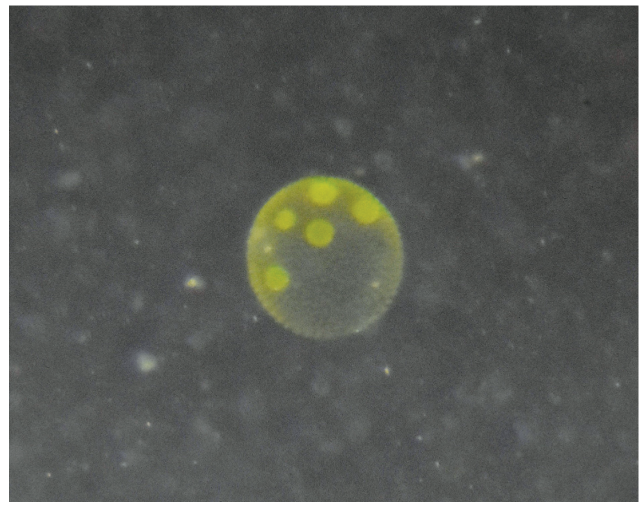
"At the same time plant and animal, and neither animal nor plant"

Jon McAlice

In the late 1600s, when Antoine van Leeuwenhoek first focused his self-made microscope on samples of water taken from the ponds, the rain barrels, and the roadside ditches of his native Delft, he discovered a previously unknown world. This is the world of little things, expressions of life too small to be noticed in the context of how we normally experience the world. When we look into the water flowing through a streambed or filling a pond or wetland, there are things that we can see — the rocks at the bottom, the shape of a fish holding itself stationary in the current, the yellow underside of a box turtle's neck as it disappears into the depths. We can also see the forms of eddies and vortices in the water itself, wave patterns and turbulence. We can see the green of aquatic plants and, at the right time of year, the colors of their blossoms on the surface. Shapes and shifting forms speak to us of movement. We can listen to the burbling of the water. These impressions belong to the macroscopic world of freshwater. We become aware of them as belonging to the world we live in. We can perceive them without the help of instruments.

What van Leeuwenhoek discovered is that within this readily perceptible world is another world: the microscopic world. Since his first descriptions of the "animalcules" living everywhere around us, our understanding of the microscopic world and its significance for the health and well-being of all life, including that of our planet, has grown enormously. Life would not exist on earth without these invisible organisms. Van Leeuwenhoek's discoveries opened a new field for natural scientific research. Water especially showed itself as an environment where life came to expression with a magical blend of simplicity, richness, and immediacy.

The observational boundary between the macroscopic and the microscopic is not a hard boundary. It is fluid. Consider water again. We can dip a glass into the water of a pond and hold it up to the sunlight. There is evidently something in the water. We can see flecks, sometimes small green bodies. If we watch closely, they appear to be moving around. But what are they? How are they shaped? How do they go about their lives? How do they relate to other



(All photographs by Jon McAlice.)

Magnified volvox

aspects of the watery world? These are questions that can only be answered with the help of a microscope. Without its help, we can discover that they are, but not *how* they are.

Two organisms that live on this boundary between the macroscopic and the microscopic have captured the attention and appreciation of researchers continuously since van Leeuwenhoek first mentioned them in his letters to the Royal Society in London at the beginning of the 18^{th} century. Both are what we might term boundary organisms. Volvox is a colonial alga with cellular differentiation; hydra are freshwater polyps (Phylum Cnidaria) with remarkable regenerative capacities. Volvox is considered to be a plant, yet displays a sensory and a vegetative pole, a distinction found in animals. Hydra is an animal, with regenerative capacities once thought only possible in plants. Further complicating the issue is that the most common species of hydra (and the first observed closely), *Hydra veridissima*, is pale green suggesting a plantlike quality.

Both volvox and hydra are found in freshwater ponds and wetlands. I have found both organisms in water samples taken from a wetland lying just north of The Nature Institute. This wetland is fed by a seasonal stream and empties into the Agawamuck Creek which flows through our local Hawthorne Valley. My sampling point is just to the south of a small road that divides the wetland into two distinct parts. The downstream section is smaller and contains a beaver dam, upstream of the road the wetland stretches back into a wooded valley. The larger upstream section is about 30 acres. I sample on the downstream side, just below and off to the side of a culvert connecting the two sections. The flow of water through the culvert has been relatively stable throughout the fall and winter. Once the stream passes through the culvert and enters the body of standing water it forms a gentle eddy curling back on itself upstream. It is a point where the water is constantly being refreshed, yet which remains relatively still. A small clump of brown, broken stalks of last season's phragmites stands along the downstream edge of the eddy. This is where I take samples.

I began sampling in early November, a time of year in which volvox are believed to be absent. Yet in samples taken regularly through December and January at water temperatures as low as 4°C, volvox have been present, as have hydra. They appear in all stages of development giving no indication that they go into a state of dormancy in the winter months. I have regularly brought water samples directly from the wetland and examined them under the microscope before they have warmed. I find myself constantly surprised by how much activity is taking place in the cold water. It is alive with tiny creatures merrily living.

In what follows, I will focus on one of these two organisms, the hydra.

Although van Leeuwenhoek mentioned hydras in 1702, the Swiss naturalist Abraham Trembley was the first to describe them in detail. Trembley discovered them in 1740 when he was working as a tutor to the two young sons of a Dutch nobleman, Count William Bentinck. His interest in natural history led him to sampling the water in the ponds and ditches around the Count's estates. He and the boys gathered samples and placed them in glass jars on shelves in one of the estate's greenhouses. He writes about his first glimpse of a hydra in his *Memoirs on the Natural History of a Type of Fresh Water Polyp with Arms Shaped Like Horns*:[1]

> Having noticed various small animals on the plants that I had taken from a ditch, I put some of these plants into a large jar filled with water, placed it on the sill of a window, and then set about examining the creatures it contained. Soon I discovered a great many of them, all quite common indeed, but most of them unfamiliar to me. The novel spectacle presented me by these little animals excited my curiosity. As I scanned this jar teeming with creatures, I noticed a polyp[2] fastened to the stem of an aquatic plant. At first I paid it little heed, for I was following the livelier little creatures which naturally attracted my attention more than an immobile object. The casual observer, especially one completely unfamiliar with such physically similar animals as marine polyps, could scarcely avoid taking the freshwater polyp for a plant. I have said that the polyp I had noticed was motionless. The point is not that it was unable to move, but at that time I knew nothing about whether it could move or not. (Trembley, p. 5)

Hydra with radial tentacles

Trembley first thought the hydra to be parasitic plants. Their shape, their coloring, and their lack of motion appeared plantlike. At first glance, a casual observer would have little trouble agreeing with Trembley's assessment. *Hydra veridissima*, the green hydra that Trembley first observed, appears as a pale, lovely green stalk stretching out into the surrounding water topped by threadlike tentacles that may exceed the length of the stalk quite markedly. Its greenness extends out into the tentacles, although these become increasingly translucent the thinner they become. When I observe more closely and over time, however, it begins to show me other facets of how it is in the world. The movement of the tentacles first appears to be brought about by ambient motion in the surrounding water. Yet they do not all drift in the same direction but reach out radially, at times perpendicular to the stalk. Each tentacle can move individually.

Truly surprising is that when the hydra is disturbed, it immediately contracts; the tentacles all but disappear, the stalk becomes a small green blob close to the surface to which it is attached. I have observed this often yet at times not been able to determine exactly what brought it about. What does the hydra perceive in its surroundings that calls forth this sudden response?

It was events such as these that first captured Trembley's attention. He noticed that the tentacles appeared to move on their own and then he saw the hydra contract.

> One day I jogged ever so slightly the vessel holding the polyps in order to see how the ensuing movement of the water would affect their arms. I was completely unprepared for the result. I expected to see their arms and even their bodies merely shaken and dragged along with the motion of the water. Instead, I saw the polyps contract so suddenly and forcefully that their bodies looked like mere particles of green matter and their arms disappeared from sight altogether. I was caught by surprise. (Trembley, p. 6)

And he continues: "This surprise served to excite my curiosity and make me doubly attentive." He began to question whether he had been too quick in judging them to be plants. What he observed "roused sharply in [his] mind the image of an animal" (Trembley, p.,6).

Trembley now found himself in a state of what we might call today *productive discomfort*. Was hydra a plant or was it an animal? He became increasingly attentive. He noticed that the hydra in one glass appeared to congregate on the side of the glass receiving the most light. What he did next changed the course of scientific inquiry. He reached out and turned the glass halfway round. Would the hydra move back into the light?

> The day after turning the jar I found the poorly lit side on which I had left many polyps was almost devoid of them. The polyps were on their way to the best-lit side … After seeing the same thing a number of times, I became convinced that the polyps had a distinct propensity for the best-lit area of the jar. I did not venture to decide whether this propensity was directly related to the light or whether some other factor attracted them to the best-lit side. (Trembley, p. 7)

The modest simplicity of this last statement belies its significance. From the very beginning Trembley's experimental interactions with living hydras arose from questions that awakened in him as he observed them. He did not conduct experiments to prove or disprove theories. In fact, he explicitly warned against jumping to conclusions based on insufficient observation:

> When facts are lacking in such research, it is more appropriate to suspend judgment rather than to make decisions which almost always are based on the presumption that Nature is as limited as the faculties of those who study her. (Trembley, pp. 69 –70)

The only way to truly know the hydra was to know the hydra fully in all the expressions of its specific way of being. Trembley proceeded carefully.

His discovery of the movement of hydra toward the well-lit side of a jar was followed by the observation that the number of tentacles differed from hydra to hydra and that the length of the tentacles differed on a single hydra. Despite his growing inner certainty that a hydra was an animal, these observations caused him once more to wonder. What could decide the question one way or the other? At the time it was widely accepted that plants had regenerative capacities not to be found in animals.

Hydra budding

> At this point I speculated anew that perhaps these organisms were plants, and fortunately I did not reject this idea. I say fortunately because, although it was the less natural idea, it made me think of cutting up polyps. I conjectured that if a polyp were cut in two and if each of the severed parts lived and became a complete polyp, it would be clear that these organisms were plants. Since I was much more inclined to think of them as animals, however, I did not set much store by this experiment; I expected to see the cleaved polyps die. (Trembley, pp. 7–8)

They didn't. Over the course of the next ten days each of the two parts grew back the part that was missing: the original "foot" grew a new "head"; the original "head" a new "foot." The results of this experiment did not, however, lead Trembley to conclude that hydras were plants. He realized that what he was observing was an organism expressing the characteristics of an animal with regenerative capacities found among plants. At one point in his *Memoirs* he refers to them as plant-animals.

I have never felt inclined to repeat Trembley's sectioning experiments. Others have, however. When word first began to circulate in the scientific communities of Paris and London of Trembley's discovery, sectioning hydras became quite the rage. They were sectioned and observed in laboratories, drawing rooms and the literary salons of Paris. Trembley's polyps took the continent by storm. This was in part due to his generosity. Once having observed the regenerative capacity of the polyps he reached out and shared his observations with other naturalists. And not only his observations. He devised special containers that would allow him to also share his polyps, sending them on horseback, by coach, and by boat to various acquaintances in Europe and England. Trembley's generosity was so unself-serving that others ended up publishing his experiments before he could. But that didn't matter. Alexander Trembley's name became inseparable from the tiny creature that, no matter how you cut it, would grow again and be whole.

Hydras have a relatively simple bodily organization. It consists of a long tube with a foot and a head. The head is comprised of a dome-like swelling at the center of which is the mouth, and a ring of tentacles. The body consists of two layers of epithelial cells — the ectoderm and the endoderm. They are separated from one another by an extra-cellular matrix. A network of nerve cells extends through the ectoderm. The inner layer forms a digestive cavity that extends from the mouth to the foot or basal disk. The mouth is the only opening. On the outer surface of the tentacles, and to some extent the body of the hydra, are cnidocytes or nematocytes. These are stinging cells. Four different types are found in most hydra, the largest of which contains a spine that is ejected with enough force to pierce the shell of a small crustacean and a thread that injects toxins powerful enough to paralyze it.

Both the layers of cells in the body column as well as a third population of cells, termed interstitial cells (since they are located in spaces between the epithelial cells) are actively dividing stem cells. They retain this embryonic characteristic throughout the life of the organism (Martinez 2012, pp. 479-487). The stem cells are undifferentiated, multipotent cells. Depending on their origin, they give rise to the differentiated cells of various parts of the hydra's body. Ectodermal and endodermal stem cells give rise to the differentiated cells of the tentacles, the basal disc and their interiors. The interstitial cells differentiate into nerve cells, stinging cells, secretory cells and gametes. Hydras thus do not have clearly distinct somatic and germ cells. New cells are constantly being formed in the center of the organism's body then moving outward towards the more differentiated distal ends. The differentiated cells are sloughed off and constantly replaced. The entire hydra, with exception of the tentacles and the basal disk, is in the ongoing process of becoming hydra. Its body is a veritable fountain of new life.

Most animal organisms have life cycles that include clear stages of birth, growth, development, maturation, reproduction, aging, and death. Hydras go about things somewhat differently. Although sexual reproduction is possible under certain conditions, hydras usually reproduce by budding. (The following is based on observations of *Hydra veridissima*.) A bud will appear on the side of the hydra's body between 1/3 and 1/2 of the way up. It begins as a small bump that in relatively short time grows out into something resembling the tip of a new shoot. The tip swells and begins to dome out. The base of the dome begins to show signs of a radial starlike differentiation. I have observed between five and eight such growth points appearing. Others have reported more. These growth points begin to extend as the tentacles are formed. At this point the digestive tract of the bud is still connected with that of the parent. This connection remains intact until after the budding hydra begins to capture its own prey. Once the digestive tracts separate, it is a short time until the newly formed hydra lets go of the parent, which, depending on the conditions, may already have brought forth one or two new buds. Even the term "bring forth" does not seem to appropriately describe the budding process. Bringing forth has a connotation of intent: Hydra bring forth. This is not the impression one gains when observing the process. The budding appears to be but one aspect of a hydra's continuous process of becoming. I have observed a bud forming on a young hydra only 48 hours after it had separated.

Thus birth, growth, development, maturation, and reproduction come to expression in hydra not as distinct stages in a life cycle but rather as a continuously flowing stream of generation, differentiation, and activity. Hydra becoming hydra. What about aging and death?

In 1998, Daniel Martinez, a hydra researcher at Pomona College in California, published the results of his four-year observation of three cohorts of hydra living in a lab environment (Martinez 1998 pp. 217–225). Very few hydras died over the course of this study and, when he published his results, the cohorts were still going strong. His paper gave new weight to the notion, first voiced at the beginning of the 20th century, that a hydra is immortal in the sense that although individual cells are lost and replaced, the organism as a whole shows no signs of senescence or aging. Hydras retain throughout their lives the vitality and generative capacities usually found in embryonic development and young organisms. They remain forever young. Death may come from without through adverse environmental conditions or predators but it is not part of hydra's life-cycle in the way we usually think of it. Hydras live and go on living.

None of this is immediately apparent when we observe a hydra through a magnifying glass or under a microscope. What appears is a fragile, flexible organism whose way of being is as flowing and omni-directional as its surroundings. The terms "foot" and "head" are to some extent misnomers, since they call to mind notions of up and down. There is no up nor down in the world of the hydra. One end of the hydra holds fast. The other extends out into its environment. It is not uncommon to find a hydra "holding fast" to the underside of the water surface with the body and tentacles extending out below. The tentacles can extend so far that they become almost invisible in the surrounding water. Yet even the distinction between holding on and extending out is not absolute. When moving from one location to another in still water, hydras travel by means of slow somersaults. The foot and the tentacles each take on the function of holding on, one after the other. I have also watched a hydra lie down among the debris at the bottom of water and raise its foot up while extending its tentacles out among the weeds, holding on with its body.

Trembley opened his *Memoirs* with the remark that "[t]he little creature whose natural history I am about to present has revealed facts to me which are so unusual and so contrary to the ideas generally held on the nature of animals" (Trembley, p. 1). The more time one spends with these "little creatures" the more apt this remark appears. There is an uncommon fluidity in being a hydra. The simple tubular body structure with the radial symmetry of the mouth and tentacles can appear in one moment to be compact and globular then grow to be an oval body with short tentacles. A moment later it appears to be little more than a thin, flexible stalk with fine filaments reaching out into the water around it. If a tiny shrimp brushes up against one of the tentacles the stinging cells incapacitate it, and it is drawn back into the mouth and slowly digested as it is moved down towards the foot. As one watches, the form constantly shifts. At the cellular level, the constant generation of young cells gives rise to an ongoing regeneration of the organism's entire body. It is a bit like watching the shape of an eddy in a flowing stream. As long as the flow continues, the eddy is visible.

Abraham Trembley's scientific work was shaped by his research with hydra. He too was fascinated and somewhat mystified by this "little creature" and what it had to tell us about the natural world. Thoughts on the doing of science appear throughout the four volumes of his study of hydra. At the end, he returned once more to the problem of attempting to classify organisms based on general rules.

> [I]f one were to cling scrupulously to the quite generally accepted ideas on the nature of plants and animals, it would follow that a polyp, in view of its various properties, is at the same time plant and animal, and neither animal nor plant. (Trembley, p. 1&2)

Trembley embodied an approach to understanding nature that rests on the premise that what the natural world has to teach us goes far beyond the ideational frameworks we construct to explain it. Each organism has something to teach us about the whole of which they — and we — are a part. In Trembley's words:

> Nature must be explained by Nature and not by our own views. These are too limited to envision so grand a Design in all its immensity. The beauty of Nature certainly shines forth all the more when what we know about it is not mixed with our fancies. Seen clearly, Nature inspires ideas within us more worthy of the infinite wisdom of its Author and thereby more suitable for shaping our spirits and our hearts. This thought is what we should keep before us in all our researches. (Trembley, pp. 187–188)

Notes

1. The quotes from Abraham Trembley's Memoirs are taken from Sylvia and Howard Lehnhoff's translation, which was published in 1986 following over 30 years of research. It is the first complete translation of Trembley's Memoirs in English.

2. When Trembley first began to observe hydras he called them simply "little creatures." After repeating Trembley's experiments, the French naturalist Rene Reaumur named them polyps. Trembley mentions the term "*Hydre*" in his Memoirs referring to the many-headed creature he created through grafting experiments. It called to mind the mythical Greek Hydra. Linnaeus gave it the scientific genus name *Hydra* in 1758.

References

Martínez, D.E., Bridge, D. (2012). "Hydra, the everlasting embryo, confronts aging." *Int J Dev Biol*. 56(6-7-8):479–487. doi:10.1387/ijdb.113461dm

Martınez, D.E. (1998). "Mortality Patterns Suggest Lack of Senescence in Hydra." *Experimental Gerontology*. 33(3):217–225. doi:10.1016/S0531-5565(97)00113-7

Trembley, Abraham (1744). *Memoirs Concerning the Natural History of a Type of Freshwater Polyp with Arms Shaped Like Horns,* in: Lehnhoff Sylvia G. and Howard M. *Hydra and the Birth of Experimental Biology —1744*. The Boxwood Press; 1986.