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There is a central, yet rarely stated, dilemma facing all who study the microscopic world: that to learn about the way that these hidden worlds are constructed and how they work, one first has to wrench this world apart, flatten its components under a cover slip and then view them at light intensities far exceeding anything that they encounter naturally. Freshwater ecologists risk losing any sense of the complexities of the systems they study, resorting instead to a “name-and-count” approach to their discipline. Regaining this perspective requires a leap of imagination akin to that which drove early palaeontologists to start depicting dinosaurs as living animals inhabiting a recognisably different world to our own.

Written in Water

The optical tricks we use – phase contrast, fluorescence, differential interference contrast – pile on yet more distortions yet somehow we convince ourselves that we are improving the quality of our insights.

I have spent the past twenty years studying the algae that live in streams as part of the “periphyton”, those microscopic organisms that live attached to stones and other submerged surfaces. I often find myself wondering whether any alga really looks like the neat illustrations I see in Floras and identification guides. Are these pictures no more than consistently reproducible archetypes, caricatures even, of the organism’s true form? Are we really, like Plato’s cave-dwellers, looking at shadows and mistaking these for reality? On top of this, the demand for a rigorous quantitative approach to freshwater ecology leads, if we are not careful, to the adoption of a “name and count” approach, with the data we produce being little more than feedstock for multivariate statistical programs. Ecologists studying the macroscopic world have a reference point: they can look at their data and visualise the communities, even if they did not perform the original survey. They know how the species relate to one another – which are trees, which are epiphytes, ground layer herbs, or whatever. This in turn informs their interpretation of the patterns that their ordinations reveal. But the ecologist of the microscopic world rarely has comparable knowledge about species interactions.

It has not always been this way. Look at images of the diatom *Gomphonema* in a modern Flora and you will see row upon row of cleaned valves (the silica cell wall), invariably highly magnified and photographed and arranged impeccably, but with all their organic contents removed. Compare these with images of *Gomphonema truncatum* in Arthur Hill Hassall’s *History of the British Freshwater Algae* published in 1845 (Fig. 1). Here, the diatoms are displayed as a tangled bush of stalks, each topped by a live cell, complete with chloroplast. Of

course, the microscopes available to Hassall were primitive by modern standards, and the high resolution mountants that a modern diatomist regards as essential would not be invented for another hundred years. But there is more to it than this. Hassall lived towards the end of an era in which science had been infused with the spirit of Romanticism, an era where leaps of imagination were more acceptable than, perhaps, they are now. He would have watched as the palaeontologists of his time started to depict dinosaurs as animals inhabiting a recognisably different world, rather than piles of bones, and applying the same thought processes to algae would have been a logical step.

This was my starting point for the series of paintings reproduced here. They represent a point on a journey which started whilst standing in front of a Renoir seascape in the Musée d’Orsay in Paris and wondering at how the series of marks that appeared formless and even garish when viewed close up coalesced into a realistic and vibrant scene when I stood back. Curious to learn more, I signed up for a painting course when I returned home. This was in the late 1990s, when adult education departments attached to British universities were being rebranded as Departments of Lifelong Learning which meant that I emerged from this course, six months later, with twenty first level university credits and, more importantly, a curiosity piqued by these first tentative steps, to learn more. Ten years, and one change of institution later, I emerged with a fine art degree from Sunderland University.

Studying fine art after training as a scientist was illuminating. For a start, there are far fewer facts to be crammed into student’s heads, and relatively little formal teaching of methods. Most of the time, from the second year onwards, is devoted to self-directed study, enlivened by “crits”, either with a group of peers or one-to-one with a tutor. The emphasis is on exploring ideas, not producing finished works, and the starting point for each module is, almost literally, a blank piece of paper.



Fig. 1. Plate XCVIII from Arthur Hill Hassall's *A History of the British Freshwater Algae* (1845) showing *Gomphonema geminatum* (now *Didymosphenia geminata*) (top) and *Gomphonema truncatum* (bottom).

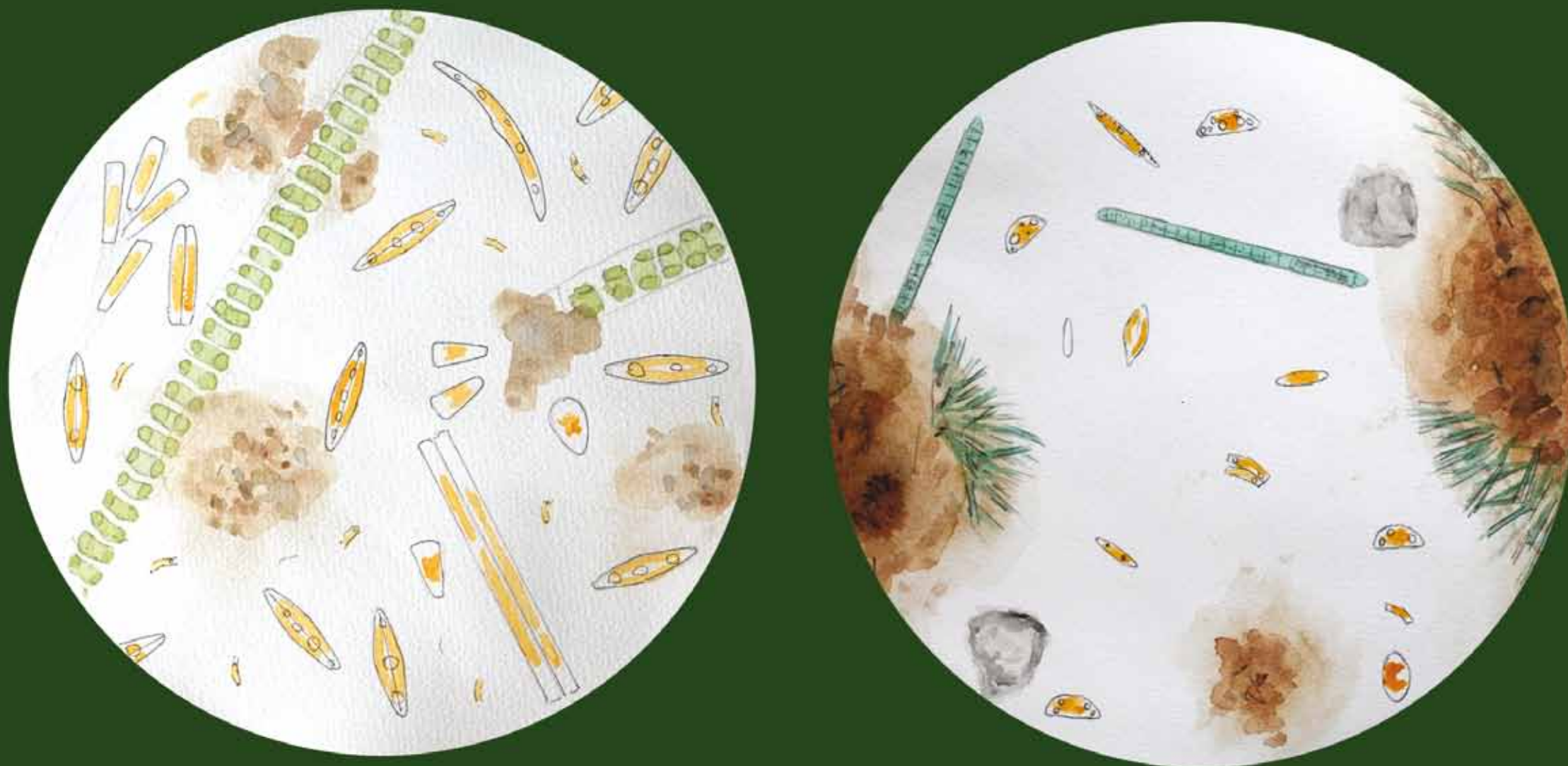


Fig. 2. Fields of view: studies of the view down a high power microscope, using samples from the River Wear at Wolsingham in March (left) and June (right). 2009. 62 x 62 cm. Mixed media (watercolour, charcoal, pencil) on paper.



Fig. 3. Visualisation of the biofilm in the River Wear at Wolsingham in February 2010. 34 × 44 cm. Mixed media (watercolour, gouache, pastel, pencil) on paper.

Students are encouraged to dig into their own experiences to find the germs of ideas that they will go on to explore. Immersed in a professional life focussed on freshwater algae, this was a natural line to pursue.

What I did not expect was how this fine art training would catalyse my scientific work. My day job involved helping the Environment Agency to use ecological data to evaluate the condition of rivers and lakes. This work was driven by a piece of EU legislation called the Water Framework Directive (WFD). Whereas before the WFD, ecology tended to play a subsidiary role in decision making, now it moved to centre stage with the implication, in my case, that assessments of hitherto invisible and ignored algae might now affect everyone's water bills. There is, invariably, a hard quantitative component to these assessments but there is, in addition, a challenge of explaining the ideas I was developing with colleagues to non-specialists and this led me back to my art training. The first outcomes were schematic illustrations, used first in talks and training workshops and later, encouraged by their positive reception, in a scientific paper (Kelly *et al.*, 2009) which tried to bridge the gap between the hard quantitative knowledge that we had acquired and a softer, more subjective "natural history" interpretation which I regarded as necessary if we were to be able to interpret ecological status assessments correctly.

The next step was to add an extra dimension and to put the viewer inside the periphytic world, on the same scale as the organisms themselves. This is a common device for portrayals of Deep (geological) Time – *Walking With Dinosaurs* being the latest in a line that extends back to the 1830s. At their best, such images can act as thought experiments – testing ideas about how extinct organisms may have functioned in their ecosystems, and providing a springboard for informed discussions. Breathing life, in other words, back into the fossil remains. The same approach may, I reasoned, also help hone our

insights into freshwater ecology and into what we understand by ecological status.

Figures 2-4 are based on data collected from the River Wear at Wolsingham in north-east England. This is a site just at the edge of the Pennines, and a few kilometres above the first major sewage input. Each month during 2009, I collected a sample of the periphyton by scrubbing the top surface of cobble-sized stones with a toothbrush, and storing this in a plastic bottle along with a small amount of stream water. A drop of this suspension, placed on a slide with a cover slip lowered on top made a "wet mount", which I could then view using my microscope. Fig. 2 shows views of two samples, from different months, as they appeared at 400x magnification. The sampling process had, in effect, uprooted the components of the peiphyton community and strewn them randomly across the slide surface. The next step was to name the organisms and make estimates of their relative abundance. The former involves poring over a pile of Floras, trying to match the organisms to pictures and descriptions. The latter can be as simple as counting the number of each type or it can include an estimate of the relative mass or volume of the organisms, so that a few individuals of a small species do not appear to be more important than a single large cell of another species. The unprepossessing samples that I had collected and analysed in this way typically contained thirty or more different species of diatoms and other algae. Over the course of the year, I found 100 different algae at this single site.

A list of names was, however, only the start of the story. The next step was to imagine what this community of algae might have looked like before I uprooted it with my toothbrush. Take the February sample as an example (Fig. 3). The predominant organisms in this sample were two species from the *Gomphonema olivaceum* aggregate, illustrated on the left hand side of the picture. These are stalked diatoms, forming dense "bushes" over much of the substratum, and comprising much of the

approximately two millimetre thick biofilm on the stones. Also abundant in the sample, and pictured amongst the *Gomphonema*, is *Navicula lanceolata*, a common diatom of late winter and spring samples in rivers. This is a motile diatom and, in our sanitised laboratory-based view of the microscopic world, *Navicula* is often depicted gliding over the smooth surface of slides and cover slips. It does this by exuding mucus through a slit, called a "raphe" in the cell wall. Watching *Navicula* in the context of these samples, it is perhaps better to envisage *Navicula* as a rock climber in a narrow chimney, or a potholer in a tunnel, edging along, using both its upper and lower raphes to pull itself through the dense entanglement of *Gomphonema* stalks plus organic and inorganic detritus.

On the right-hand side of the picture there is a filament of the green alga *Ulothrix*. A month later, this formed a dense "canopy" across most of the biofilm and a month after that it had disappeared. Like *Navicula lanceolata* and *Gomphonema olivaceum*, it is a species of cold water. Finally, in the foreground, there are a few cells of *Achnanthyidium minutissimum*, each attached to the substratum by short mucilage stalks.

Returning to the same site four months later, the biofilm was very different, even to touch, being appreciably thinner than the February biofilm. The list of taxa was also very different, suggesting, in turn, a completely different architecture (Fig. 4). The bush-like colonies of *Gomphonema olivaceum* ag. had gone and *Achnanthyidium minutissimum* was now the most abundant diatom, accompanied by two Cyanobacteria (blue-green algae): *Phormidium retzii* and *Homoeothrix varians*. Whereas the February biofilm had presented a lush growth of microbial vegetation in the absence of invertebrate grazers, by June chironomid larvae were just visible with the naked eye on the upper surface of the cobbles, and the *A. minutissimum* formed a "turf" of grazed vegetation within which were scattered patches of less palatable Cyanobacteria. By July, the

chironomids were accompanied by caddis larvae but, a few days after I sampled, there was a major flood and the August biofilm presented a radically different assemblage; thick and slimy to the touch and dominated by motile *Nitzschias*, presumably thriving after the invertebrates had been washed away.

Fig. 5 is from the River Team, twenty kilometres north of Wolsingham, at a similar altitude but a couple of kilometres downstream from a sewage effluent discharge. The illustration is, like Fig. 3, from a sample collected during the summer. Even with the naked eye, the periphyton looks quite different, with skeins of filamentous algae trailing from many of the stones. Under the microscope, I found almost none of the species that were abundant in the Wear and, rearranging the list of taxa into a three-dimensional image, we can see how pollution can distort the near-natural assemblages that we saw in the Wear.

The most obvious difference was that the periphyton was now dominated by the long, branched filaments of the green alga *Cladophora glomerata*, well known to be highly competitive and successful in waters with elevated concentrations of nutrients. The diatoms and other smaller algae that live on the rock surface found themselves under a dense canopy of *Cladophora*. So, instead, we see diatoms epiphytic on the *Cladophora*: the filaments on the right hand side have been colonised by *Cocconeis placentula* whilst, in the left foreground, there are two cells of *Rhoicosphenia abbreviata*. Tangled around the *Cladophora*, there are also filaments of the green alga *Microspora amoena* in the right foreground and, on the left, branched filaments of the red alga *Audouinella*. The *Cladophora* filaments, in their turn, trap sediment – both organic and inorganic – and this forms a matrix within which motile diatoms such as *Nitzschia palea* live.

Just a few metres away from this *Cladophora*-covered stone were others, smaller and, presumably



Fig. 4. Visualisation of the biofilm in the River Wear at Wolsingham, June 2010. 34 × 44 cm. Mixed media (watercolour, gouache, pastel, pencil) on paper.



Fig. 5. Visualisation of the biofilm in the River Team at Causey Arch, August 2009. 34 × 44 cm. Mixed media (watercolour, gouache, pastel, pencil) on paper.

too unstable for *Cladophora* to colonise. These, like the stones in the River Wear, were a heavily-grazed “pasture” but, this time, it was *Cocconeis placentula* rather than *Achnanthyidium* which was most abundant. A Simuliidae larva writhed around as I watched under the microscope, trying to graze the prostrate, surface-hugging cells of *Cocconeis*.

Figures 2-4 are no more than artist's impressions of the biofilms in these two rivers, bearing the same relationship to reality as do episodes of *Walking With Dinosaurs*. That is to say, they are bridges between the incomplete scraps of data and information that we have about a hidden world and the world with which we are already familiar. The “bushes” of *Gomphonema* and the “turf” of *Achnanthyidium* are metaphors to breathe life into what can become sterile data matrices. We should not, of course, interpret these dioramas too literally: portraying a biofilm as a subaquatic Serengeti calmly grazed by herds of chironomid larvae is dangerous if we forget the harsh, cold and turbulent environment that these organisms inhabit, a world where water is a stickier, more viscous fluid than large organisms such as ourselves would recognise.

So, what lessons can we draw from these studies? My introduction commented on the temptation of the “name and count” approach that faces ecologists of the microbial world. In 1987, Geoffrey Fryer wrote an essay for the journal *Freshwater Biology* just before he retired from the Freshwater Biological Association in which he lamented the invasion of mathematics into biology. He did not object to quantification per se; rather he argued that this was invariably at the expense of description. The real world, he suggested, consists not of numbers but of shapes and sizes and quantification is simply a result of certain defects in the human nervous system that do not permit us to form complex images of topological structures. You can continue counting and measuring, in other words, but without a leap of

the imagination you will never be able to approach the reality to which we all aspire.

The point of the WFD is to introduce ecological thinking into, and thus create a sustainable framework for, water management. Those of us caught up in the scientific aspects of the WFD are in continual danger of getting lost in the detail. In my case, I was deeply involved with a group responsible for making sure that the ecological ideas in the WFD were applied consistently throughout the EU's Member States. The meetings were long, and usually involved detailed discussions about appropriate statistics without ever visiting any rivers or lakes. The headlong rush to quantification was a necessary evil as these discussions would, ultimately, set standards for what was regarded as the acceptable state of rivers right across Europe. Yet, there is a fine line, often transgressed, between using statistics to inform your interpretation of ecological observations and those statistics becoming an end in themselves.

These pictures grew out of a frustration that those of us who dealt with the microscopic world, in particular, were losing sight of the ecological reality. At the same time, I was entering the final year of my BA and had to write a dissertation on an Art History topic. I chose the work of Henry de la Beche (1796-1855), an English geologist who, in 1830, produced an engraving of what he imagined Dorset looked like in the Jurassic age. This, *Duria Antiquior*, was the first attempt to visualise the world in which dinosaurs roamed and here were the seeds of my own subsequent experiments. The image can be viewed at www.gtj.org.uk/en/large/item/GTJ30520.

Duria antiquior was based on the best evidence available in 1830 and there is plenty that is “wrong” with the way that de la Beche depicted life in the Jurassic age, even to a non-paleontologist. We have

learnt much more about the anatomy of dinosaurs and the form that their world took since then and can now make more informed speculations about their habits, so de la Beche's original concept has been revisited and refined many, many times since *Duria Antiquior* was published. But what de la Beche got spectacularly “right” was that there is only so far one could go with disparate piles of bones before those leaps of imagination - flawed though they may be - were necessary to catalyse a new way of thinking about his discipline.

References

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