ABSTRACT

This paper aims to illustrate the advantages of critical realism for biological scientists and to offer an example, for others in philosophy and the social sciences, of applied natural science in practice. A case study is offered using a first-person account of the latter. This relates to research on biting flying insects that are vectors of some infectious diseases in animals and humans. The account illuminates a range of matters that can be understood productively, using critical realism as a metatheoretical resource. These include the challenges for a neophyte researcher joining a pre-existing ongoing line of scientific inquiry, dealing with existing fallible knowledge, working between open systems in the field and the closed system of the laboratory and the necessity of working in interdisciplinary networks. These are discussed in order to highlight the antecedent condition of possibility for the research reported and its implications for human and animal health.

KEYWORDS

Autoethnography; natural science; social science; open and closed systems

Introduction

Roy Bhaskar took an early interest in the theory and practice of natural science (Bhaskar [1975] 1997) but by the end of his life, he recognized that his work had attracted more interest in philosophy and social science (Bhaskar 2016, 210). He also noted that applied or practical critical realism ought to be ‘the heartbeat of CR’ (Bhaskar 2014; cited in Melia 2020); it should ‘walk the talk’. As the title of the paper indicates, critical realism continues to remain a resource for the natural sciences and therefore its practitioners.

Accordingly, the paper has two broad aims. The first is to offer an example of this ongoing relevance about natural science for those philosophers and social scientists who mainly constitute the community of scholars interested in critical realism. The second aim is to explore the utility of critical realism for researchers in applied natural science. To this end, a range of learning points and cues for reflection will be highlighted.
through an autoethnographic account from the first author, a junior research biologist, which will constitute the second part of the paper.

It is not common for researchers in natural science to problematize their work metaphysically. A reason that scientific research practice may be deemed to be unchallenging philosophically is the routine confidence natural scientists have in their empirical detachment, compared to those in the social sciences (Bhaskar [1975] 1997). In their everyday consciousness, this detachment may extend to insulating them from the need to reflect much on the social context of their work. Instead, they tend to focus their attention on the matter of methodological rigour and its consequent credibility for peers and funders. Historically, there may have been a particular confidence in the Humean assumption of constant conjunctions and the consequent faith in correlations between two variables denoting causality. However, today, daily laboratory work reflects both pre-Popperian and post-Popperian assumptions in practice. That is, scientists do still rely on correlations but their interpretation and elaborated work beyond the experiment includes probabilistic reasoning and epistemic humility in their daily conversations with one another.

Any residual confidence in a particular form of deduction and verification is fragile, especially when natural scientists are investigating and are part of open systems. They are participating in an ongoing form of social activity, which can be illuminated by our four planar social being. That is, any focus of scientific investigation will implicate the natural world, interpersonal relationships, embedding socioeconomic structures and the concrete singularity of the investigators and their topic.

The unreflective natural scientist may be tempted, within their norm of empirical detachment, to ‘rest on their laurels’ in the first plane. However, as described in the case study and discussion below, the other planes are important to reflect on as well. Scientists work together and/or compete, so their relationality is part of reality. They are embedded in socio-economic structures so expectations and drivers of their host society can (or should) be considered. Finally, specific experiences emerge for individuals working on their unique piece of research in their particular biographical context.

Given this ontological picture of science-in-practice, a methodological confidence in deduction and verification is problematic and actually other forms of practice emerge from necessity. Applied scientists, in particular, have to engage with option appraisals about potential antecedents to account for a current empirical picture (retrodiction), with a view to tentatively identifying particular relevant mechanisms (retroduction).

Biological science in practice is like the wider sense-making of the detective, with plenty of uncertainty and speculation being encountered and false trails being pursued. This means that everyday scientific research, contra its white coat image of precision and predictability, is fraught with messy fallibilism. The hope is that this point will now be clearer through the description and reflections of a case study.

In the case presented, the four planar social being framework, just noted, helps us to trace some basic interconnections about ontology with their implications for knowledge production. Midges bite people, as well as some animals that matter to people. Accordingly, this study is relevant to social life via its contribution to understanding material transactions with nature. In addition, the economic and institutional aspects are part of the social possibilities of the biosciences.
Moreover, critical realism affords us the possibility of examining the axiological aspects of science in practice by discarding the false fact-value separation encouraged in the past by positivism. In the case of the work described below, the relationship between biological ontology, and the forms of knowledge that have then been generated about it, have been of interest to scientists because of its human value. For example, there is public disquiet about genetically modified insects and insecticides to control their spread of disease. This makes it clear that scientists need a moral, not just a methodological, mandate for their work.

This paper then will raise a number of points relevant for critical realists, summarized here, as signposts for the reader, before their later expansion:

- Critical realism offers axiological reflections on the value of bioscience research being undertaken (e.g. about the commercial context of science and human values).
- Interdisciplinarity and interpersonal relationships can allow for reflective moments on bioscience culture. Guidance from critical realism can play a useful part in the critique of knowledge generation.
- Critical realism can be used as a tool for addressing how erroneous studies come about, and the existence of these studies should not be merely dismissed as part of an ongoing process of ‘science correcting itself’ via methodological rigour and peer review alone.
- Junior researchers in the applied natural sciences might well benefit from training in the critical realist approach to RRREIC (Resolution, Redescription, Retroduction, Elimination, Identification, Correction) in the social sciences, given that they are investigating, and are part of, open not closed systems.

**Starting context of the case study**

**Vector-borne diseases and their control**

Vector-borne diseases are infections transmitted by blood-feeding invertebrates. The most well-known examples of these infections are pathogens spread by mosquitoes, although tick and midge-borne diseases are also of importance (Gubler 2009). For example, *Anopheles* and *Aedes* mosquito species transmit malaria and flaviviruses (e.g. dengue, Zika and yellow fever viruses), causing hundreds of thousands of human deaths every year (World Health Organisation 2019). Vector-borne diseases are also of importance in the veterinary world including pathogens such as tick-borne *Babesia* sp. (babesiosis in several mammals and birds) and mosquito transmitted *Dirofilaria immitis* (heartworm in dogs and cats).

Traditional vector control approaches have relied heavily upon the removal of breeding sites and the use of insecticides (Flores and O’Neill 2018). However, these are proving insufficient to cope with human population density increases, resulting from urbanization, particularly in tropical regions (Pang, Mak, and Gubler 2017). Additionally, meteorological factors can influence the reproduction and survival of vectors meaning that climatic variables can influence the range of the vector’s impact (Takken and Knols 2007). Approximately a third of emerging diseases are deemed to be vector-borne (Jones et al. 2008), suggesting that new health interventions are of pressing need.
One vector control approach aims to reduce insect population numbers. Population suppression approaches include sterile insect technique (SIT) where male vectors are sterilized via irradiation or chemical treatment. As a consequence, females fail to produce offspring after mating (Lees et al. 2015). Another approach is the release of genetically modified insects, which leads to early mortality when a lethal gene is switched on in the wild (Phuc et al. 2007). The shortcomings of these approaches include the limited epidemiological evidence available to suggest effectiveness, the reduced competitive fitness of laboratory-reared mosquitoes compared to their wild counterparts (particularly irradiated insects), and the negative public perception of releasing genetically modified insects into nature (Flores and O’Neill 2018). An approach which aims to overcome some of these obstacles is the use of symbionts (symbiotic bacteria residing within the body or cells of insect hosts).

Symbiont protection of insects was first observed in Drosophila fruit flies infected naturally with the bacteria Wolbachia, which were protected against fungal and viral pathogens (Teixeira, Ferreira, and Ashburner 2008; Panteleev et al. 2007). Further experimental work demonstrated the ability to introduce sustained infections of mosquito species with Wolbachia leading to a blocking effect of several viruses of human importance (van den Hurk et al. 2012). Importantly as symbionts are often transmitted maternally, this allows for the spread of this virus-blocking effect through vector populations, although the exact mechanisms of how symbionts confer this protection are unclear. This lack of certainty is in keeping with a core assumption of critical realism that deep ontology involves absence and uncertainty.

Encouragingly, the results of releasing symbiont-infected mosquitoes into the wild indicate a viable method to control these viruses. For example, since the 2017 release of Wolbachia-infected Aedes aegypti mosquitoes in Malaysia, there has been a decrease in dengue fever incidence near release sites (Nazni et al. 2019). Importantly, as symbionts are naturally occurring and ubiquitous, public acceptance of these Wolbachia-based initiatives may be seen as more acceptable than other genetic modification interventions. Despite these promising field advancements, symbionts are often a neglected factor in non-mosquito-borne disease dynamics.

Culicoides biting midges and their symbionts

Turning to the specific study for this paper, it entailed the examination of Culicoides biting midges. These are blood-feeding flies which spread numerous pathogens including blue-tongue and Schmallenberg viruses (BTV and SBV). BTV results in lameness and mouth lesions of ruminants. It caused serious economic and animal health damage to the European livestock industry during the last major outbreak in 2006 (Wilson and Mellor 2009). SBV can lead to severe and fatal congenital malformations along with stillbirths and abortion in sheep. Other viruses are known to affect horses including African horse sickness virus, which is of great significance for animal welfare, as well as the horse racing industry.

Apart from the economic and animal health implications of these veterinary viruses, the midge-borne Oropouche virus, which affects humans in the Americas, also makes these vectors of human health significance (Anderson et al. 1961). Indeed, a recent review (Sick et al. 2019) suggests Culicoides are possibly a neglected vector of human diseases, with the lack of information deriving from a bias towards surveillance of
mosquitoes. So far, control interventions of midge-borne viruses rely primarily on vaccination. However, the various circulating strains (BTV) and unpredictable emergence (SBV) of these viruses have led to the pressing need for novel control interventions, such as the use of symbionts in their blocking role. This recent legacy of research was the context of the first author’s new investigation of midges and their symbionts.

Now a first person account of the first author is given, in order to illustrate the general points made in the first part of the paper.

**My personal entrance to the field of research**

The study began with my appointment as a doctoral training fellow. I had just completed my training as a veterinary practitioner, which had included an intercalated master’s degree in infectious disease and epidemiology. The latter involved a small research project which examined Wolbachia. This provided some legitimacy for my application for a funded fellowship focusing on symbionts. The original structure of the project was determined by a study (see below) from the research group I was joining in my host university. The initial title of my project was ‘The role of symbiotic bacteria in vectors of Schmallenberg and bluetongue viruses’.

**The early challenge of inheriting flawed data**

Previous studies of Culicoides had described the presence of the symbiont Cardinium. However, a suitable system to study Cardinium-midge interactions did not exist. This was due to difficulties in initiating laboratory-based experiments involving Cardinium infected midges. Before overcoming this hindrance, I first had to identify a suitable ‘candidate’ midge species, which could be used to study interactions between the symbiont and insects.

Recent work in the laboratory I joined seemed to have described the presence of Cardinium in two UK midge species of vector importance (Culicoides pulicaris and Culicoides punctatus). Therefore, as my work was also based in the UK, I set upon clarifying the feasibility of using these two species as model organisms to continue future work looking into interactions between the insect host and its symbiont.

An ideal midge-Cardinium system for investigation would involve the use of a Culicoides species which:

1. Contains Cardinium at intermediate prevalence, i.e. populations containing a mixture of individuals where the symbiont is present or absent. This allows for natural negative controls (symbiont absent) to be used in experiments investigating potential effects of the bacteria on the midge.
2. Is present at high levels in field populations. This allows for readily available material to bring into a laboratory for scrutiny.
3. Is known as a vector species, as not all Culicoides species are thought to be epidemiologically significant.

This ‘ideal’ picture reflects the interaction of the physiology of the insects, their ecological characteristics in open systems and their relevance to human and animal health.
(hence why there might be epidemiological significance). Thus, the term ‘ideal’ here refers to the pragmatic access to a midge species that reflects this scenario of the relationship between open and closed systems (see more on this point below).

Thus, during the initial proposal for my project, the plan was to use *C. pulicaris*, because provisional work inherited from colleagues had suggested the above criteria fitted this species. The samples they had investigated had been retained for further examination by me and I could augment that with new material from the field.

As the midge season in the UK generally lasts between May and September, and my project began in October, fresh *C. pulicaris* samples for the study were not immediately available to me. I decided then initially, and as a baseline for further work, to ‘simply’ replicate the study previously undertaken by colleagues, using the retained samples. This would have validated the *Cardinium* screening method to be used when material became available to me next season. This building of the baseline was possible as the materials (e.g. DNA extracts of specimens) used in the recently inherited study were still readily available in my laboratory. However, during repeated and failed efforts on my part to validate the original findings noted above, I concluded that cross-contamination of DNA extracts had occurred in the earlier study (Pilgrim et al., "Identifying Candidate," 2020). This seemed to have emerged from the unintended mixing of samples during initial processing. An important part of midge research is the accurate taxonomic identification of species of interest, with genetic markers deemed the gold standard for such classification. When amplifying a commonly used genetic marker (the COI gene) I found conflicting results using two separate methods. For the ‘*C. pulicaris*’ DNA extracts which were positive for *Cardinium* in the original study, the COI gene suggested both *C. pulicaris* and *C. punctatus* as the designated species. However, this was not plausible because each individual DNA extract was supposed to be aligned to an individual midge. Overall, this indicated to me that cross-contamination of DNA extracts between *Cardinium* positive *C. punctatus* and negative *C. pulicaris* DNA extractions had occurred in the original study. Further work assessing fresh *C. pulicaris*, undertaken by others (Pagès et al. 2017), failed to detect *Cardinium* and suggests symbiont infection is not common in this species and likely has little biological significance.

**Challenges of redirected work**

As most of my intended project was based on the assumed validity of the (flawed) work inherited, plans for the project now required re-evaluation. Fortunately, a colleague who was tasked with studying the genome (the entire genetic material of an organism) of *Cardinium* serendipitously identified another symbiont, *Rickettsia*, which was the first finding of its kind in midges. This now formed a new basis of work for the project.

Through an extensive search for *Culicoides* harbouring *Rickettsia*, I found approximately 1/3 of all species contained this newly found symbiont (Pilgrim et al. 2017). However, most midge species carried *Rickettsia* at nearly 100% prevalence, meaning that antibiotic curing would be necessary to achieve negative controls for experiments. Additionally, at this point, none of the *Rickettsia*-containing species had been successfully colonized and maintained (the importance of lab-rearing midges was noted above and returned to below), adding to the complexity of furthering this body of work.
While I was considering the problem of finding a practicable midge-*Rickettsia* system to work with, I was speculating about the potential significance of the bacterium by exploring tissue-specific infections. For example, infection of *Rickettsia* in salivary glands has previously been reported for blood and sap-sucking insects, which indicates the transmission of the bacterium to animals and plants, respectively. Thus, I set about investigating the presence of *Rickettsia* in various tissues of several developmental life stages in the species *Culicoides impunctatus*. *C. impunctatus* is prevalent across Northern Europe but it is most abundant in the Highlands of Scotland. Here they are a biting nuisance with ‘midge attacks’ accounting for a significant economic impact, with losses in the Scottish tourist and forestry industries (Hendry and Godwin 1988).

Most biting midges require a blood meal to reproduce. However, *C. impunctatus* are able to reproduce once in the absence of a blood meal (a process called ‘autogeny’), with only subsequent egg batches requiring a blood meal. This means that large numbers can develop even where animal/human blood hosts are not available (Boorman and Goodard 1970). I read that *Rickettsia* presence in booklice is necessary for egg development (Perotti et al. 2006), and so it was possible that *C. impunctatus Rickettsia* could be assisting in autogeny. This prospect could offer *Rickettsia* as a target for population suppression in the future.

**Moving from the laboratory to the field**

In order for me now to investigate the possibilities emerging, after the false start of my project it was necessary to examine the species of interest in its natural habitat. In simple terms, this required me travelling to Scotland during midge season to get bitten. This was in the knowledge that the individuals biting me would produce eggs (and subsequently larvae/pupae) to analyse back in the laboratory.

There were several difficulties in attaining specimens for this study. First, the climatic conditions of the field site at the time of collections in Scotland were unusually dry. I surmised at the time this was due to the desiccation of breeding sites leading to lower than expected numbers. Secondly, visits to the Scottish site of necessity were short, this was because I needed to get back to the laboratory (in Liverpool) within a short time frame. That time pressure came from my need to analyse the samples as quickly as possible; blood-fed midges will lay eggs approximately after 5–9 days.

Some previous studies of *C. impunctatus* had utilized field laboratories. However, in my case, the original proposal for my project did not anticipate the necessity for such a facility. Moreover, once the midges had been transported back to the laboratory, I still faced the challenge of rearing them from egg-larva-pupa-adult (to assess *Rickettsia* presence in different life stages). I wanted to cultivate a live and complete life cycle in laboratory conditions, which based on previous literature I knew would be challenging.

In comparison to mosquitoes and other flies, lab cultivation of midges is difficult, in part due to problems in optimizing larval rearing environments. Although I was able to rear midges to pupa, this was only a small percentage of starting material. Most of the insects died during larval development. At this point, I recognized the challenges involved in moving between the open system of the field and the closed system of the laboratory. The latter clearly was not providing the complex and not fully understood sustaining system of the midge’s natural habitat.
Despite these hurdles, I was able to collect enough material to study *Rickettsia* in multiple life stages of *C. impunctatus* back in the laboratory. I found *Rickettsia* present in the ovaries suggesting maternal transmission and suggesting effects on egg development could be occurring. I also found the connective tissues surrounding the ovaries to be infected with *Rickettsia*. This indicated a possible route for how the symbiont enters developing eggs (Pilgrim et al., “Tissue Tropisms,” 2020).

Additionally, I found infections in the fat body (an organ analogous to our livers) of *C. impunctatus*. As BTV replicates in the fat body before travelling to the salivary glands, this indicated to me that possible interactions (like those observed in *Wolbachia* and mosquitoes) could be occurring in midges in *Rickettsia*. A study occurring at the same time (Möhlmann et al. 2020) described *Rickettsia* infection of *C. sonorensis*, a vector species of North America, which is already colonized and is used as a gold standard for infection experiments. Thus, by the end of the funded project a model species to test *Rickettsia*-effects on midge-borne viruses was available and I could complete and submit my PhD thesis.

**Looking back on the study**

Some of the reflections I now summarize occurred during the research project but I opted not to report them, or only fleetingly, in the thesis. Others have come to mind after the PhD was completed. I developed the strong impression that typically biological scientists in their lab discussions and social chats take political and social matters as givens and so discuss them little. The norms of empirical detachment noted earlier discourage a regular and systematic reflection about these matters. The fact that I am offering a separate and *post hoc* exercise of reflection in this paper indicates that I complied with the norms of the applied science culture I had joined (I elaborate this point later in the context of scientific knowledge production).

Outside my clinical and research work, I was more generally interested in the role of science in society. Critical realism offered a framework for the latter because it neither made a fetish of scientific self-confidence (the methodologism borne of positivism) nor did it reject the present and future role of science for human flourishing, which can be found in some nihilistic and anti-realist postmodern accounts. Bhaskar’s work offered me a way into appraising science, which was both respectful and appropriately sceptical.

During my time working with colleagues in the laboratory, in field work and in academic meetings both their content and process offered points of learning, when viewed through the lens of critical realism to understand the context of scientific activity. Here I offer some personal learning points in relation to three main topics: the commercial context of science including for profit and not-for-profit funders; interdisciplinarity/interpersonal relationships; and the implications of working within open biological systems.

**The commercial context of science**

In my working context of British university-based science, colleagues relied upon one after another funded projects (spanning a finite number of years each). They have a constant and anxious eye on competing and emerging literature in a field of inquiry, as that will be the setting for the next credible research bid (to industry, research councils or
charities). Matters such as benefit to health or human welfare tend to be taken for granted, as are the general market position of ideas in the biotech industry or for state and other research funders. In this particular case, the prospect of government or industry funding was a function of the socio-economic impacts of vector-borne diseases. Commodities such as insecticide impregnated nets offer profits. Herd diseases in sheep and cattle affect profitability in the farming industry. Human health is affected by these diseases (malaria being the most prevalent) and this has implications for morbidity and mortality as well as healthcare costs.

Before our species existed the mechanisms of interest about vectors and the relationship between bacteria and viruses they contain were simply there (and would be there after the Anthropocene). Mammals and birds would be affected by them, whether or not this eventuality is of any interest to humans. Microbe-insect interactions would still come with fitness costs or benefits to participants, contributing to the ongoing process of evolution by natural selection. This natural flow of competition between organisms would be ongoing in the world even without humans as observers.

For now, that flow of competition in my field of inquiry is morally codified, as are all descriptions of disease or pathology. Scientific activity is directed inter alia at infectious diseases and its character and scale is one manifestation of ‘why things matter to people’ (Sayer 2011). In this case, vector-borne diseases matter for two main reasons. First, they are one source of suffering and early death in humans and other species. Second, the impairments accruing from that impact have social and economic implications.

Parents to be do not want foetuses affected by the Zika virus. The Scottish tourist industry would prefer not to have swarms of midges in the summer. Farmers want to avoid diseases affecting their cows and sheep. The biotech industry profits from technical interventions produced by science in this field. From insect repellents and insecticide treated nets to genetic engineering and vaccines, profits are awaiting. And even if that industry were to be socialized, rather than profit-driven, it would still be directed at the protection of human and animal welfare. This is already reflected in the not-for-profit sector, where the Bill and Melinda Gates Foundation has donated approximately $3 billion towards programmes aimed at the eradication of malaria (Bill and Melinda Gates Foundation 2020).

Relationality within interdisciplinarity and ‘Mode 2’ knowledge production

I noted that teamwork is the norm now in science. Any working scientist can simply take that for granted (as a child might take for granted living in their family). However, critical realism can help us move beyond this form of doxa to consider other matters. This is particularly the case in relation to topic-focused applied research. It is possible to conduct research in a uni-disciplinary manner (in both the natural and social sciences). However, those efforts will be inadequate for the study of open systems and their features or components (which include the biological world in general and human life in particular). That recognition of complex multi-layered reality preceded its emphasis from Bhaskar and could be found in the proponents and development of General Systems Theory (Weiss 1969; von Bertalanffy 1968). In other words, the laminated reality of open systems can only be feasibly elucidated in practice by some sort of multi-disciplinary
research effort, which works towards the possibility (but not inevitability) of transdisciplinary forms of knowledge production (Wilden 1972).

Sociologists of scientific knowledge have noted that this necessary shift during the twentieth century reflected the limits of uni-disciplinary knowledge production (‘Mode 1’) in the face of complex ontology. Accordingly, this was replaced by multidisciplinary and topic focused research about real-world challenges (‘Mode 2’) (Gibbons et al. 1994). These shifts in knowledge production were inevitable on pragmatic grounds, given the complex ontology of stratified systems. Uni-disciplinary knowledge production would always risk a form of reductionism. The study I conducted then exemplified this point about the interpersonal plane of ontology, when investigators of different backgrounds come together in a shared purpose, to overcome their own disciplinary limitations and risks of reductionism.

A shift away from mode 1 knowledge production requires an agreed-upon methodological consensus between the interdisciplinary participants. This might entail multiple methods applied in a variety of ways, according to the object of inquiry or topic at hand. However, this still might simply imply eclectic empiricism and is no guarantee of transdisciplinary integration (Bhaskar, Danermark, and Price 2018; Danermark 2019).

In addition to a self-confidence in empirical detachment that encourages methodologism in natural science, the latter is further legitimized by Mode 2 knowledge production; a tendency that also affects applied social science (for example in health services research). Thus, it is possible to join a scientific community with the double confidence of both empirical detachment and a focus on a methodological consensus of pragmatic relevance to the topic in hand. That double confidence generates little necessity for metatheoretical reflection for science to work in practice. What critical realism offers then is the opportunity for scientists in the interdisciplinary context, illustrated in my work above, to develop social oversight about their work (about human values and socio-economic processes shaping their work). This affords all the participants to reflect on the complexities of deep ontology in open systems, in the light of their own immediate empirical challenges.

Although it is possible that an over-reliance on empiricism (eclectic or not) exists among natural scientists, in informal discussion, there were episodic intimations in my work of an interest in the examination of their ontological and epistemological positions. However, these would not be consciously be named and reflected upon by colleagues; they are applied scientists not philosophers. I give an example here of this type of discussion, which explored the culture of science and tension between collaboration and cooperation in knowledge production.

During a group meeting, colleagues were discussing the practicalities of the current peer-review process; specifically, the merits of single, double or non-blinded peer-review. A discussion ensued, highlighting how the production of particular work of research topics and groups was dependent on these variants of peer-review processes and the relevance of interpersonal relationships of competing or congenial individuals involved as reviewer or author. In particular fields of inquiry peers working across institutions in the world get to know one another in various states of amicable cooperation or wary competition. This sort of ‘insider’ knowledge was shared often during informal conversations in my research team.

Regardless of the merits of the various peer-review systems, this revealing moment of relationality and contemporary socio-economic norms in scientific culture suggests a
curiosity about the non-empirical aspects of the culture of life science. The assessment of scientific work is not in fact limited to the scrutiny of published data, methods and analyses, but under the right conditions, can include the various antecedent considerations necessary to result in communicated work itself. These reflective moments are where critical realism can play a part in the critique of the ‘scientific method’ in its applied social context and could be encouraged (e.g. within ‘journal clubs’ or ‘seminars’).

In the relational work of science, which I noted during my project, strong uni-disciplinary claims or theory preferences tended to be subordinated to the pragmatics of finding the appropriate methodological consensus about addressing a topic agreed by the group in general and its principle investigators in particular. A division of labour of sub-tasks then flowed from this negotiated order, with individual scientists applying themselves within the legacy of their original disciplinary background.

In my own work, my smattering of understanding of a range of cognate biological disciplines from my clinical training was a start but it still left me woefully in the dark about what I was struggling to understand at times. Without the different backgrounds of my supervisors and colleagues in microbiology and ecology, I could not have completed my research and reported it in my thesis. Accordingly, the relational aspects of scientific teams (plane two in our four planar social being noted above) are important to reflect on when we think about interdisciplinary work.

When I entered the world of biting insects, it soon became apparent to me that research questions pertaining to vectors of disease were in the process of being answered by researchers from varying backgrounds. These included: epidemiologists, microbiologists, ecologists, virologists, climatologists and computer programmers. For example, the effects that fluctuating temperature has on the ability of a mosquito to survive and/or transmit a virus can be examined in a laboratory setting by an ecologist/microbiologist. However, it is through the expertise of a climate scientist, that a model can be created to extrapolate these findings to map and predict vector risk globally (cf. Price 2019).

My clinical work (predicating itself on a multi-disciplinary training curriculum) offered the odd insight but it required the sustaining interdisciplinary context of my research just noted. For example, I observed that the gut and the ovaries were focal points of *Rickettsia* infection under the microscope. Having mused about the potential connection between these two strongly infected areas, I remembered from my veterinary training that a ligament exists in animals suspending the ovaries to the body wall, which prevents twisting and tissue damage. I soon discovered insects also have a similar protective structure. Through a focused attention on this ligament under the microscope (previously uncharacterized in midges) I found that it was connected to the focal point of infection at the gut, leading to a possible explanation for why these two areas were infected. Thus, a memory from my earlier training of surgery (spaying cats and dogs) led to a tenuous connection that the suspensory ligament of the ovary could be biologically significant for symbiont delivery to ovaries (Pilgrim et al., “Tissue Tropisms,” 2020).

I soon realized the importance of the collaborative nature of science when my project became unstuck early on. With the plans for my initially intended project now obsolete, it was a colleague working on the same area (but a different research question) which led to the discovery of *Rickettsia* in midges and allowed me to pivot my research. Scientists work in teams and networks (with brilliant autonomous hero innovators rarely existing) and I soon learned the positive aspects of this in my research group. These included a
shared enthusiasm for a shared venture and a generous willingness to think about individual problems in regular team meetings (Rowe 2008).

However, the efficiency of communication to maximize group efficiency I noticed was variable. Moreover, the doctoral system of the necessary individualism (to become a ‘candidate’ who personally has to personally ‘defend’ their thesis in their viva voce) can at times create loneliness and uncertainty.

For example, I had a discussion with a fellow PhD student, who was having trouble with getting an experiment to work. It became clear that they had not attempted to discuss the matter with someone with more experience in their lab. This seemed to be from a reticence borne of embarrassment. They were an intelligent and committed student of science but their efforts alone were not sufficient for a functional experiment. To mitigate these risks, as I noted above, within the culture of life science, research group meetings are encouraged and well received by colleagues of all grades. However, this does not inevitably lead to all problems being aired by participants, with equal confidence. Individuals in their particular projects might opt to struggle on privately.

A significant private moment during my work project was the discovery of flawed work undertaken by colleagues in the same research group, which exemplified the messy fallibilism of research. It prompted me to read around the challenge at the time. I found that despite the reported detailed methodologies in papers, natural science has a ‘reproducibility’ or ‘replicability’ challenge (Baker 2016). To further mitigate the problem of replicability, some journals are now requesting all raw data and analyses to be included in published papers for transparency.7 Despite this, when replicability is unsuccessful, it may be unclear wherein the process the problem might lie.

When I failed to reproduce the initial study on which my project was to be based, this could have been due to my lack of experience in the lab or the deterioration of the samples’ quality during storage. The alternative explanation was the failure of the original study. This could be unintentional (methodological or analytical error) or intentional (falsified data). In the case of my account documented above, it was clear a methodological error had occurred; namely, the inappropriate storage of DNA extracts, such that cross contamination of samples had occurred. Regardless of intent, flawed studies can take a long time to acknowledge and it is likely that many are not acknowledged at all.

Of course, erroneous studies occur leading to epistemic and ontic fallacies, and scientific rationalism in the Popperian tradition assumes that ‘science corrects itself’ through transparent peer scrutiny. However, this tells us nothing of how erroneous studies exist in the first place. Critical realism provides an opportunity to explore science as a social activity by examining the interest and work of scientists themselves, and the socio-economic processes that encourage and sustain their activity. In the flawed inherited study documented above, were the competencies of the scientists to blame? If so, were these due to work pressures or inadequate training and support? These are just some of the questions that can be answered through understanding the sociology of scientific culture prompted by critical realist assumptions.8

**Biological science at the cusp of open and closed systems**

Another observation from my account above is the problem of directing research between the field and laboratory (an open and closed system). An open system is
broadly defined as a system which has external interactions. In contrast, a closed system is isolated from its environment. Laboratories are designed to furnish methodological control (confounding variables are ‘controlled out’) but a price is paid. In simple terms, this might involve us getting it ‘wrong’ about our findings for practical human relevance.

That insight about the relationship between ontology and epistemology was emphasized by Bhaskar in his work on science, while recognizing that laboratory science could proceed at times on the basis of closed systems reasoning. My work embodied that ambiguity within biological science as an ongoing social activity and in this case, I was not working much of the time in the closed system of the laboratory but in the field, of necessity an open system in constant flux.

To elaborate, my field work studying *C. impunctatus* involved collecting numbers of insects, the success of which was determined by several fluctuating and often immeasurable external variables. In contrast, the maintenance of a laboratory colony of midges undergoes a predictable repeated number of methodological steps and will often give the same predicted results (i.e. if successful the emergence of multiple midge adults every three weeks).

The climatic variables which led to problems in collecting materials included unexpected dry weather and sporadic windy days, which were both suboptimal for collections of large insect numbers. In addition, the limitations of relying on unpredictable short-term weather conditions were exacerbated by the UK midge season only lasting a few months of the year, meaning repeated field trips were limited during the year.

The closed system of rearing *C. impunctatus* in a laboratory environment posed another set of problems. Attempts to mimic the environment to allow for the successful cultivation of *C. impunctatus* can lead to inherent problems in the task of data collection. Without altering components of the insect’s natural environment, it is difficult to measure the detailed processes underlying midge biology. In this case, allowing for the rearing of larvae in their natural soil habitat in the laboratory obscured my observation of important behaviours (e.g. feeding habits and movement), as well as development (e.g. metamorphosis).

Therefore, a separate system, *which was very much detached from the midges’ natural environment*, was used (transparent agar plates) to monitor development and life stages needed for further analysis. Colleagues and I in this field, are faced with uncertain trade-offs. For example, simplifying the out of soil diet in order to observe the insects accurately may be misleading, as their behaviour and development may then be an artefact of the closed system of laboratory.

When considering these trade-offs, the insights of critical realism may help applied biological sciences. Specifically, this implies the recognition that investigation of open systems invites the imagination of investigators, especially in relation to understanding the redescription (e.g. can the various components of the dietary and temperature requirements of midges in their natural habitat be mimicked or not in the laboratory?) and retrodictive possibilities (e.g. which range of possible antecedents might account for why midges die prematurely in an artificial environment?). Settling on the best retroduduced mechanism is not impossible but it is challenging in open systems. For this reason, biological scientists may find it helpful, like social scientists, to use the RRREIC (Resolution, Redescription, Retroduction, Elimination, Identification, Correction) frame of analysis for their work. As I found in my own work and observing that of those close by this was illustrated on an ongoing basis for us. Variants of questions colloquially kept coming up of the type: what is going on within the complexity I am starting with (Resolution)?; can I
account for them from existing theories in order to explain my particular observation (Redescription and Retroduction)?; of all the retrodictive possibilities, which ones can be fairly excluded (Elimination) and which ones are most likely (Identification)?; and how might we understand things now in the light of the investigation compared to what was already known (Correction)? The account I gave above of sense making in open systems showed that these sorts of questions recur in practice and are characterized by a messy mixture of confidence and guess work.

**Conclusion**

A case study has been offered of an exercise in natural rather than social science for consideration by those with an interest in critical realism. This has required an account for an interdisciplinary readership of the technical details of working within biological research, directed at mitigating the impact of some forms of infectious disease. In particular the focus has been on the messy fallibilism of knowledge production in a form of inquiry, which may be assumed culturally to be working with clear empirical descriptions, guided by simple neat methodologies, which are amenable to certainties in the laboratory. The reality in practice for researchers is somewhat different.

I offered some reflections on the social and economic linkages that can be traced in the ongoing social activity of science, which is being constantly joined by new investigators. In this particular case, tiny flying insects have many implications for human and animal health and shape the emergence of products in the biotech industry, as well as philanthropic endeavours.

In addition, the difficulties of positioning the individualistic ethos of doctoral research for junior scientists, within the typical scenario of research networks constituted by those from a wide range of disciplinary backgrounds, have been explored. Specifically, the second plane of our social being (interpersonal relationships) is integral in offering insights into the culture of science and should be formally acknowledged in praxis through seminars or journal clubs detailing the value of critical realist metatheory.

Junior researchers in the applied natural sciences, working in open systems might benefit from training in the critical realist approach to RRREIC in the social sciences. Apart from the expectation of errors (and their link to recurrent and expected fallibilism), the axiological considerations about why we and others might, in various ways, value the science we are doing can be reflected upon by practitioners. Post-Popperian science now permits them to discuss the value-laden aspects of their work and critical realism offers a metatheoretical resource for that task.

**Notes**

1. Critical realism does not avoid axiological considerations but embraces them. By contrast more conservative systems thinking, by retaining positivist assumptions and favouring the study of isolated systems, such as ‘an organisation’ in management studies, may avoid wider axiological and structural reflections (Wilden 1972). This potential for conservative drift in systems thinking is avoided in critical realism, by utilising the framework of our four planar social being, case by case.

2. Hypotheses for symbiont-conferring blocking include the competition for resources between pathogen and symbiont, as well as increased immune-sensitivity due to symbiont presence.
3. A Biotechnology and Biological Sciences Research Council Doctoral Training Program award
4. Title was later changed to ‘The prevalence of endosymbiotic bacteria in Culicoides biting midges and the distribution of Torix group Rickettsia’. Thesis available at: https://liverepository.liverpool.ac.uk/3075607/1/200597841_Feb2020.pdf
5. If a symbiont is at high prevalence in a population, it is possible to ‘cure’ the insect of its symbiont using antibiotics but this can lead to confounding of studies as perceived direct (toxic) effects of the antibiotics cannot be distinguished easily from the indirect effects of eliminating the bacteria.
6. For a discussion of General Systems Theory and CR see Mingers (2011).
7. Examples include Scientific Data (Nature) and GigaScience (BMC).
8. By contrast, a postmodernist sociologist would simply describe different kinds of discourse with no assumptions about causality and judged reroduced mechanisms.
9. Cannibalism of larvae was observed on my agar plates but it is uncertain if this was an artefact of the artificial environment they are reared in, which likely provided an unpalatable food source compared to diets otherwise available in the wild.

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