

## AN EVALUATION OF PAUL FEYERABEND'S ANARCHICAL APPROACH IN PHILOSOPHY OF SCIENCE

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### **Abstract**

*This article focuses on an evaluation of Paul Feyerabend's anarchistic approach in philosophy of science. Feyerabend advocated for anarchism in science which encourages plurality of methods in scientific investigations. His anarchistic approach was a source of great controversy among contemporary philosophers of science because of its revolutionary nature. The basic questions are: What does Feyerabend mean by anarchistic approach in scientific investigation? Does such contradict the nature of science as an organized and systematic enterprise? Has Feyerabend's anarchism any implication for scientific methodology and progress? What are the strengths and weaknesses of Feyerabend's anarchistic approach in philosophy of science? In the bid to address these and other related issues, this article employs analytical and hermeneutical methods of philosophical investigation to examine the intricacies of Feyerabend's anarchism in philosophy of science. The researcher argues that though Feyerabend's anarchism elicited criticisms from some philosophers of science because of its controversial nature, Feyerabend contributed immensely towards the development of knowledge in contemporary philosophy of science. This article maintains that despite the loopholes and shortcomings of Feyerabend's anarchism in philosophy of science, it is an invitation for scientists to discover and explore many new methods of scientific investigation.*

**Keywords:** Science, Anarchism, Philosophy and Method

### **INTRODUCTION**

Paul Feyerabend is one of the influential philosophers of science. He made enormous and remarkable contributions towards the development of philosophy of science in the contemporary period. Among his remarkable contributions in contemporary philosophy of science is his anarchistic approach. Anarchism is quite unique, and it appears very strange in matters that concern scientific investigation. His idea of anarchism in the domain of philosophy of science is very controversial. Such controversy is basically because of the fact that it seems to contradict the nature of science as a systematic, methodic as well as organized discipline. The fundamental questions are: What is anarchism? How does Feyerabend apply it in the domain of philosophy of science? What are the implications of Feyerabend's anarchistic approach to scientific methodology and progress? What are the problems associated with Feyerabend's anarchistic approach in philosophy of science? What are the positive aspects of Feyerabend's anarchism? These

and other related issues are to be given scholarly as well as detailed attention in this article.

This article is partitioned into three sections. The first section analyses the concept of anarchism in general. The second section examines Paul Feyerabend's anarchistic approach in philosophy of science. The third section centres on the evaluation as well as conclusion of the article.

### **THE CONCEPT OF ANARCHISM**

The term 'anarchism' is the key concept in this article. This section of the article focuses on the clarification and analysis of the concept of anarchism. Obviously, clarification of the concept of anarchism enables one to understand as well as appreciate Feyerabend's anarchistic approach in philosophy of science.

Basically, the term 'anarchism' is most commonly used in the political domain. Etymologically, it was derived from the Greek word 'an archos' meaning 'no government'. From etymological perspective, it means quest for absence of government. It has to do with the desire for absence of law as well as desire for freedom in a political setting. *Oxford Advanced Learner's Dictionary of Current English* (2000) describes anarchism as “the political belief that laws and government are not necessary.”(p.36) Hence, it could be said that anarchism is a system that desires for freedom in the strict sense of it. In a similar way, *Cambridge English Dictionary* defines anarchism as “the political belief that there should be little or no formal or official organization to society but that people should work freely together”. It becomes clear that anarchism desires for a type of society that is very similar to Thomas Hobbes' 'state of nature' in which people were allowed to do whatever pleased them. In agreement with the above definitions, Fiala (2021) defines anarchism thus:

Anarchism is a political theory that is skeptical of the justification of authority and power. Anarchism is usually grounded in moral claims about the importance of individual liberty, often conceived as freedom from domination. Anarchism also offers a positive theory of human flourishing, based upon an ideal of equality, community and non-coercive consensus building. Anarchism has inspired practical efforts at establishing utopian communities, radical and revolutionary political agenda and various forms of direct action. (para. 1)

Anarchism is revolutionary in nature and it emphasizes mainly on human freedom as well as absence of law. An anarchist prizes his freedom above every other thing, and despises law as much as possible. Elaborating further on the meaning of anarchism and bringing out very clearly the views of some anarchists, Sterba (1999) states:

It maintains that no coercive institutions are justified. Proudhon, the first self-described anarchist, believed that coercive institutions should be replaced by social and economic organizations based on voluntary contractual agreement, and he advocated peaceful change toward

anarchism. Others, notably Blanqui and Bakunin, advocated the use of violence to destroy the power of coercive institutions.(p.628)

, but insists that there are no overriding rules in science. In his words: From the foregoing, it is clear that anarchism is basically obtainable in political dimension. However, it is also applied in other dimensions of life. It is now fashionable to talk of religious anarchism, ethical anarchism, scientific anarchism etc. However, the concern of this article is basically the employment of anarchism in the domain of philosophy of science. Paul Feyerabend championed scientific anarchism. In fact, he advocated for anarchistic approach in scientific investigation. Hence, this article focuses on evaluating Paul Feyerabend's anarchistic approach in scientific investigation.

### **FEYERABEND'S ANARCHISTIC APPROACH IN PHILOSOPHY OF SCIENCE**

Science is generally conceived as a methodic and systematic investigation of phenomena. Such systematic investigation enables science to offer explanations of phenomena in the world, and as well predict future occurrences. The method of scientific investigation is one of the issues that have pre-occupied the attention of philosophers of science. Paul Feyerabend is among the contemporary philosophers of science that have given serious attention to the method of scientific investigation. He advocated for anarchistic approach in scientific investigation, and maintains that such approach is necessary for scientific progress. Feyerabend (1981) argues that “There is no method according to the most advanced and sophisticated methodology in existence today” (p.161). However, Feyerabend admits that science is systematic in approach just like other ideologies

Science often proceeds systematically, but so do other ideologies (just consult the records of the many doctrinal debates that took place in the church) and, besides, there are no overriding rules which are adhered to under any circumstances; there is no 'scientific methodology' that can be used to separate science from the rest. *Science is just one of the many ideologies that propel society and it should be treated as such* .(Feyerabend, 1981, p.162)

He denies the existence of scientific methodology that distinguishes science from other ideologies. This denial contradicts the popular view that science employs unique approach in its investigation of phenomena in the world. However, such denial paved way for Feyerabend's introduction of his anarchistic approach in scientific investigation. Feyerabend (1984) argues that science is anarchistic, and such anarchism encourages progress. According to him: “*Science is an essentially anarchistic enterprise: theoretical anarchism is more humanitarian and more likely to encourage progress than its law-and-order alternatives.*” (p.53) This implies that there is no need to maintain specific laws in scientific investigation. The quest for non-maintenance of specific laws in scientific investigation is the essence of Feyerabend's anarchistic approach. He values anarchism and holds it in a very high esteem in the domain of science. Hence, Feyerabend (1984) maintains that anarchism “is certainly excellent medicine for epistemology and for the

philosophy of science.” (p.53) It follows from the foregoing that Feyerabend has high regard for anarchistic approach, and thus insists on its employment in scientific investigation. This entails that it is not necessary to create a scientific tradition that is governed by strict rules. He offers two reasons for this position thus:

There are two reasons why such an answer seems to be appropriate. The first reason is that the world which we want to explore is a largely unknown entity. We must, therefore, keep our options open and we must not restrict ourselves in advance. Epistemological prescriptions may look splendid when compared with other epistemological prescriptions or with general principles- but who can guarantee that they are the best way to discover, not just a few isolated “facts”, but also some deep-lying secrets of nature? The second reason is that a scientific education as described above... cannot be reconciled with a humanitarian attitude. It is in conflict “with the cultivation of individuality which alone produces, or can produce, well-developed human beings”, it “maims by compression, like a Chinese lady's foot, every part of human nature which stands out prominently, and tends to make a person markedly different in outline” from the ideals of rationality that happen to be fashionable in science, or in the philosophy of science. The attempt to increase liberty, to lead to a full and rewarding life, and the corresponding attempt to discover the secrets of nature and of man entails, therefore, the rejection of all universal standards and of all rigid traditions ( Feyerabend, 1984, pp.55-56)

Feyerabend's advocacy for anarchism in scientific investigation is rooted in his belief that the world is unknown, and as such we do not need rigid laws or methods in the attempt to explore the world. It becomes logical from Feyerabend's perspective to apply varied methods in the investigation and exploration of the unknown world. Furthermore, it may not be easy to prove that the adopted laws or methods of investigation are actually the best. Hence, the acclaimed method of scientific investigation may not actually be the best. Basically, Feyerabend is opting for liberty in scientific investigation, which for him, is necessary for scientific progress. Restrictions through laws may not aid scientific progress, but may rather impede such progress.

It is certain that Feyerabend has little or no regard for laws in scientific investigations. This explains why he opts for anarchism in science. There are some activities that are associated with professional anarchists in science. Such activities distinguish them and make them unique in the domain of science. Feyerabend (1984) articulates such activities thus:

Professional anarchists oppose any kind of restriction, and they demand that the individual be permitted to develop

freely, unhampered by laws, duties or obligations. And yet they swallow without protest all the severe standards which scientists and logicians impose upon research and upon any kind of knowledge-creating and knowledge-changing activity. Occasionally, the laws of scientific method or what are thought to be the laws of scientific method by a particular writer, are even integrated into anarchism itself. (p. 56)

Thus, he upholds anarchistic methodology as well as an anarchistic science. It could be argued that lack of laws in anarchistic science will lead to chaos, and such may not encourage progress. Contrary to this, Feyerabend argues that the reduced regard for law and order in anarchistic science will not lead to chaos. Consequently, he insists that “*The only principle that does not inhibit progress is: anything goes*” (Feyerabend, 1984, p.57). This implies that anything is possible in scientific investigations.

He further argues that there is no rule in science that is not at times violated, and such violation is necessary for scientific progress and growth of knowledge in general. Contrary to Feyerabend's argument, it ought to be noted that the fact that rules are at times violated in science does not in any way imply that rules are not necessary in scientific investigations. It is difficult to see any sector of life where rules are not at times violated. However, Feyerabend insists that scientists should be free in their scientific investigations, and not restrict themselves to strict rules. According to him:

We find then, that there is not a single rule, however plausible and however firmly grounded in epistemology, that is not violated at some time or other. It becomes evident that such violations are not accidental events, they are not results of insufficient knowledge or of inattention which might have been avoided. On the contrary, we see that they are necessary for progress. Indeed, one of the most striking features of recent discussions in the history and philosophy of science is the realization that events and developments, such as the invention of atomism in antiquity, the Copernican Revolution, the rise of modern atomism (kinetic theory, dispersion theory, stereochemistry, quantum theory), the gradual emergence of the wave theory of light, occurred only because some thinkers either *decided* not to be bound by certain “obvious” methodological rules, or because they *unwittingly broke* them (Feyerabend, 1984, p.57)

The implication of Feyerabend's argument is that there are certain conditions when it is necessary not to obey rules, or even to contradict the rules completely in scientific investigations. Neglect of rules and contradiction of rules are essential aspects of Feyerabend's anarchism. Such neglect of rules are at times necessitated by certain circumstances in scientific investigation. Elaborating on the circumstances that can necessitate the neglect or violation of rules, Feyerabend (1984) states:

...there are always circumstances when it is advisable not only to ignore the rule, but to adopt its opposite. For example there are circumstances when it is advisable to introduce, elaborate, and defend *ad hoc* hypotheses, or hypotheses which contradict well-established and generally accepted experimental results, or hypotheses whose content is smaller than the content of the existing and empirically adequate alternative, or self-inconsistent hypotheses, and so on. (pp.57-58)

The point Feyerabend tries to emphasize is that it is needless sticking to the traditional method of scientific investigations. There is always need to explore new ways of scientific investigations. Such plurality of methods is better than strict adherence to one particular method. This idea expresses and articulates the anarchistic approach that Feyerabend is advocating for in scientific investigation.

In fact, Feyerabend sees anarchism as the only principle that is defensible in all situations, and insists that it is necessary for scientific progress. He argues that “a law-and-order science will succeed only if anarchistic moves are occasionally allowed to take place.” (Feyerabend, 1984, p.60) This implies that the successfulness of law- and-order science is dependent on anarchism, which is a necessary pre-requisite for scientific investigation. Anarchism in science, for Feyerabend, is quite better than law and order-based science. From this perspective, science that is based on law and order can only be fruitful if it is punctuated with anarchism. Hence, scientific investigation cannot do without anarchism, and such is a necessary condition for scientific progress. Analysing Paul Feyerabend's anarchism, Broad (1989) states:

Feyerabend argues that science does not proceed according to a rational method. If there has been progress, it is only because working scientists have broken every principle in the rationalist's rule book and have adopted the motto “anything goes”. The pool of resulting theories has increased, but individual theories are not consistent with one another. (p.534)

From the foregoing, it is obvious that, for Feyerabend, the principle of 'anything goes' becomes the underlying principle of scientific investigation, and as such, every scientific investigation ought to adopt such principle. Tsou (2003) brings out very clearly the two different but related interpretations or rather versions of Feyerabend's anarchism in philosophy of science, which are supported by history of science thus:

Feyerabend's anarchism, then, consists in two substantive claims: (1) science is accurately characterized as an anarchistic enterprise, and (2) science should be an anarchistic enterprise. The first claim is a descriptive claim regarding the nature of the history of science, while the second is a prescriptive claim on how science ought to proceed. In order to support both of these claims, Feyerabend appeals to the history of science, focusing on physical theories from Newtonian mechanics to wave mechanics. (p.209)

These two versions of Feyerabend's anarchism are quite related, and they communicate the same message, viz. the centrality of anarchism in scientific investigation. Tsou (2003) further argues that Feyerabend, in his anarchistic science, is advocating for the principle of theoretical pluralism in scientific investigation. This is quite correct based on Feyerabend's insistence that one particular method is not adequate for scientific investigations. Hence, there is strong need for the exploration of many alternatives in scientific investigations. According to Tsou (2003):

In prescribing anarchism as a defensible principle for science to follow, Feyerabend is urging for a science that follows a principle of theoretical pluralism. Specifically, Feyerabend is calling for a science that follows a principle of proliferation, i.e., a science that is organized to require the continuous generation of alternatives. This perspective is premised on the idea that the only process of scientific change that can produce genuinely objective knowledge requires a context that encourages a plurality of theories and methods. A context that discourages theoretical pluralism (viz., theoretical monism), by contrast, tends to promote both dogmatism and a self-fulfilling confirmation of received views. (p. 210)

It is certain from the above that Feyerabend champions theoretical and methodological pluralism in science. Such, for him, discourages rigidity in science. Tsou (2003) demonstrates a very good knowledge of Feyerabend's anarchism. This is evident in his scholarly analysis of Feyerabend's anarchistic approach in philosophy of science. Elaborating further the intricacies of Feyerabend's major thesis in this regard, he states:

I have presented Feyerabend's anarchism as the normative suggestion that a context of methodological and theoretical pluralism should be encouraged for the sake of the progress of scientific knowledge. This suggestion is premised on a minimal assumption of realism (viz., the methodological assumption that scientific theories should be “interpreted realistically” because theories, to some extent, accurately describe aspects of reality) and the idea that there is no fixed method or fixed theory of rationality that will always provide beneficial results for science. It is important to recognize that Feyerabend's anarchism does not reject method or rationality... As such, the anarchist maxim of “anything goes” is not a positive recommendation of “hedonism” (as Feyerabend sometimes jokingly referred to it) for science, nor does it encompass the claim that all forms of knowing... are equally legitimate. Rather “anything goes” is Feyerabend's iconoclastic way of emphasizing that sustained criticism and deviations from accepted scientific rules are both reasonable and absolutely necessary for the growth of scientific

knowledge (McMullin 1988, pp. 7–10). This potential benefit of methodological and theoretical pluralism, Feyerabend believes, is evidenced most prominently by cases of “revolutionary science.” (pp.223-224)

It follows that Feyerabend is completely against dogmatism with regard to the method of scientific investigation. Hence, no specific method of scientific investigation should be accepted as a 'dogma'. At this juncture, Feyerabend seems to agree with Karl Popper that science should be anti-dogmatic. Popper argues that scientists ought to be critical as well as anti-dogmatic, and thus champions the idea of 'critical rationalism in science. However, it ought to be noted that Feyerabend's anti-dogmatism is mainly concerned with the method of scientific investigation. No 'method' should be held tenaciously as the only method of scientific investigation.

Furthermore, Feyerabend seems to agree with Thomas Kuhn's 'revolutionary science' as opposed to 'normal science by maintaining that 'revolutionary science' gives evidence to methodological as well as theoretical pluralism in science. Also, Feyerabend, just like Thomas Kuhn and quite unlike logical positivists, has high regard for the history of science and at the same time acknowledges its importance in scientific investigations. This explains why he maintains that anarchism is supported by the history of science. He further argues that:

Standards compete just as theories compete and we choose the standards most appropriate to the historical situation in which the choice occurs. The rejected alternatives (theories, standards: facts) are not eliminated. They serve as correctives (after all, we may have made the wrong choice) and they also explain the content of the preferred views... Knowledge so conceived is an ocean of alternatives channeled and subdivided by an ocean of standards. (Feyerabend, 1981, p. 159)

Thus far, the researcher has given scholarly attention to the analysis of Feyerabend's anarchistic approach in philosophy of science. Such approach appears revolutionary in nature. This stems from the fact that it questions and contradicts what seems to be the traditional method of scientific research.

## **EVALUATION**

Feyerabend's anarchism in scientific investigation is actually very controversial. It elicited severe criticisms from different scholars and philosophers of science. Some scholars condemn Feyerabend's approach to science, and thus criticized him very strongly, while some scholars argue that his approach may be beneficial to the nature of science. Treiblmaier (2018) attests to this thus:

Being one of the most controversial epistemologists and not shying away from pointed criticism, Feyerabend has experienced a lot of rejection as well as appreciation, but his ideas have not led

to the emergence of a dedicated school of followers. This is not surprising since his “epistemological anarchism”, which propagates openness and flexibility, makes it hard to directly derive specific guidelines regarding best practices on how to conduct research. However, his approach has been labeled as an “antidote to the totalitarian tendencies of modern science” (Spariosu 1989, p. 300) and we believe that it allows for the critical investigation of the foundations of any research community. (p.12)

It is certain that the criticisms given against Feyerabend's anarchistic approach were as a result of the controversial nature of his thesis and approach. His approach contradicted completely the fundamental assumption of scientists with regard to the method of scientific research. Treiblmaier (2018) notes that Feyerabend “was labeled the “worst enemy of science” (p.2). This is due to his principle of 'anything goes' which he upholds in the scientific world. It doesn't seem to the researcher that it is right to label Feyerabend the 'worst enemy of science'. It ought to be noted that his anarchistic approach is not meant to destroy science, but rather to open up more avenues and methods of scientific investigations.

Another scholar that criticized Feyerabend's anarchism is Tsou (2003). He was dissatisfied with Feyerabend's anarchistic approach, and thus argued that his anarchism will not bring about a more objective scientific knowledge. According to him:

If one takes Feyerabend seriously on his own (somewhat sobered) terms, one criticism that can be raised against Feyerabend's recommendation of anarchism is that anarchistic science, characterized primarily by proliferation and rule-breaking, would not necessarily lead to a better or “more objective” scientific knowledge. (Tsou, 2003, p.224)

Certainly, Tsou (2003) based this criticism on Thomas Kuhn's argument that normal science which is characterized by fidelity to the rules and method of the prevailing paradigm can give rise to revolutionary science which brings about scientific progress. The researcher argues that Tsou (2003) seems to neglect the fact that proliferation as well as plurality of method may enable scientists make more scientific discoveries.

Most other criticisms given against Feyerabend's anarchism by other scholars revolve around complete neglect of the traditional method of scientific investigations. Such criticisms are quite expected because his anarchism challenged the traditional assumptions of science. As was already stated in this article, Feyerabend argues that the only defensible approach to science is 'anything goes'. It could be argued that such approach robs science of its systematic and methodic approach to investigation of realities. Traditionally, science has its unique qualities that distinguish it from other disciplines. Brain and Anderson (2021) articulate such qualities thus:

Among the activities often identified as characteristic of science are systematic observation and experimentation, inductive and deductive reasoning, and the formation and testing of hypotheses and theories.

How these are carried out in detail can vary greatly, but characteristics like these have been looked to as a way of demarcating scientific activity from non-science, where only enterprises which employ some canonical form of scientific method or methods should be considered science...(para. 1)

Science is empirical in nature and its approach to investigation of phenomena in the universe is fundamentally systematic in approach. Such has enabled science to achieve many verifiable discoveries which have improved human condition of existence in the world. By opting for anarchistic approach in scientific investigation, Feyerabend is advocating for something that is alien to the practice of scientific investigation. Such anarchistic approach may lead to unverifiable results and chaos in scientific research. Anarchism ought not be the method of scientific investigation. Such stifles science of its unique systematic as well as verifiable approach to investigation of phenomena in the universe.

Despite the above criticisms, Tsou (2003) acknowledged that Feyerabend's anarchism is beneficial to the nature of science. Thus, he states:

Although Feyerabend was no apologist for science and his arguments against scientific method have often been perceived as “anti-scientific,” it is clear that Feyerabend's anarchism is presented in promotion of better science and a more accurate perspective for understanding the nature of the sciences (p.208).

Obviously, Feyerabend's anarchism is revolutionary in nature. This explains why it was criticized by many scholars. However, his anarchistic approach which encourages plurality of methods is an invitation for scientists to discover many new methods of scientific investigation. It ought to be noted that his approach may be beneficial in discovering new avenues and methods of scientific enquiry.

## **CONCLUSION**

Effort has been made in this article to evaluate Paul Feyerabend's anarchistic approach in philosophy of science. Feyerabend is one of the renowned scholars in contemporary philosophy of science. His anarchistic approach in philosophy of science is one of his remarkable contributions in contemporary philosophy of science. As it is very clear in this article, he argues consistently that the only defensible approach in science is 'anything goes'. Obviously, his anarchistic approach is very controversial because of its revolutionary nature. It is obvious from the discourse in this article that though Feyerabend's anarchism elicited criticisms from some philosophers of science because of its controversial nature, Feyerabend contributed immensely towards the development of knowledge in contemporary philosophy of science. He actually broadened the understanding of science in the contemporary era. This article concludes that despite the shortcomings of Feyerabend's anarchism in philosophy of science, his unique as well as strange approach is an encouragement for scientists to discover and explore many new methods of scientific investigation.

## References

- Brain, H. and Andersen H. (2021) 'Scientific method', *The Stanford encyclopedia of philosophy*, Edward N. Zalta (ed.), Retrieved from URL=<https://plato.stanford.edu/archives/sum2021/entries/scientific-method/> (13/11/21).
- Broad, W. J., (1989) 'Paul Feyerabend: Science and the anarchist', *Science* vol. 206, Issue 4418. Retrieved from <https://science.sciencemag.org/content/206/4418> (20/03/22).
- Cambridge English Dictionary*, Retrieved from <https://dictionary.cambridge.org/dictionary/english/anarchism> (13/03/22).
- Feyerabend P. (1984) 'Against method'. In Richard H. Popkin & Avrum Stroll(eds) *Philosophy and contemporary problems :A reader*;New York: CBS College Publishing.
- Feyerabend, P. (1981) 'How to defend society against science'. In Ian Hacking(ed.) *Scientific revolutions*, (pp.156-167) New York: Oxford University Press
- Fiala. A., (2021), 'Anarchism', *The stanford encyclopedia of philosophy*, Edward .N. Zalta (ed.), URL=<https://plato.stanford.edu/archives/win2021/entries/anarchism/> (13/11/21)
- Hornby, A. S., (2000) *Oxford Advanced Learner's Dictionary of Current English* 6<sup>th</sup> ed., New York: Oxford University Press.
- Sterba, J.P., (1999), 'Political philosophy', *The cambridge dictionary of philosophy*, Robert Audi (ed) Cambridge: Cambridge University Press.
- Treiblmaier, H. (2018) *Paul Feyerabend and the art of epistemological anarchy- A discussion of the basic tenets of against method and an assessment of their potential usefulness*. Retrieved from [https://www.researchgate.net/publication/325373744\\_ThePhilosopher%27s\\_corner\\_Paul\\_Feyerabend\\_and\\_the\\_Art\\_of\\_Epistemological\\_Anarchy](https://www.researchgate.net/publication/325373744_ThePhilosopher%27s_corner_Paul_Feyerabend_and_the_Art_of_Epistemological_Anarchy).(26/08/21)
- Tsou, J.Y. (2003) 'Reconsidering Feyerabend's "Anarchism" *Perspectives on science*, vol. 11, no 2. Retrieved from <https://www.mitpressjournals.org> (09/06/21).
- Voit, E. O. (2019), *Perspective: Dimensions of the scientific method*. Retrieved from <https://journals.plos.org/ploscombiol/article?id=10.1371/journal.pcbi.1007279> (10/03/22).