

# Alleviating the burden of malaria with gene drive technologies? A biocentric analysis of the moral permissibility of modifying malaria mosquitoes

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## ABSTRACT

Gene drive technologies (GDTs) have been proposed as a potential new way to alleviate the burden of malaria, yet have also raised ethical questions. A central ethical question regarding GDTs relates to whether it is morally permissible to intentionally modify or eradicate mosquitoes in this way and how the inherent worth of humans and non-human organisms should be factored into determining this. Existing analyses of this matter have thus far generally relied on anthropocentric and zoocentric perspectives and rejected an individualist biocentric outlook in which all living organisms are taken to matter morally for their own sake. In this paper, we reconsider the implications of taking a biocentric approach and highlight nuances that may not be evident at first glance. First, we shortly discuss biocentric perspectives in general, and then outline Paul Taylor's biocentric theory of respect for nature. Second, we explore how conflicting claims towards different organisms should be prioritised from this perspective and subsequently apply this to the context of malaria control using GDTs. Our ethical analysis shows that this context invokes the principle of self-defence, which could override the pro tanto concerns that a biocentrist would have against modifying malaria mosquitoes in this way if certain conditions are met. At the same time, the case study of GDTs underlines the relevance of previously posed questions and criticism regarding the internal consistency of Taylor's egalitarian biocentrism.

## INTRODUCTION

Malaria continues to have an enormous negative health impact, claiming the lives of 627,000 individuals and affecting a total of 241 million people in 2020 alone.<sup>1</sup> Children, the elderly, and people living in poverty are disproportionately impacted.<sup>1,2</sup> Although antimalarial medication and preventive measures such as bed nets and insecticides have led to a decline in morbidity and mortality over the years, further progress is among others hindered by drug and insecticide resistance.<sup>3</sup> Moreover, even the optimal application of existing interventions may not be sufficient to alleviate the burden of malaria in highly affected regions.<sup>3</sup>

The morbidity and mortality of malaria, coupled with the inefficiency of conventional strategies, have provided an incentive to research innovative strategies to control malaria, such as gene drive technologies (GDTs).<sup>4-7</sup> GDTs are developed with

the aim of promoting the rapid, progressive spread of a particular genetic element within a population of non-human organisms. If organisms reproduce quickly, the genetic element could spread rapidly and permanently across this population.<sup>8</sup> The most common vector for malaria in sub-Saharan Africa, and therewith also the primary mosquito species that is studied in the context of applications of GDTs to target malaria, is *Anopheles gambiae*. *Anopheles gambiae sensu stricto* is one of more than 3000 mosquito species that exist globally.<sup>9</sup>

GDTs are currently researched and tested in laboratory and small-scale cage studies, and there are knowledge gaps, complexities, and uncertainties involved with the development of GDTs and estimations of their effects and risks if they were deployed in the wild.<sup>10</sup> These technologies could be used for two main strategies of mosquito<sup>ii</sup> control. In the first strategy, 'population replacement', the spread of the genetic element changes the genotype of the mosquitoes in a way that makes them unable to contract and spread malaria.<sup>11</sup> In the second strategy, 'population suppression', the spread of the genetic element causes the number of mosquitoes in a population to decrease, for example by reducing their fertility or by biasing sex ratios.<sup>12</sup>

A central ethical question regarding GDTs relates to whether it is morally justifiable to intentionally modify or eradicate mosquitoes in this way and how the inherent worth and interests of humans and non-human organisms should be balanced in determining this.<sup>8,10,13</sup> While some may consider it evident that human interests trump those of mosquitoes, others have argued that it is essential to re-evaluate beliefs of human superiority over non-human nature.<sup>10,14-16</sup> This sentiment was for instance expressed in an interview study on professional experts' moral views on GDTs, in which one expert stated: 'I'm seeing, more and more, human beings as part of the whole biosphere and therefore not just having a special claim in a way' (p. 7).<sup>10</sup> A report by CSS, ENSSER and VDW similarly argues that it is important to consider justice between humans and non-humans.<sup>14</sup> If this is so, it is essential to also consider the inherent worth of non-human organisms in analysing the moral permissibility of GDTs.

Analyses of this matter have thus far generally relied on anthropocentric and zoocentric

other vector-borne diseases, invasive species, and agricultural pests.<sup>8</sup>

<sup>ii</sup>For the purposes of this paper, when we speak of mosquitoes, we refer to *Anopheles gambiae sensu stricto*.

<sup>i</sup>This paper focuses on the application of GDTs in the context of malaria, but these technologies have also been proposed as a potential strategy to control



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perspectives that respectively consider only humans or humans and non-human animals to matter morally for their own sake. In his analysis of the moral permissibility of eradicating mosquitoes with GDTs, Jonathan Pugh for instance adopts Singer's consequentialist zoocentric perspective, in which sentience is a necessary condition to afford organisms direct moral status.<sup>iii</sup> 17 Since it is not clear that mosquitoes possess sentience, he argues, it is not clear that they should be attributed direct moral status.<sup>7</sup> He concludes that neither individual mosquitoes nor the species as a whole possess moral status and that these considerations thus do not provide an argument against eradicating mosquitoes with GDTs.

Moreover, existing analyses have predominantly focused on species-related considerations, that is, whether it is morally permissible to use a suppression drive to intentionally eradicate a mosquito species,<sup>7 18 19</sup> with various authors arguing that this can indeed be morally justified. Callies and Rohwer analysed the instrumental and intrinsic value of *Anopheles gambiae*. They argued that this species has redundant instrumental value and no objective 'final' or intrinsic value and that its eradication would correspondingly be morally permissible.<sup>18</sup> Similarly, Pugh has argued that mosquito species do not hold a significant degree of moral status that would render it impermissible to eradicate them.<sup>7</sup>

These existing analyses tend to reject an individualist biocentric outlook in which all living organisms are taken to matter morally for their own sake and tend to assume that the use of GDTs would be considered impermissible from a biocentric perspective. In a discussion of the interrelationship between the direct moral status of species and the direct moral status of individual mosquitoes, Pugh for instance contends that views that attribute moral status to all living things or species have indefensible conclusions that would amount to a reductio ad absurdum that opponents of GDTs cannot plausibly defend.<sup>7</sup> To avoid the

<sup>iii</sup>Notably, a variety of different ethical terms are used to express that entities respectively matter morally for their own sake or for the sake of something else. One can for instance refer to 'direct moral status', 'intrinsic value' or 'inherent worth' to express the former, whereas 'indirect moral status' and 'instrumental value' may be used to express the latter. At the same time, there has been substantial discussion about different conceptions of each of these terms as well as how different concepts should be distinguished from each other.<sup>21 34–37</sup> Some for instance consider direct moral status a binary notion (an entity either has moral status or not), whereas others distinguish different types or degrees of moral status.<sup>38</sup> Similarly, while the term 'intrinsic value' generally expresses that an entity has value in and of itself, this value can be based on the value attributed to it by human valuing ('subjective intrinsic value') or on its properties or features independent of human valuing ('objective intrinsic value').<sup>37</sup> The term 'inherent worth' is generally used to express the idea that entities have intrinsic value by virtue of having a good of their own and has been argued to express a particular view regarding objective intrinsic value.<sup>37</sup> Since this paper focuses on Paul Taylor's biocentric perspective we predominantly use his concept of inherent worth when discussing which organisms matter morally for their own sake. Taylor specifically distinguishes the concept of inherent worth from the concept of intrinsic value (which he conceives of as subjective intrinsic value). According to Taylor, 'to say that (...) an entity X has inherent worth is to assert the following: A state of affairs in which the good of X is realised is better than an otherwise similar state of affairs in which it is not realised (or not realised to the same degree), (A) independently of X's being valued, either intrinsically or instrumentally, by some human valuer and (B) independently of X's being in fact useful in furthering the ends of a conscious being or in furthering the realisation of some other being's good, human or nonhuman, conscious or nonconscious' (p. 75).<sup>21</sup>

conclusion that some of modern medicine's greatest triumphs such as the eradication of the variola virus are morally impermissible, he argues, opponents of GDTs must provide an argument as to why we have reason not to eradicate mosquito species that do not apply to viruses and other life forms. To do so, he contends they 'must appeal to a more nuanced picture whereby not all living things (...) have moral status' (p. 579).<sup>7</sup>

In this paper, we investigate this matter in more detail and will highlight nuances that may not be evident at first glance when considering a biocentric approach. Indeed, we will argue that if one adopts a biocentric perspective that attributes inherent worth to all life forms, the inherent worth of mosquitoes and malaria parasites may not render the deployment of GDTs to alleviate malaria morally impermissible.<sup>iv</sup> As contentious technologies such as GDTs may plausibly require pluralistic support if they were to be deployed, it is interesting that this encompassing view which might appear to be incompatible with GDTs, may not consider the modification of malaria mosquitoes through GDTs morally impermissible under certain conditions. It is important to note that this paper focuses on the *intended* effects of GDTs and centres on a particular ethical consideration from a biocentric perspective. Among other things,<sup>v</sup> other ethical considerations regarding (the uncertainty around) the potential unintended effects of GDTs and (who are engaged in) the development of these technologies are essential for an all-things-considered moral evaluation of GDTs, yet beyond the scope of this paper.

Our argument is built up in the following way. First, we shortly discuss biocentric perspectives in general, and then outline Taylor's biocentric theory of respect for nature. Then, we explore how conflicting claims towards different organisms should be prioritised from this perspective and subsequently apply this to the context of malaria control using GDTs. Our ethical analysis shows that this context invokes the principle of self-defence, which could under certain conditions override the pro tanto concerns that a biocentrist would have against modifying mosquitoes through GDTs. Finally, we discuss various potential objections to our ethical analysis. As this discussion underlines, the case study of using GDTs to alleviate the burden of malaria also brings up previously posed questions and criticism regarding the internal consistency of Taylor's egalitarian biocentrism. All in all, our paper clarifies various considerations regarding Taylor's biocentric view on the ethical permissibility of modifying malaria mosquitoes through GDTs.

## TAYLOR'S BIOCENTRIC PERSPECTIVE

Biocentric theories consider all living beings to matter morally for their own sake. In general terms, important differences between biocentric ethical theories concern whether they are egalitarian or inegalitarian (that is, whether they attribute all living beings the same inherent worth or not), value monistic or pluralistic (e.g. whether other capacities than being alive are

<sup>iv</sup>We do not mean to suggest that if modifying malaria mosquitoes through GDTs could be prima facie justified from this perspective, this would necessarily also be the case for less-encompassing perspectives. Taylor's perspective may have certain limitations or weaknesses that need not be present in other (less encompassing) perspectives.

<sup>v</sup>See for instance De Graeff, Jongsma & Bredenoord (2021), De Graeff et al. (2021), Neuhaus (2018), Emerson et al. (2017), and Long et al. (2020)<sup>10 39–42</sup> for an overview of various other relevant ethical issues that would need to be considered.

taken to contribute to an organism's moral significance) and based on virtue ethics, consequentialism or deontology.<sup>20</sup>

We will take a biocentric theory that attributes equal inherent worth to all living organisms as a starting point for our analysis: the egalitarian biocentric position of Paul Taylor. Next to being an encompassing perspective on which organisms possess inherent worth, Taylor's theory is very detailed and provides guidelines for rules of conduct. It consists of three parts: a belief system called the 'biocentric outlook', an attitude of 'respect for nature', and a system of moral rules and standards.<sup>21</sup> Although a short article such as this one cannot do justice to the richness and complexity of Taylor's theory,<sup>vi</sup> we will shortly summarise these three parts in what follows.

Taylor argues we ought to adopt a 'biocentric outlook': a species-impartial world view which is based on four beliefs.<sup>21</sup> First, it is based on the belief that humans are part of what Taylor calls the 'Earth's community of life'. Among others, this belief is grounded in the recognition that we share many biological features as well as environmental dependencies with other species. Second, it rests on the recognition that the natural world and the whole realm of life consist of interconnected and interdependent living entities. Third, the biocentric outlook is grounded in the recognition that both human and non-human organisms are teleological centres of life: they are goal-directed toward their own good, and can correspondingly be benefited or harmed in (being prevented from) achieving this good. Fourth and finally, it rests on the denial of human superiority over other living things. Taylor discusses different interpretations of what it could mean to consider humans morally superior and argues that arguments that could be given to defend interpretations of this claim are groundless and unjustified. While humans for instance have certain capacities that other species may lack, such as our capacity to reason, the reverse is also true: non-human organisms have many capacities that humans lack. Correspondingly, we should not judge the inherent worth of organisms by values that are connected to what it is for a member of the human species to live a good life, but rather by a species impartial standard.

This biocentric outlook, in turn, warrants the adoption of a moral attitude of 'respect for nature', which undergirds the adoption of standards of good character<sup>vii</sup> and rules of right conduct. Specifically, Taylor stipulates four basic rules of conduct: (1) the rule of non-maleficence: the duty to refrain from harmful or destructive acts towards wild organisms or species-populations; (2) the rule of non-interference: the duty to refrain from restricting the freedom of individual organisms and to adopt a general 'hands off' policy regarding organisms and species-communities; (3) the rule of fidelity: the duty not to deceive or betray wild animals that are capable of being deceived or betrayed; and (4) the rule of restitutive

justice: the duty to make appropriate restitution if harm to wild organisms has been inevitable.<sup>21</sup>

## PRIORITISING CONFLICTING DUTIES TO DIFFERENT ORGANISMS

If we reflect on the impact of human actions, one can see that following Taylor's four basic rules of conduct is likely to produce conflicting duties. If we (want to) take antibiotics that kill bacteria or build roads, theatres, or hospitals that would destroy the habitat of non-human organisms, we are inevitably confronted with moral dilemmas regarding whose interests should be prioritised. Taylor acknowledges this and posits that, in fact, our duties towards wild organisms may be outweighed by duties that humans, as moral agents, owe to other humans.<sup>21</sup> In other words, while moral agents have a pro tanto duty to live by the four basic rules of conduct, it can be morally acceptable to breach them. To determine how to resolve and prioritise conflicting claims for cases where a fundamental moral dilemma exists due to a conflict between the realisation of human values and the good of other living organisms, Taylor stipulates five priority principles.<sup>21</sup>

The first of these five principles, the *principle of self-defence*, applies when wild organisms are harmful to humans, that is, when these organisms threaten humans' basic interests such as survival or health.<sup>21</sup> Specifically, the principle of self-defence states that it is permissible for moral agents to protect themselves against dangerous or harmful organisms by destroying them (p. 264–5).<sup>21</sup> Like we may, if need be, forcefully protect ourselves from an attacking human that threatens our life, this also holds if we are threatened by non-human organisms. Abiding by such a principle does not imply that an attacking or threatening organism has a lower inherent worth than the organism that engages in self-defence, nor that it is morally permissible to use force on them or use them to further our interests in other contexts.<sup>21</sup> According to Taylor, the principle of self-defence holds only when two conditions are met. First, moral agents should not reasonably be able to avoid being exposed to organisms that harm their survival or health. We will call this the 'reasonable care' criterion. Second, only those strategies that will do the least possible harm to the organisms in question while preserving the survival and functioning of moral agents should be used. We will call this the 'least restrictive alternative' criterion.

The other four priority principles apply to situations where wild organisms are harmless to humans or where their harmfulness can reasonably be avoided. If the basic interests of non-human organisms are at stake, and the non-basic interests of humans, the principles of proportionality and minimum wrong apply.<sup>21</sup> The *principle of proportionality* holds that greater weight should be given to basic than non-basic interests, regardless of whether the organism that holds the interests is human or non-human. This principle applies to situations in which the non-basic interests at stake are fundamentally incompatible with the attitude of respect for nature, that is, when these interests in themselves exemplify an exploitative attitude towards nature, as is for instance the case when elephants are killed to use the ivory of their tusks for items that can be sold to tourists. As recreational hunting is intrinsically incompatible with the attitude of respect for nature and does not give priority to the basic interests of elephants rather than to the non-basic interests of humans, the principle of proportionality dictates that such killing is not proportional and indeed morally impermissible. The *principle of minimum wrong*, in turn, applies to situations in which the

<sup>vi</sup>Moreover, biocentrism in general, and Taylor's theory in particular, have also faced criticism. We will address one of the criticisms of Taylor's theory in section 5, as this criticism is also brought to the fore by a biocentric analysis of modifying malaria mosquitoes through GDTs. However, this paper does not evaluate the coherence or persuasiveness of these perspectives more generally, see for instance Basl (2019) and Watson (1983)<sup>35 43</sup> for more general critical discussions of biocentrism.

<sup>vii</sup>Taylor distinguishes between general virtues that contribute to the fundamental character traits of moral strength and moral concern, and special virtues that are necessary to comply with the duties that are specified by the basic rules of conduct.<sup>21</sup>



non-basic human interests at stake do not in themselves express an exploitative attitude towards nature, but satisfying these interests nonetheless results in effects that should be avoided whenever possible out of respect for nature. An example where this principle applies is when the building of an art museum or library would lead to the destruction of a natural habitat. Taylor argues that this principle implies that achieving these ends should be done in such a way that the least wrong is done to the natural world. Moreover, there should be no alternative ways to achieve the same ends which would produce fewer wrongs.<sup>21</sup>

If the *basic* interests of both humans and non-humans are at stake, the *principle of distributive justice* applies. According to this principle, natural sources of good that could benefit human and non-human organisms alike should be shared equally between these different organisms. This principle for instance gives rise to the obligation to be a vegetarian rather than a carnivore, since a vegetarian diet requires significantly less land to be cultivated. As a result, more land would be available for organisms of other species.<sup>21</sup> Taylor argues that even the fairest distributive methods cannot guarantee a perfectly equal distribution, and that is where the fifth and last priority principle comes in: the *principle of restorative justice*. If wrongs are done to non-human organisms, for instance because all individual organisms are *not* treated equally, we ought to make up for these wrongs.<sup>21</sup>

## MORALLY EVALUATING THE USE OF GDTs

### Situating GDTs in the context of Taylor's biocentric perspective

To morally evaluate the use of GDTs from Taylor's biocentric perspective, it is essential to first identify the intended effects of the use of a GDT on non-human organisms. As discussed in the introduction, we can broadly distinguish between two types of GDTs: population replacement GDTs and population suppression GDTs. The intended effects of a population replacement GDT would be that mosquitoes obtain a disease-refractory gene that would prevent malaria parasites from developing in them.<sup>11</sup> The intended effects of a population suppression GDT would be that mosquitoes obtain a gene that reduces their fertility or biases the sex ratio of their offspring, such that they for instance only get male offspring.<sup>12</sup> As a result, the overall size of the mosquito population would be reduced or it would even be eradicated. Moreover, both population replacement and population suppression GDTs have intended effects on the malaria parasites, which would be deprived of their host. If they do not find another host, they would not be able to reproduce and continue living. If we relate these intended effects to Taylor's four rules of basic conduct, the rules of non-maleficence and non-interference are of primary relevance.

The rule of non-maleficence among others implies that it is pro tanto impermissible to kill non-human organisms and to engage in acts that prevent organisms from pursuing their own good in accordance with the laws of their nature.<sup>21</sup> While the use of GDTs would not kill mosquitoes nor parasites directly, it would result in the reduction or eradication of the species-populations of malaria parasites, which Taylor would consider pro tanto morally problematic.<sup>viii</sup> In the case

of a suppression drive, the intended effects could moreover include the eradication of the species-populations of mosquitoes. Additionally, as being able to reproduce and being able to get offspring from both sexes could be considered examples of the laws of the nature of mosquitoes, the use of a population suppression drive would be considered an act that is detrimental to the good of mosquitoes from Taylor's biocentric perspective. The ability to carry a malaria parasite, in contrast, does not appear to be one of the laws of nature of a mosquito. While both types of GDTs would thus violate the duty of non-maleficence, a population replacement drive would not harm mosquitoes in the same way a population suppression drive would.

The rule of non-interference, in turn, stipulates that moral agents have the duty to refrain from restricting the freedom of individual organisms and to adopt a general 'hands off' policy regarding organisms as well as species-communities. To start, this rule implies moral agents should not perform actions that prevent or hinder the normal activity and healthy development of malaria parasites and mosquitoes. As stipulated above, GDTs would hinder the development and survival of malaria parasites and therefore violate this duty. With regard to the mosquitoes involved, a population suppression GDT also violates this duty, while the intended effects of a population replacement drive would not hinder their development and survival. Moreover, the rule of non-interference implies moral agents should not meddle with the wildness of non-human organisms and let them alone. Even though humans would not directly interact with wild mosquitoes, but rather would release GDT mosquitoes into the wild, this would introduce a human-engineered gene into wild organisms, and in that sense could be said to affect their wildness. Finally, the rule of non-interference also implies that moral agents should not attempt to manage or control species populations, which would most certainly be the case if a population suppression GDT was used.

All in all, while population suppression GDTs raise more moral concern than population replacement GDTs, the use of both kinds of GDTs would be pro tanto impermissible from Taylor's biocentric perspective. At the same time, the duties discussed thus far may be at odds with duties that humans may have to other humans. In what follows, we will evaluate how these competing claims should be prioritised based on Taylor's priority principles.

### Applying the priority principles

As was discussed in the introduction, the transmission of malaria from mosquitoes to humans significantly threatens humans' lives and basic health. Indeed, it has been claimed that *Anopheles gambiae* is the 'deadliest animal in the world' (p. 194).<sup>18</sup> Given this harmfulness and the negative effects on humans' basic interests, the principle of self-defence is applicable to the context of alleviating the burden of malaria. Whether any method of self-defence against malaria, be it GDTs or another method, could be justified in this context depends on whether the reasonable care criterion and least restrictive alternative criterion can be met.

as such to have a good of its own that is independent of the good of its individual members.<sup>21</sup> That being said, eradicating a species-population of mosquitoes through a suppression drive could still be considered harmful to a species-population from his biocentric perspective as it would lower the 'median level of their good-realisation' (p. 69).<sup>21</sup>

<sup>viii</sup>Taylor considers it pro tanto morally impermissible to eradicate a species-population, yet not for the sake of the population as a whole. While he considers it statistically intelligible to speak of furthering the good (and vice versa, decreasing the good) of a whole species-population, he does not consider the population

According to the reasonable care criterion, moral agents should not reasonably be able to avoid being exposed to organisms that harm their survival or health.<sup>21</sup> This criterion ensures that the principle of self-defence cannot be misused to justify situations of recklessness in their interaction with wild organisms. As Anna Wienhues aptly describes it, if one were to travel to the North Pole just to pet a polar bear and subsequently be taken back not to get a warm welcome, it would be difficult—if not impossible—to argue that the reasonable care criterion was met.<sup>22</sup> In contrast to polar bears that live in mainly uninhabited areas in low numbers, however, malaria mosquitoes are abundant and people in malaria-endemic areas are exposed to them in great quantities. To contextualise this exposure, it is relevant to look at the number of infectious bites people suffer per year in malaria-endemic regions: the entomological inoculation rate (EIR). The EIR has a wide range,<sup>23 24</sup> but a recent overview study reported that the average EIR in rural areas is 144 infected bites per person per year.<sup>24</sup> In rural areas with high malaria transmission, the EIR can even be as high as 850 infected bites per person per year.<sup>23 24</sup> Importantly, moreover, this number of infectious bites occurs *despite* the use of (insecticidal) bed nets and indoor residual spraying.<sup>24</sup> ix While the removal of stagnant water can help to reduce the burden of malaria by preventing malaria larvae from breeding in it, *Anopheles gambiae* also breed in commonplace human-made structures that are important for our sustenance, such as water tanks.<sup>24</sup> Similarly, while improving access to malaria treatment could help to reduce the burden of this disease, it would by no means altogether prevent malaria infections and the resulting morbidity and deaths. All in all, then, the exposure people in malaria-endemic regions continue to have despite the extensive use of control methods provides ground to conclude that the reasonable care criterion is met in this context. If this is so, the pro tanto concerns against malaria control could be overridden and self-defence could be permissible. Whether GDTs would be a permissible means of carrying out such self-defence depends on whether the ‘least restrictive alternative’ criterion is also met.

According to the least restrictive alternative criterion, only those strategies should be used that will do the least possible harm to the organisms in question while preserving the survival and functioning of moral agents.<sup>21</sup> In evaluating this, it is relevant to compare GDTs to currently available alternative strategies for malaria control. All different strategies, if effective, would be equally harmful to the malaria parasite, which would be deprived of either its mosquito or human host.<sup>x</sup> The effects on mosquitoes, in contrast, would differ between alternatives. Insecticides, to start, kill mosquitoes and thereby harm them in a more severe way than GDTs—which would either render them resistant to malaria or infertile—would. As Taylor argues in the context of the principle of minimum wrong, moral agents should choose an alternative that eliminates direct killing entirely, if possible.<sup>21</sup> Other prominently used control methods such as bed nets and preventative clothing, are less harmful to mosquitoes than GDTs would be: they may restrict their movement some-

what, yet do not restrict them in pursuing their own good in accordance with the laws of their nature. However, as was argued in the previous paragraph, these methods as such fail to suppress malaria and thus do not preserve the existence and functioning of moral agents.<sup>xi</sup> Malaria vaccines, finally, would be considered to be the best malaria control alternative of all, as they would not harm the mosquito in any way. However, while initial studies are promising,<sup>25 26</sup> no large-scale available malaria vaccine has been brought to the market yet. In sum, if GDTs are indeed effective in preventing malaria and there are no available alternatives that are equally or more effective yet less harmful to non-human organisms than GDTs, the least restrictive alternative criterion could be satisfied. As was outlined in the previous subsection, a replacement drive would be considered less harmful to mosquitoes and thereby less restrictive than a suppression drive.

All in all, this analysis implies that the principle of self-defence is indeed applicable, and the pro tanto concerns that Taylor would have against the use of GDTs could be overridden if certain conditions are met. Nevertheless, this conclusion raises various potential objections, which are discussed in the following section.

## POTENTIAL OBJECTIONS, NUANCES AND CRITICAL REFLECTIONS

A first objection that this conclusion may raise is that the use of GDTs would not in fact constitute *self-defence*.<sup>27</sup> Indeed, with some exceptions—such as that of a person that swats a malaria-carrying mosquito just before it is about to bite her—mosquito control in the context of malaria is usually carried out or at least aided by other humans than the human that could herself be infected. Similarly, GDTs would be developed by scientists and deployed by policymakers to prevent the population at large from malaria. In that sense, GDTs would be deployed to a large extent in *other-defence*, rather than *self-defence*. However, as an example from human ethics discussed by Shelly Kagan illustrates, the principle of self-defence is generally taken to extend to defence by others too: if person A attacks person B, not only is person B permitted to use force to stop person A, but others can also do this on her behalf.<sup>28</sup> While Taylor does not discuss this point in depth, he also contends that the principle of self-defence can be applicable to other-defence, for instance, when he contends that the pro tanto concerns against killing may be outweighed when it is the only way to protect the lives of one’s family.<sup>29</sup> In sum, even though the term self-defence may not be conceptually appropriate, this does not render the modification of malaria mosquitoes through GDTs impermissible as such.

Second, it could be questioned whether the use of GDTs would constitute defence even though the organisms under attack could be considered innocent in various different senses, and if so, if this would make harming these organisms impermissible.<sup>28–30</sup> In a first sense, both malaria parasites and mosquitoes could be considered innocent: they are (as far as we know) not moral agents and thus do not consciously aim to cause harm to humans. Nonetheless, it could be argued that it would be permissible to use harm against them, just like it would be permissible—as Taylor himself contends<sup>29</sup>—to use defensive harm against a mentally insane person if that was necessary to prevent her from killing you.<sup>28–30</sup> Additionally, if this type of innocence did constitute a convincing reason to refrain from

<sup>ix</sup>As will be discussed in the next paragraph in more detail, insecticide-based control methods kill mosquitoes and would thus also be considered pro tanto impermissible by Taylor.

<sup>x</sup>Both mosquitoes and humans are vectors for malaria parasites, with mosquitoes spreading the parasites to previously uninfected humans, which subsequently spread the parasite to previously uninfected mosquitoes if those bite them.<sup>44</sup>

<sup>xi</sup>Whether GDTs would in fact succeed in suppressing malaria in this way is obviously also unclear at this point. However, as stipulated in the introduction, this paper focuses on GDTs’ intended effects and evaluates whether Taylor’s biocentric perspective would consider GDTs (im)permissible in principle.

defensive harm in the context of (self-)defence, this would hold for (self-)defence against all (non-human) organisms that are not considered to be moral agents. This is not in line with Taylor's theory, nor does it seem a tenable position. Mosquitoes could, however, also be considered innocent in two other senses. To start, they are the mere vectors of disease, and do not actually cause any *direct* harm themselves. Moreover, not all *Anopheles gambiae* mosquitoes in malaria-endemic regions in fact carry malaria, yet mosquitoes that do not would also be targeted by a GDT.<sup>xii</sup> Notably, harm to organisms that are innocent in this sense also occurs in other scenarios of self-defence against microbes. For instance, when we take antibiotics or even wash our hands with soap, this kills both disease-causing and beneficial bacteria.<sup>22</sup> Both these types of innocence would be considered morally relevant to Taylor, who considers it fundamentally wrong to harm organisms that do not harm us.<sup>21</sup> Nonetheless, Taylor stipulates that it can be permitted to harm creatures that do not harm us if doing so is a practical necessity because the harmless organisms cannot be separated from the harmful organisms against which humans are defending themselves (p. 266).<sup>21</sup> Faced with the choice between not targeting any mosquitoes including the harmful ones that carry malaria parasites, and targeting all mosquitoes including the innocent ones (with a GDT or another control method), the latter would not be principally objectionable from Taylor's perspective. Importantly, if we were to act consistently with the attitude of respect for nature, it seems that the wrong inflicted on these innocent mosquitoes would have to be restituted, for instance by protecting a wild region of nature that is currently threatened by human exploitation or consumption.<sup>xiii</sup>

If such harm to innocent mosquitoes (and 'guilty' malaria parasites) can be justified, this raises a third objection. If all living organisms have equal inherent worth, how could it ever be considered proportionate to deploy a harmful gene drive that will affect a very large number of mosquitoes and malaria parasites to defend a smaller number of humans? According to many positions on justified self-defence, the harm inflicted by defensive force should be proportionate to the harm prevented.<sup>31</sup> As for Taylor, he would indeed find the large number of violations of the duties of non-maleficence and noninterference that are involved in malaria control generally and the use of GDTs specifically pro tanto objectionable. Moreover, this objection could only be outweighed if GDTs were the least restrictive alternative for malaria control. Interestingly, however, his biocentric position does not stipulate a proportionality criterion for self-defence in which the harm inflicted and harm prevented are balanced as such.<sup>xiv</sup> By not doing so, Taylor's theory avoids a complication that could arise due to the large numbers of non-human organisms in general and microbes in particular, and the corresponding duties moral agents have to them. Indeed, an egalitarian environmental ethic that endorses a proportionality criterion could essentially collapse into a 'microbe ethic' because the large number of duties towards them would always outweigh the duties to other (human) organisms.<sup>22 xv</sup>

<sup>xii</sup>This is, of course, also the case for many currently used methods of malaria control, such as insecticides.

<sup>xiii</sup>We do not go into the most appropriate form of restitution in-depth due to space limitations. See eg, p. 186–197 of Taylor's *Respect for Nature*<sup>21</sup> for relevant considerations.

<sup>xiv</sup>As discussed in section 3, one of Taylor's priority principles is called the 'principle of proportionality', but this principle is applicable to situations in which the *basic* interests of non-human organisms are at stake, and the *non-basic* interests of humans. It therefore does not serve as a proportionality criterion to the principle of self-defence.

<sup>xv</sup>Relatedly, even though Taylor's theory is deontological rather than consequentialist, the endorsement of a proportionality

At the same time, the absence of a proportionality criterion raises other questions and concerns. The internal consistency of Taylor's biocentric approach has among others been questioned by James Sterba and William French, who argue that his approach is still biased in favour of the human species and thereby not in fact egalitarian.<sup>32,33</sup> Indeed, one may wonder, can an egalitarian biocentric theory plausibly stipulate priority principles that differentiate between humans and non-humans at all?<sup>32</sup> Can the normative foundations of Taylor's theory be squared with his priority principles? If our analysis is correct, the case of using GDTs to alleviate the burden of malaria underlines the relevance of this criticism. It may be questioned if Taylor's biocentric egalitarianism truly attributes the same inherent worth to non-human organisms if it can be used to justify acts that would in his view violate duties towards many non-human organisms. It would be relevant to explore these considerations in more depth in future research.

## CONCLUDING REMARKS

All in all, our analysis demonstrates that Taylor's principle of self-defence is applicable to the situation of using GDTs to alleviate the burden of malaria, which could override the pro tanto concerns that a biocentrist would have against modifying malaria mosquitoes in this way if certain conditions are met. Whereas previous analyses of the moral permissibility of modifying mosquitoes through GDTs predominantly focused on anthropocentric and zoocentric perspectives and generally rejected biocentrism or assumed the use of GDTs would be principally incompatible with a biocentric perspective, our analysis has highlighted various considerations that may not be evident at first glance.

It should be noted that our analysis centred on one particular ethical consideration, was limited to the intended effects of GDTs, and assumed they will be effective in targeting malaria, which is by no means certain. Among others, an all-things-considered ethical evaluation would need to consider (the uncertainty around) the potential benefits of GDTs and their potential unintended effects on (other) organisms and the ecosystem. Moreover, our analysis underlines that it would be relevant to reflect in more detail on previously posed questions and criticism regarding the internal consistency of Taylor's egalitarian biocentrism, which are also brought up by the case study of using GDTs to alleviate the burden of malaria.

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criterion would lead to problems akin to the repugnant conclusion.<sup>30</sup>

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