The Ethics of Eliminating Harmful Species: The Case of the Tsetse Fly

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Wildlife species harmful to humans are often targets of control and elimination programs. A contemporary example is the tsetse fly, a vector of sleeping sickness and African animal trypanosomosis. Tsetse flies have recently been targeted by a pan-African eradication campaign. If it is successful, the campaign could push the entire tsetse family to extinction. With the emergence of effective and efficient elimination technologies, ethical assessment of proposed elimination campaigns is urgently needed. We examine the ethics of tsetse fly elimination by considering arguments predicated on both the instrumental and the intrinsic values of the species at local and global scales. We conclude that, although global eradication of tsetse flies is not ethically justified, localized elimination campaigns targeting isolated populations are ethically defensible. We urge assessments of this kind be conducted regularly and in context, so that all relevant factors underlying decisions on species elimination are routinely laid bare for evaluation.

Keywords: ethics, Glossinidae, sleeping sickness, sterile insect technique, trypanosomosis, vector control

Humans have caused the extinction of wildlife species worldwide, likely initiating a sixth mass extinction event (Ceballos et al. 2015). The disappearance of most, if not all, of these species has been an unintended consequence of human population growth and related activities. Recognizing the value and significance of biodiversity, global efforts to halt or reverse species loss have been coordinated—for example, by the International Union for Conservation of Nature and the United Nations Convention on Biological Diversity. Recently, however, humans have developed the technical capacities to purposefully eradicate undesirable species, such as insect vectors of a variety of pathogens. Policymakers are now tasked to determine whether and to what ends such technologies should be used. The moral seriousness of this decision cannot be overstated. In the middle of the only known mass extinction to be caused by humans, all relevant factors underlying a decision to intentionally eliminate a species, whether a pest or not, should be laid bare and carefully evaluated as a part of responsible and informed ethical deliberation.

As part of such a deliberative process, in the present article, we examine and evaluate key arguments for and against the purposeful elimination of tsetse flies (figure 1 and box 1), vectors of sleeping sickness and African animal trypanosomosis. Trypanosomosis is a major but neglected human disease and the main pathological constraint to cattle farming in approximately 10 million square kilometers (km^2) of tsetse fly–infested sub-Saharan Africa. Sixty million people are at risk of contracting sleeping sickness and the annual livestock and crop losses are estimated at $4750 million (Vreysen et al. 2013). Despite considerable research, no vaccines for human and animal trypanosomosis are yet available, so controlling the diseases requires controlling the tsetse fly vector (Bouyer et al. 2013, Solano et al. 2013), although this is still under debate for sleeping sickness. Numerous tsetse fly elimination programs have been established across Africa, many housed under the Pan African Tsetse and Trypanosomosis Eradication Campaign (PATTEC). Recently, six countries (Ghana, Burkina Faso, Mali, Uganda, Kenya, and Ethiopia) were involved in the first phase of PATTEC (Simarro et al. 2008). Other countries, including Senegal, Zimbabwe, and Botswana, have also successfully eliminated tsetse flies from part of or their full territory using sources of funding other than PATTEC (Kgori et al. 2006).

Many elimination programs target populations of nonnative species (Simberloff 2009), which can cause severe ecological damage, including the loss of endemic species (Clout and Veitch 2002). These programs are generally noncontroversial (Myers JH et al. 2000). Tsetse fly elimination, on the other hand, is an interesting and potentially more controversial case study for ethical analysis. Tsetse flies are endemic, with a complex biology and unique evolutionary history. For example, they have a unique reproduction system (box 1), close to that of mammals, with ovoviviparity and lactation of the larvae, which they share only with

BioScience 69: 125–135.
doi:10.1093/biosci/biy155 Advance Access publication 19 December 2018

*Figure 1. A wild tsetse fly (***Glossina palpalis gambiensis***) in a protected gallery forest near the "mare aux hippopotames," Burkina Faso. Photograph: Olivier Esnault.*

the biological group of pupiparous insects (Hippoboscidae, Streblidae, Nycteribiidae; Solano et al. 2010). Tsetse flies also have learning capacities (Bouyer et al. 2007), as is evidenced by their preferential return to the first host species they feed on for ulterior blood meals. However, although they are biologically and evolutionarily remarkable, tsetse flies are also specific vectors of diseases with a large detrimental impact on human well-being (box 2). Furthermore, given sufficient political and financial support, tsetse flies can now be eliminated locally and possibly even eradicated worldwide. As a basic rule of ethics, however, *can* does not imply *should*. We suggest a full ethical evaluation of tsetse fly elimination is essential to support sound decision-making around the usage of new technologies, to assess whether or under what conditions elimination of an endemic species harmful to humans might be justified.

Background: Feasibility of tsetse fly elimination

The development of efficient technologies (box 3) has made the elimination of tsetse fly populations more feasible than in the past (Dicko et al. 2014). Already several countries have succeeded in eliminating tsetse flies in a large part of their original distribution area (one-third in Zimbabwe, with progress ongoing; Murwira et al. 2010). Local populations of *Glossina austeni* have already been eliminated in Zanzibar using the sterile insect technique (SIT; Vreysen et al. 2014), and populations of *Glossina morsitans centralis* have been eliminated in the Okavango Delta of Botswana using the sequential aerosol technique (SAT; Kgori et al. 2006). Isolated areas in Senegal, such as the Niayes (figure 2), have had tsetse fly populations eliminated as well, and efforts are underway to eliminate all *Glossina palpalis gambiensis* populations in a 1000 km^2 target area using innovative technologies, including the aerial release of chilled adult sterile males with an automatic release machine (Dicko et al. 2014).

The alternative to elimination is integrated control of trypanosomosis by farmers, with the aim of reducing tsetse fly densities below the detection threshold or to levels compatible with cost-effective cattle production (Bouyer et al. 2013). This alternative strategy relies on the combined use of trypanocides and control of the vector through insecticide treatment of cattle (ITC) and insecticide treated targets (ITT). However, the adoption of these relatively new technologies by farmers remains a major challenge, and early case studies suggest integrated control has not been as effective as elimination strategies (Diall et al. 2017).

Undertaking any elimination program requires not only technological ability but also social and political support, along with sufficient funding (Vreysen et al. 2014). Since 2001, under the umbrella of the African Union, African governments have been implementing PATTEC with the explicit objective to eradicate the tsetse fly in Africa (Kabayo 2002). In Senegal, the program is supported by the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency, with financial help from the United States. This elimination project, including a SIT component, cost \$8.5 million for a 1000-km^2 project area in Senegal (Bouyer et al. 2014) and \$5.7 million for a 1650-km^2 area in Zanzibar (Bouyer et al. 2014). Although it is costly, elimination of isolated tsetse fly populations (Vreysen et al. 2013) is considered to be the best economic strategy (Bouyer et al. 2014), given the long-term benefits it produces (Shaw et al. 2014). As such, despite technical and financial challenges, tsetse fly elimination campaigns will likely increase with the general economic development of Africa.

Although political, economic, and technical conditions and capabilities are generally conducive to tsetse fly elimination, the important ethical question remains: Is tsetse fly elimination morally appropriate? Because tsetse flies disappeared from North America millions of years ago (Cockerell 1907), tsetse fly distribution is presently restricted to Africa. Continent-wide eradication of tsetse flies, as was proposed by the PATTEC program, would result in the extinction of the entire tsetse fly family (Glossinidaea), including 31 species and subspecies. Alternatively, past experience suggests that elimination technologies can be used to create pest-free areas, which allow agricultural production without worldwide eradication of entire species. An excellent example is the elimination of the medfly (*Ceratitis capitata*) in the Los Angeles basin in 1996 using SIT, followed by preventive releases, which still continue today (Hendrichs et al. 2002). This program was highly successful technically, economically, politically, and environmentally, and it addressed public opposition to recurrent aerial bait spraying over urban areas.

Next, we examine the ethical basis for these two options by considering whether they appropriately reflect accepted notions of value and concomitant moral obligations. As a terminological note, in the discussion that follows we use the word *elimination* to refer to localized programs directed at removing tsetse fly populations. We use the word *eradication* to refer to programs whose objective is to remove tsetse flies

Box 1. Presentation, taxonomy and biology of tsetse flies.

Tsetse flies (Diptera: Glossinidae) are Brachycera Cyclorrhapha Diptera, Schizophora and Calyptratae, close to Muscoidae, from which they differ by the adaptation of their mouthparts to blood sucking (Solano et al. 2010). The single genus (*Glossina*) includes three subgenera and 31 species and subspecies. The three subgenera are subgenus *Nemorhina* (also known as the *Palpalis* group), subgenus *Glossina* sensu stricto (*Morsitans* group) and subgenus *Austenina* (*Fusca* group). They are the sole cyclical vector of trypanosomes that go through a full extrinsic development cycle in their definite host before being transferred to vertebrates during a bite (Solano et al. 2010). All tsetse fly species can potentially transmit trypanosomes but their relative importance depends on the intensity of their contacts with susceptible hosts. The *Morsitans* and *Palpalis* groups, mainly found in natural savannahs and riverine forest vegetation respectively, are the most important epidemiologically.

Living a very long time for a fly, 50–100 days, but up to 8 months in captivity, its reproduction cycle is more similar to that of mammals than to a domestic fly: It has very few offspring (5–10) that are carried by the ovoviviparous female in its uterus and fed thanks to milky glands. Larvae are laid every 10 days on the ground, where they immediately metamorphose into pupae and then into imagoes without requiring any extra food resources in the environment.

Box 2. Relative epidemiological importance of tsetse fly species.

The different species contribute to very different degrees to the transmission of human and animal African trypanosomes. In the case of sleeping sickness, *Glossina fuscipes* subspecies are responsible for approximately 90% of human cases and together with *Glossina palpalis* subspecies, they are probably responsible for close to 100% of the cases of the Gambian form of the disease (*T. brucei gambiense*), which represents approximately 97% of human cases (Simarro et al. 2010). This is all the more intriguing considering that in the past, these two species complexes were considered to be subspecies (*G. palpalis palpalis* and *G. palpalis fuscipes*): The importance of these vectors is mainly due to a strong resilience to human changes, with populations found in major capital cities such as Conakri, Abidjan or Kinshasa. *G. fuscipes* SL is also a major vector of the Rhodesian form of the disease (*T. brucei rhodesiense*). *G. swynnertoni*, *G. morsitans morsitans* and *G. pallidipes* are also important vectors for this form, particularly at the wildlife reservoir interface.

Considering African animal trypanosomosis (AAT), species of the *Morsitans* group were originally the most important vectors (Solano et al. 2010) and this is still the case in eastern and southern Africa, where large protected areas still offer “bed and board” for their persistency, leading to the interface cycle, which is clearly the most dangerous for cattle (Van den Bossche et al. 2010). However, in western Africa, the *Palpalis* group is presently responsible for most animal cases, thanks to its resilience to anthropic changes, and with increasing human encroachment, this situation is currently extending to most of Africa.

The *Fusca* group, corresponding to almost 50% of known species and subspecies, is generally very sensitive to human encroachment, specific to wild hosts, and generally has little epidemiological impact, with the exception of *Glossina brevipalpis* in southern Africa, which can be an efficient vector of AAT. Most species, such as *Glossina medicorum* in Burkina Faso, have a distribution, which is limited to specific types of vegetation, do not feed at all on humans, and have almost no contact with livestock.

Box 3. Tsetse fly control methods.

The sterile insect technique (SIT) is based on the release of irradiated males that sterilize wild females as unfertile mates. SIT is clearly the technique with all the necessary “qualities” for species elimination (Dyck et al. 2005), because its efficiency increases when the target population is only present at low density. In Senegal, SIT is crucial for elimination (Dicko et al. 2014). The sequential aerosol technique (SAT) is based on the aerial spraying of microdroplets of a formulation containing pyrethroids used at very low doses (0.33–0.35 grams of active ingredient per hectare). It is very efficient against the *Morsitans* group in open environments (Kgori et al. 2006) but more difficult to use against the *Palpalis* group in dense vegetation or in hilly areas (De Deken and Bouyer 2018). Finally, the two other available methods of controlling tsetse flies are insecticide treated targets (ITT) and cattle (ITC). ITT is the use of a visually attractive device generally impregnated with pyrethroids (Rayaisse et al. 2012). Their attractiveness can be increased by the use of odour baits (Rayaisse et al. 2010). In the case of ITC, cattle—or pigs—are impregnated with pyrethroids and used as live baits (Ndeledje et al. 2013).

from Africa altogether, which, to reiterate, would effectively bring multiple tsetse fly species to extinction.

The ethics of elimination and eradication

Ethics is a broad domain, including, among other things, considerations of justice, care, welfare, duty, and rights. A full ethical analysis of tsetse fly elimination is far beyond the scope of this article, so we narrow our focus to attributions of value. Value is a basic underpinning of moral obligation: How we value an entity informs normative beliefs about how we ought to treat or interact with that entity (Elliot 1992). We also limit our discussion of value to ecological

*Figure 2. Habitat of tsetse flies (***Glossina palpalis gambiensis***) in the Niayes area of Senegal. Old Euphorbia edges provide the suitable microclimate necessary for the flies to circulate between patches of anthropic and natural tree habitats. Photograph: Jérémy Bouyer.*

collectives (species and populations), setting aside the value of individual tsetse flies (but see, e.g., Taylor 1981, Vucetich and Nelson 2007, Wallach et al. 2018 for perspectives on obligations to individual living beings). Numerous types of value are attributed to species, including intrinsic and various instrumental values (discussed below), relational values (Chan et al. 2016), and transformative values (Norton 2014). We focus on the first two types, because they are relatively well established and widely endorsed within the conservation community (United Nations 1992, Trombulak et al. 2004).

Instrumental values

Instrumental value lies solely with an entity's utility or function as a means to an end. Ethically, we have no moral obligations to entities possessing only instrumental value. Such entities are properly regarded as objects and warrant only indirect moral concern, to the extent that they contribute to some inherently worthy end (Muraca 2011). Species have innumerable instrumental values for humans (as well as for biological communities and ecosystems), but species also arguably have disvalues (Morito 2003) or provide disservices (McCauley 2006) that counteract the human good. This observation is exemplified by so-called pest species, such as tsetse flies, which actively detract from human well-being.

In practical terms, we can compare instrumental values and disvalues by calculating the relative benefits and costs associated with a species. Following strict utilitarian logic, we ought ethically to pursue elimination programs whose total value or benefit exceeds the value or benefit associated with the species' persistence. To clarify this chain of reasoning, we will provide a formal argument for elimination premised on the instrumental values and disvalues of tsetse flies. An argument, formally, is a logical sequence composed of premises (P) leading to a conclusion (C). For an argument to be sound, it must have a valid structure; that is, the conclusion must follow necessarily from the premises, and all the premises must be true or otherwise justified (Copi and Cohen 2008, Nelson and Vucetich 2012). An analysis of arguments is a basic method of the scholarly discipline of ethics and, as such, is well suited to the discussion at hand.

The utilitarian argument outlined above can be formulated as follows: (P1) Tsetse fly elimination provides benefits. (P2) Tsetse fly elimination incurs costs. (P3) The benefits of tsetse fly elimination exceed the costs. (P4) A program whose benefits exceed costs should be implemented. (C) Therefore, tsetse fly elimination should be implemented.

P1 is certainly true. Widely recognized as a significant contributor to the African continent's continuing struggle to emerge from economic, social, and political problems, the tsetse fly has been named "The Poverty Fly" and even "Africa's Bane," because of its negative impacts on both human and animal health (Nash 1969, Kabayo 2002). There is solid correlative reason to believe that the removal of tsetse flies, and trypanosomosis by extension, would have substantial direct and indirect benefits for local communities, enhancing opportunities for rural development. For example, two economic surveys conducted 2 and 5 years after completion of a local tsetse fly elimination campaign in Zanzibar revealed a substantial increase in the number of small farmers holding cattle (from 31% to 94%), holding improved cattle breeds (from 2% to 24%), selling milk (from 10% to 62%), and using oxen for ploughing (from 5% to more than 60%; Vreysen et al. 2014). In addition, milk production tripled and the average income per month of farming households increased by 30% (Vreysen et al. 2014). In eastern Africa, a recent FAO study estimated that the average benefits to livestock keepers would be approximately \$160 per km^2 per year (Shaw et al. 2014). In Senegal, a tsetse fly elimination project (Dicko et al. 2014) is projected to lead to a threefold increase in milk and meat sales, corresponding to approximately \$3720 per km^2 per year, to the benefit of local farmers (Bouyer et al. 2014). Although the financial costs of tsetse fly elimination are significant, as was noted earlier, the net effect is arguably beneficial, considering not only economic outcomes but also the dramatic improvement in human health. Therefore, setting aside P4 for the time being (we return to it below), the argument premised on relative costs and benefits of tsetse fly elimination appears to be sound.

However, critics may point out that the relative benefits and costs of tsetse fly elimination have not been accurately accounted in the discussion above. Specifically, if costs are more broadly conceived, to encompass more than just financial expenses associated with elimination, the costs of elimination may not be outweighed by resulting benefits. In this case, by the same reasoning outlined above, cost–benefit analysis would not justify implementation of an elimination program. In other words, (P1) Tsetse fly elimination provides benefits. (P2) Tsetse fly elimination incurs costs. (P3) The costs of tsetse fly elimination exceed the benefits. (P4) A program whose costs exceed benefits should not be implemented. (C) Therefore, tsetse fly elimination should not be implemented.

The broader suite of costs encompassed in P2 might include adverse effects on food chains, nontarget organisms, and protected areas. A closely related critique might alternatively contend not that the costs of tsetse fly elimination outweigh the benefits, but that the ostensive benefits of tsetse fly elimination would not actually materialize. We briefly evaluate each of these possibilities next.

Adverse effects on food chains

One concern is the adverse impact of tsetse fly elimination on the food chain. Tsetse fly adults and pupae are predated by a variety of predators including vertebrates and arthropods (Rogers and Randolph 1990). These predator species could suffer from tsetse fly elimination at the local scale. However, no insectivorous species is currently known to solely feed on tsetse flies, and the reduction in insectivorous birds during tsetse fly control campaigns is more likely due to the simultaneous insecticide-related removal of other insect species, such as horseflies, than to the disappearance of tsetse flies themselves (De Garine-Wichatitsky et al. 2001). In addition, tsetse flies are purely hematophagous, and unlike, for example, horseflies, they are not involved in pollination (De Garine-Wichatitsky et al. 2001). Unquestionably, however, the significance of tsetse flies to local food chains should be carefully assessed in context before any elimination effort begins, because the potential for adverse effects may be specific to the group that is targeted. For example, food chain effects were found to be an important issue in mosquito elimination (Pace et al. 1999).

Adverse effects on nontarget organisms

Perhaps of greater concern is the impact of elimination techniques on nontarget organisms. Grant (2001) reviewed the environmental impacts of tsetse fly control operations and showed that the impacts have gradually declined over time, from deliberate destruction of host populations of wild mammals and tsetse fly habitat prior to the 1940s to severe wildlife mortality associated with the toxic effects of residual insecticides used in the 1950s and then to relatively minor effects on nontarget insect and arthropod populations through the use of nonresidual insecticide techniques (SAT, mainly based on endosulfan and pyrethroids) beginning in the 1970s (Adam et al. 2013). The reduction of environmental impacts associated with tsetse fly control culminated with the use of insecticide targets and traps that allow a specific delivery to tsetse flies but also affecting other biting flies, including Tabanidae and Stomoxyinae, and more generally to a variety of dipterans. SIT is specific (box 3) and has no impact on nontargeted species. It is classified as environment friendly. For SAT, the insecticide dosage is very low (box 3), and environmental monitoring showed that its impact on nontarget organisms was low and temporary. Inferences from these monitoring programs are limited, because most monitoring programs are short lived and not focused on the species level. As such, continuous monitoring in situ is recommended.

Figure 3. Animal shown is a cross-breed between a trypanotolerant breed (Ndama) and a meat breed (Gobra) in the Niayes area of Senegal. The removal of trypanosomosis allows a genetic improvement of local breeds associated to a three folds increase of animal sales (milk and meat) associated to a 45% reduction of cattle herd size. Photograph: Jean-Jacques Etienne.

ITT (box 3), on the other hand, is not specific and many other insect groups are attracted to the device. Furthermore, targets must be placed at regular intervals (4–30 per km^2), which generally requires building hundreds of kilometres of trails. Targets have an effect on habitat use by several species of large and medium-size wild mammals (De Garine-Wichatitsky et al. 2001), and the trails can give poachers access to national parks and game reserves. ITC (box 3) can affect cattle dung fauna (Vale et al. 2004), although reducing the insecticide treatment to tsetse fly feeding sites (leg extremities and belly) can reduce the amount of insecticide needed tenfold.

Although ITT and ITC are known to have adverse impacts on nontarget organisms, it is important to realize that both technologies are also used in integrated control by farmers (Bouyer et al. 2013). As such, negative impacts associated with these technologies are not limited to tsetse fly elimination programs and would also potentially result from alternative strategies of integrated pest control. In fact, if completed quickly, tsetse fly elimination may even have less impact on nontarget species than traditional continuous control programs do. Permanent control using traps, poisoned bait, or aerial spraying of broad spectrum insecticides has wide-ranging negative effects on biodiversity (Ogada 2014). For example, the increasing use of insecticides on farmland affects 80% of threatened butterfly species in Europe (van Swaay et al. 2006). Expeditious and effective elimination programs might preclude such detrimental effects. A mass-rearing facility in Guatemala, for instance, produced upward of 2000 million sterile medfly males per week to help maintain the containment barrier with a minimum of insecticide use. Had medfly not been contained, 640 tons of insecticide would have needed to be applied annually to farms in California alone (Siebert and Cooper 1995). The ongoing use of insecticides can also lead to chronic toxicity in humans (Cimino et al. 2017). Between integrated control and tsetse fly elimination, in some cases, the latter may more effectively limit adverse impacts on nontarget organisms.

Adverse effects on protected areas

Tsetse fly elimination might increase human and animal encroachment inside protected areas or their vicinity. For example, in Zimbabwe, tsetse fly elimination favoured the expansion of arable fields and subsequently reduced the presence of elephants (Murwira et al. 2010). Geographic range contraction of tsetse flies due to climate change might also allow cattle production to occur in areas in which it was not feasible before, potentially increasing the likelihood of negative interactions between herders and large carnivores, such as African lions (*Panthera leo*; Carter et al. 2018). On the other hand, tsetse flies can increase spatial competition between extensive cattle-raising systems and protected areas by rendering intensive cattle rearing systems impossible. Extensive cattle-raising systems can increase competition with wild fauna for land and are a major cause of land degradation and ecosystem disturbance through overgrazing (figure 3; Budde et al. 2004). In Burkina Faso, particularly in the peripheral areas of protected forests, such as the transboundary W Regional Park or around the Comoé-Léraba protected area, biodiversity has declined dramatically with the increase in human activities and extensive cattle breeding systems, despite the continuing presence of the tsetse fly at high densities. One study suggests that a tsetse fly elimination program in Senegal, coupled with use of improved trypano-sensitive cattle breeds, would, in fact, decrease herd sizes while increasing farmer revenue (Bouyer et al. 2014). Whether the tsetse fly is a guardian of wild fauna (Rogers and Randolph 1988) is therefore debatable and depends on both social and ecological conditions.

Table 1. A general rubric for evaluating the desirability of eliminating local populations of an endemic species.

Category	Questions	Answers for the tsetse fly
Socioeconomic effects of the species	Is the species negatively affecting human health?	Yes, tsetse flies are the vectors of human sleeping sickness, a neglected tropical disease affecting the poorest populations in Africa
	Is the species negatively affecting human livelihoods?	Yes, tsetse flies are also vectors of animal trypanosomosis, which is reducing the overall cattle productions by 30%, also hampering integrated farming and innovation in cattle breeding.
Political, economic, and technical feasibility of elimination	Is there a political will to eliminate the species?	Yes, PATTEC initiative launched in 2001 by African states and supported by the African Union.
	Is elimination of the species cost effective?	Yes, as has been demonstrated by several benefit–cost studies.
	Is it technically possible to eliminate the species?	Yes, elimination achieved in several countries and territories
	Is elimination a long-term solution?	Mostly no, although eliminating some isolated populations of certain species appears to be a long-term solution.
Ecological and environmental effects of elimination	Would elimination of the species lead to an empty niche?	No. Not observed in territories in which tsetse flies were eliminated more than 20 years ago.
	Would elimination of the species have negative effects on other species in the food chain?	No. On the basis of current knowledge, tsetse flies have no important roles in food chains and no specific predators. They are predating vertebrates for blood.
	Would the elimination process negatively affect nontarget species?	No. Current control techniques are very specific and only have transitory impacts on nontarget species. Expeditious tsetse fly elimination would reduce insecticide use that can be ecotoxic.
	Would elimination negatively affect nontarget species?	Possibly yes. Tsetse flies can influence the relationship between domestic and wild fauna as well as the density of cattle. Necessity for agroecological development plan in case of elimination to mitigate risks.

Note: This rubric is based on instrumental values or disvalues associated with local elimination and therefore does not incorporate the intrinsic value of the species. For each category, we present global questions that should be addressed to decide the desirability of elimination to serve as a guideline for decision-making and then summarize replies for the specific case of tsetse flies.

No benefits

A final concern pertinent to the elimination of tsetse flies, or any species, is that elimination will create an empty niche. The empty niche might then quickly be occupied by another species (Myers N 1993), which could cause even more damage than the original pest. In this scenario, the benefits of elimination would not be realized and so would certainly not outweigh the costs. However, this concern is likely not founded with regard to tsetse fly elimination. Tsetse fly are cyclical or biological vectors of African *Trypanosoma* species, including *Trypanosoma brucei* sl, *T. congolense* and *T. vivax*, whereby the parasites multiply within the insect body. In the absence of tsetse flies, Tabanidae and Stomoxinae could continue to transmit the parasites mechanically—that is, by acting as a flying syringe (Desquesnes et al. 2009). This outcome may seem likely for *Trypanosoma vivax* only, which is present worldwide even where tsetse flies are not and efficiently transmitted mechanically. *T. vivax* is the only example of a trypanosome species transmitted both biologically by tsetse flies and mechanically by other insects, and this species cannot contaminate human beings. Moreover, all trypanosomes, including *T. vivax*, disappeared from Zanzibar after tsetse flies were locally eliminated, so their mechanical transmission is not always sufficient to maintain them (Vreysen et al. 2014).

The commentary thus far has highlighted costs, benefits, and other impacts of local elimination programs and, on the basis of our analysis, it seems the instrumental values associated with local elimination generally outweigh the disvalues. However, as a general guideline, we recommend impacts (or lack thereof) should be assessed in context. To this end, we provide a rubric for evaluation (table 1). The rubric is intended to enable transparent decision-making and includes the socioeconomic effects of the species, the political, economic, and technical feasibility of elimination, and the ecological and environmental effects of elimination.

Do instrumental values support global eradication?

Before moving on to intrinsic value, it is critical to recognize that instrumental values (benefits) associated with tsetse flies must be accounted differently when we consider complete eradication of the species. Although individual tsetse flies and local populations provide no known benefits for humans, there is a unique and potentially significant form of instrumental value associated with the species as a whole, which would vanish were the species brought to extinction. We call these *unknown values*—that is, the not yet realized or not yet known value tsetse flies may have (Ibrahim et al. 2013). As we have learned about the far-reaching consequences of human-induced depletion of animal and plant species on ecosystem resilience and even human welfare (Seddon et al. 2014), our appreciation of *value* in the natural world has expanded beyond utility alone, to include the full range of services provided by ecosystems and biodiversity

(Costanza et al. 2017). Human values may continue to change over time, as we learn more about the natural world and our viewpoints correspondingly shift (Singer 2011). One could argue that the potential instrumental value of species positively outweighs any known costs associated with them, in which case their eradication would not be justified on utilitarian grounds (Myers N 1993). But even rejecting the strong claim that unknown benefits outweigh known costs, because unknown values are (by definition) unknown, so too are the magnitude and significance of the benefits they provide. Without knowing the magnitude or significance benefits tsetse flies may provide, it is impossible to weigh these benefits against other (known) benefits and costs. Therefore, in the context of species eradication, P3 is not necessarily true. As such, arguments predicated entirely on instrumental value do not provide compelling support for global tsetse fly eradication.

Beyond instrumental value

The argument outlined above can be considered sound within a singularly instrumentalist framework. That is, if the overarching objective of decision-making is to maximize net benefits relative to costs, as was summarized succinctly in P4 above, it appears elimination of local tsetse fly populations is supported. However, as was noted earlier, the conservation community writ large also acknowledges the intrinsic value of species (United Nations 1992, Trombulak et al. 2004). With this acknowledgement, an ethical premise such as P4, stating that an elimination program is justified entirely by the relative balance of benefits and costs that result, cannot be considered appropriate. As is explained next, once a species is attributed intrinsic value, it can no longer be treated merely as an instrumental means to (human) ends. This is not to suggest instrumental values are irrelevant. Although inherently ethical (Soulé 1985), species conservation and management are also conditioned by broader social, economic, and political contexts (Brechin et al. 2002), in which knowledge of instrumental value and disvalue is essential to informed decision-making. But if we are committed to the claim that species possess intrinsic value, ethical analysis cannot be reduced to a mere calculation of net benefits and costs for humans.

Intrinsic value

Intrinsic value is the value of an entity as an end in itself, beyond and regardless of any utility (or disutility) it may possess (Vucetich et al. 2015). Intrinsic value is a basic property of goodness in the world: When we acknowledge intrinsic value, we acknowledge its bearer as a good in itself and for its own sake (Batavia and Nelson 2017). Unlike instrumental value, intrinsic value is generally believed to imply that humans, as moral agents, have direct moral obligations toward its bearers (Rolston 1991). These obligations can generally be summarized as the obligation to respect or promote the good (e.g., Rolston 1991, Moore and Baldwin 1993, Davison 2012). In this sense, attributing species with intrinsic value suggests species ought to be protected and promoted, even if they actively combat human ends. In argument form, (P1) All species have intrinsic value. (P2) Entities with intrinsic value are worthy of protection and promotion. (P3) Tsetse flies are species. (C) Therefore, tsetse fly species are worthy of protection and promotion.

Needless to say, complete and intentional eradication of the species is not consistent with the obligation to protect and promote, so recognition of intrinsic value seems to provide compelling grounds against tsetse fly eradication. But are localized elimination measures also incommensurate with the intrinsic value of tsetse flies?

Elimination would be targeted at populations rather than at species as a whole, so it is reasonable to begin by asking whether tsetse fly populations also have intrinsic value. Conventional grounds for the intrinsic value of species include their evolution as unique and historically continuous corporate entities with an interest in continued existence and flourishing (Rolston 1991, Johnson 1993, Smith 2016). These conditions do not obviously obtain in the case of populations. On the other hand, Davison (2012) argues that it is ultimately arbitrary to attribute intrinsic value to some things in existence and deny the intrinsic value of others. Accepting this argument would suggest we are obligated to assume tsetse fly populations have intrinsic value, unless a sound case can be made to the contrary. It is beyond our scope in the present article to conclude that populations do or do not have intrinsic value. However, it seems reasonable to suggest they at least have constitutive value—that is, value to the extent that populations constitute intrinsically valuable tsetse fly species (see Kirschenmann 2001 for an accessible explanation). To recognize constitutive value would not imply direct moral obligations to tsetse fly populations, just as we would not generally acknowledge or uphold direct moral obligations to the individual cells constituting a human being. But it would also be inappropriate to wantonly harm constitutive elements of an intrinsically valuable entity; at a certain point, harming a person's cells would also harm the person's organs, appendages, and, eventually, her or his collective being. In a similar way, recognizing intrinsic value in tsetse fly species implies we should not gratuitously inflict harm against the species or its constitutive elements, such as populations.

But what qualifies as a nongratuitous harm? A categorical maxim condemning any harm against bearers of intrinsic value (or their constitutive elements) can lead to absurd and practically untenable conclusions. We must kill to eat and eat to live, after all, and it seems unreasonable that we would be morally impugned by our basic biological needs. Some philosophers have proposed contingency clauses whereby, given genuine trade-offs between multiple intrinsically valuable entities, necessary harms can be incurred to protect higher interests or promote the overall good (e.g., VanDeVeer 1995, Sterba 1998). This may be a useful framework for the case at hand. We suggest localized elimination represents a defensible compromise as long as harm to tsetse flies is minimized and enacted with due restraint. Elimination techniques diligently, cautiously, and selectively applied to target populations that actively compromise human communities appropriately recognize and promote the intrinsic value of human beings and human welfare but also attend to the intrinsic value of tsetse fly species by granting them due consideration and subsequently exercising moderation in enacting harm against their constitutive populations.

Conclusions

African governments have launched PATTEC with the support of the African Union to eradicate continent-wide what has been called the "fly of death." Given the ethical considerations discussed in the present article, we suggest there is a good case to be made against the global eradication of tsetse fly species. However, we also suggest it is ethically defensible to eliminate the isolated populations that are main vectors of disease for humans and their domestic animals. Eliminating populations of tsetse fly will minimally harm the species but greatly benefit human and animal health and welfare and will improve the socioeconomic development and food security of the countries concerned. We recommend that elimination programs can and should use techniques that have the lowest impact ecologically and on the species. These impacts should be carefully monitored and elimination programs regularly and comprehensively reevaluated. The rubric provided in table 1 provides a starting point for conducting comprehensive evaluations. Human values toward tsetse fly and the species they affect will almost certainly change in the future, so ethical analysis should also be included in regular reevaluations.

Above, we discussed instrumental and intrinsic values separately, without offering any commentary about how to handle both in decision-making contexts. This is a challenging task. Instrumental values (or disvalues) are obvious and often quantifiable, and therefore conducive to comparison and trade-offs (Maguire and Justus 2008). Intrinsic value, on the other hand, is a concept we struggle even to identify or understand, let alone operationalize (Batavia and Nelson 2017). For instance, although the CBD has codified intrinsic value, highlighting it preeminently in the very first words of the text (*https://www.cbd.int/convention/text/*), the convention also provides criteria in annex I for prioritizing components of biological diversity important for conservation and sustainable use (Hochkirch et al. 2017). Generally, these criteria favor instrumental values, such as "medicinal, agricultural, or other economic value," leading us to question what intrinsic value means (or why it matters) from a policy perspective, if instrumental values take priority in practical decision-making contexts.

We suggest that it is important to consider intrinsic value as a separate type of value rather than attempting to weigh or adjudicate intrinsic against instrumental values. Incorporating intrinsic value into decision contexts will less resemble a calculation than an overarching frame of reference, which shapes how other values are accounted and other factors weighed (Batavia and Nelson 2017). This approach to decision-making may not be as concrete or quantitatively justifiable as a structured exercise such as cost–benefit analysis but is arguably just as important if not more so to practical ethics. To create space for intrinsic value, we suggest ethical inquiry in issues of conservation should not be undertaken with a singular or even primary objective to arrive at one verifiably "right" solution. We counsel that decision-makers should instead adopt a more basic normative orientation toward wise conduct, an aspiration that might otherwise be characterized as a commitment to virtue (Heller and Hobbs 2014). In this light, we suggest the increasingly common cases in which we are tasked to juggle a plurality of instrumental and intrinsic values are best addressed through rational ethical discourse, as was demonstrated above, but also guided by virtues such as restraint, humility, prudence, and benevolence. It is with these virtues in mind that we suggest localized elimination of tsetse fly populations is morally justified to the extent that it enhances human flourishing without compromising or unnecessarily harming the tsetse fly species.

Acknowledgments

We are grateful to the handling editor, three anonymous reviewers, Laurence Dedieu, and Philippe Solano for their helpful comments on the article. This project received funding from the European Research Council under the European Union's Horizon 2020 research and innovation program (grant agreement no. 682387—REVOLINC), Boise State University (National Science Foundation [NSF] award no. IIA-1301792 from the NSF Idaho EPSCoR Program and the NSF) and the NSF Long Term Ecological Research Program at the H.J. Andrews Experimental Forest (grant no. DEB-1440409). This article reflects only the authors' views and the agency is not responsible for any use that may be made of the information it contains.

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