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Tsetse fly control in Kenya's spatially and temporally dynamic control reservoirs: A cost analysis

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A B S T R A C T

Human African trypanosomiasis (HAT) and animal African trypanosomiasis (AAT) are significant health concerns throughout much of sub-Saharan Africa. Funding for tsetse fly control operations has decreased since the 1970s, which has in turn limited the success of campaigns to control the disease vector. To maximize the effectiveness of the limited financial resources available for tsetse control, this study develops and analyzes spatially and temporally dynamic tsetse distribution maps of *Glossina* subgenus *Morsitans* populations in Kenya from January 2002 to December 2010, produced using the Tsetse Ecological Distribution Model. These species distribution maps reveal seasonal variations in fly distributions. Such variations allow for the identification of "control reservoirs" where fly distributions are spatially constrained by fluctuations in suitable habitat and tsetse population characteristics. Following identification of the control reservoirs, a tsetse management operation is simulated in the control reservoirs using capital and labor control inputs from previous studies. Finally, a cost analysis, following specific economic guidelines from existing tsetse control analyses, is conducted to calculate the total cost of a nationwide control campaign of the reservoirs compared to the cost of a nationwide campaign conducted at the maximum spatial extent of the fly distributions from January 2002 to December 2010. The total cost of tsetse management within the reservoirs sums to $14,212,647, while the nationwide campaign at the maximum spatial extent amounts to $33,721,516. This savings of $19,508,869 represents the importance of identifying seasonally dynamic control reservoirs when conducting a tsetse management campaign, and, in the process, offers an economical means of fly control and disease management for future program planning.

Introduction

Tsetse flies, the primary vector of African trypanosomiasis, infest the physical landscape in thirty-seven sub-Saharan African countries, an area of 8.5 million km^2 (Allsopp, 2001). They persist throughout the continent, posing a threat to physical and economic well-being despite existing knowledge and techniques capable of controlling and reducing fly populations (Molyneux, Ndung'u, & Maudlin, 2010). Significantly hindering efforts against the vector have been the costs of control and limited financial resources in tsetse-endemic areas (Kamuanga, 2003). In an effort to overcome this obstacle, this study presents a tsetse fly management simulation that accounts for the spatio-temporal dynamics of fly distributions. We then demonstrate the value of such a management campaign by conducting a costing analysis, which reveals a large savings when these dynamics are considered.

Active vector control has been waged against the tsetse fly since the beginning of the twentieth century when it most often took the form of removing the fly's preferred habitat (Jordan, 1986). Since then, fly control has ranged from aerial and ground spraying of DDT to more recent attempts to engage local communities by using point-source control techniques, such as traps and targets (Allsopp, 2001; Catley & Leyland, 2001). However, despite the active use of control techniques throughout the past century, sub-Saharan Africa continues to suffer under heavy disease and economic burdens from trypanosomiases (Fevre, von Wissmann, Welburn, & Lutumba, 2008; Grady, Messina, & McCord, 2011; Swallow, 2000; WHO, 2010).

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Torr, Hargrove, and Vale (2005) stated, “In the mid-1980s, the days of tsetse seemed numbered.” This view was the result of successful management of large-scale control campaigns, development of more cost-effective technologies and baits, and proper attention, largely sparked by environmental concerns over insecticides, given to the field of vector control (Allsopp & Hursey, 2004; Torr et al., 2005). However, due to a shift in spending that began in the 1970s and gained momentum in the 1990s with the rise of community participation, funding for large operations dropped (Hargrove, 2000, 2003a), and the optimism that may have existed in the 1980s has largely vanished. It is against this backdrop of preference for localized control operations and limited financial resources that we conduct our study.

Past costing and control simulations have paid insufficient attention to the spatial and temporal dynamics of tsetse populations. Simulations have been conducted by placing tsetse in large and often isolated “control blocks” where control methods were applied indiscriminately within the block (e.g., Shaw, Torr, Waiswa, & Robinson, 2007; Vale & Torr, 2005). Such studies have represented fly distributions as spatially and temporally static, and in the process have missed an opportunity for reductions to control costs and improvements in control outcomes. It is therefore the goal of this study to conduct a control simulation that explicitly accounts for the spatial and temporal dynamics of fly distributions. We additionally carry out a costing exercise of fly management to demonstrate the value of accounting for these dynamics.

Management of fly distributions consists of field control operations as well as surveying, monitoring, and administration tasks. It encompasses all facets of a wide-scale campaign against the tsetse fly. We use the Tsetse Ecological Distribution (TED) Model (DeVisser, Messina, Moore, Lusch, & Maitima, 2010) to identify the timing and location of spatially constrained fly populations in Kenya from 1 January 2002 to 19 December 2010. By controlling in the identified constrained areas, fewer labor and capital resources are required for vector control, leading to a more efficient use of the limited financial and human resources.

Trypanosomiasis, tsetse fly in Kenya

African trypanosomiasis, a neglected tropical disease endemic in sub-Saharan Africa, affects both humans and animals. In humans the disease is referred to as human African trypanosomiasis (HAT) or sleeping sickness, while in cattle the disease is known as animal African trypanosomiasis (AAT) or nagana. Single-celled protozoa parasites of the *Trypanosoma* genus act as the causative agent in both humans and animals (WHO, 2010). In 2009, the number of reported cases of sleeping sickness dropped below 10,000 (WHO, 2010); however, as Cattand, Jannin, and Lucas (2001) discussed, the actual number of infected individuals is underreported, and misdiagnosis is common in low endemic areas (Katsidzira & Fana, 2010). If left untreated, the disease is fatal (Simarro, Jannin, & Cattand, 2008).

The threat of nagana has been listed as the foremost issue concerning livestock development (Spedding, 1981). It is estimated that at least 46 million cattle are at risk of AAT with countless sheep, goats, donkeys, and horses additionally threatened with infection (Budd, 1999; Kristjanson, Swallow, Rowlands, Kruska, & de Leeuw, 1999). Sickened livestock exact a heavy economic loss on agricultural production in tsetse-infested areas, with the rural poor bearing a disproportionately larger share of the economic burden due to their reliance on livestock as a form of savings and income (Feldmann, Dyck, Mattioli, & Jannin, 2005). Direct and indirect impacts of trypanosomiasis on livestock include increased calf mortality rates, decreased calving rates, decreased milk and meat yields, and the disease’s effect on the use of animal traction (Shaw, 2004). All told, trypanosomiasis reduces livestock productivity by 20–40 percent (Hursey, 2001; Swallow, 2000), which results in $4.5 billion lost to the disease each year (Budd, 1999; Oluwafemi, 2009). The health and economic implications of trypanosomiasis thus make the tsetse fly a critical socioeconomic threat to sub-Saharan Africa.

Tsetse are biting flies from the genus *Glossina*. The fly feeds on wild ungulates and ruminants, which play important roles as reservoirs of trypanosomes (Jordan, 1986; Pollock, 1982a). Tsetse are classified as one of the few k-strategist insects meaning that they have low fecundity rates, are relatively long-lived compared to other insects, and their offspring have a higher degree of survival (Leak, 1999). It is due to their stable populations and low reproduction rates that even with low sustained mortality induced through fly control techniques, elimination of isolated tsetse populations is possible (Hargrove, 2003a; Hargrove & Vale, 1979; Weidhaas & Haile, 1978). Elimination has been defined as the complete removal of a tsetse species from a geographic area (Molyneux, Hopkins, & Zagaria, 2004). However, due to the difficulties in measuring complete removal, we define elimination as a fly density of 0.5 flies per km^2 or less, a density in which difficulties will arise in finding mates (Shaw et al., 2007). The target control method, which we employ in our analysis and describe in detail below, relies on these biological traits to eliminate fly populations through low daily mortalities (i.e., removal of 8 percent of a fly population each day).

In Kenya, eight species of tsetse are present in distributions described by Bourn, Reid, Rogers, Snow, and Wint (2001) as “relatively isolated” due to expanding agriculture and deforestation. It was estimated that 34 percent of Kenya was infested with the fly in 1996 (202,774 km^2) (KETRI, 2008), up from the estimated 22 percent infestation of 1973 (Ford & Katondo, 1977). The fly population in Kenya, as is the case with all tsetse distributions, relies on the presence of ecologically suitable habitat, including climate and land cover types (Pollock, 1982b). Populations concentrate in cooler, moister habitat in the dry season in order to mitigate the effects of high temperatures and/or dry conditions (Pollock, 1982b). The *Morsitans* group, which is the most widely dispersed subgenus in Kenya, seeks woody vegetation as temperatures rise above 32 °C (Pilson & Pilson, 1967). These micro-habitats provide moisture levels and temperatures that are roughly 4.5°C cooler, which support their survival (Muzari & Hargrove, 2005; Torr & Hargrove, 1999). Tsetse spatial distributions in Kenya display temporal patterns that correspond with changing seasons, and thus, the fluctuations in suitable habitat: in general terms, contraction during the hot dry season of January and February, expansion during the long rains of March through the end of May, prolonged contraction during the cool dry season from June to the end of October, and expansion once again during the short rains of November and December (Awange et al., 2008; Camberlin & Wairoto, 1997; DeVisser et al., 2010).

Costing tsetse control

Concern regarding the cost of tsetse control has existed since the very earliest campaigns. In 1909, an estate manager on the Island of Principe determined it to be cost-effective to control the fly population by ordering laborers to wear black cloths on their backs with a glutinous substance coating the cloth’s surface (Maldonado, 1910). Glasgow and Duffy (1947) concluded that, at the time, hand catching was the most economical means of eradicating the fly population, while DDT ground spraying was found to be the most economical with its introduction in the late 1940s and early 1950s (Wilson, 1953). Davies (1964) examined the savings and effectiveness of spraying only *Glossina tachinoides* and *Glossina morsitans submorsitans* habitat