BRIEF COMMUNICATIONS

Lion attacks on humans in Tanzania

Understanding the timing and distribution of attacks on rural communities will help to prevent them.

Large carnivores inspire opposition to conservation efforts[1,2] owing to their impact on livestock[3–5] and human safety[6,7]. Here we analyse the pattern of lion attacks over the past 15 years on humans in Tanzania, which has the largest population of lions in Africa[8,9], and find that they have killed more than 563 Tanzanians since 1990 and injured at least 308. Attacks have increased dramatically during this time: they peak at harvest time each year and are most frequent in areas with few prey apart from bush pigs (*Potamochoerus larvatus*), the most common nocturnal crop pest. Our findings provide an important starting point for devising strategies to reduce the risk to rural Tanzanians of lion attacks.

Figure 1a shows the reported number of attacks on people across Tanzania from January 1990 to September 2004 (for details of data collection, see supplementary information). More than 45% of all reported cases occurred in just six coastal districts in the southern half of the country, the area with the worst reputation for man-eating lions[10,11].

The total number of cases has increased strikingly since 1990 (Fig. 1b), probably because Tanzania's human population has risen from 23.1 million in 1988 to 34.6 million in 2002, with an associated loss of lion prey outside the protected areas[12]. Nearly 39% of human attacks occur in the harvest season during March–May ($n = 733$ of known date, $\chi^2 = 100.4$, $P < 0.001$). More than 18% of 538 victims of known age were younger than 10 years old; 69% of older victims were men, presumably because men are more likely to tend cattle, forage for bush-meat, walk alone at night and retaliate against man-eaters and cattle-killers with nets and spears, although women are also attacked in their homes and in fields (Fig. 1c). Lions pull people out of bed, attack nursing mothers, and catch children playing outside. Most rural houses have thatched roofs and many have thatched walls, so lions can force their way inside, and toilets are outside.

More than 27% of attacks occur in the fields (Fig. 1c), usually when people are sleeping in makeshift huts while protecting their crops from bush pigs (Fig. 2). Several interviewees specifically mentioned that lions entered their villages or fields in pursuit of bush pigs, and even reported tolerating lions because they helped to control bush-pig numbers.

Lions have been eradicated from many parts of the country, so our analysis is restricted to districts with at least one attack in the past 15 years. Attacks are most common in districts with the lowest abundance of natural prey (as estimated by the proportion of interviewees reporting kudu, zebra, hartebeest, dik-dik or impala; spatial covariance model: $P = 0.0162$, $n = 17$) and with the largest numbers of bush

Figure 2 | Makeshift hut in Rufiji district. Farmers typically sleep alone in these structures to protect their crops from nocturnal bush pigs during the harvest season, when the risk of attack by lions is highest. Lions force their way inside to pull out their victims.

pigs (spatial covariance model: $P = 0.0150$, $n = 17$). Multiple regression analysis reveals that nearly half the variance in attacks per district can be explained by these two factors (adjusted $r^2 = 0.45$, $P = 0.0059$, $n = 17$); there was no additional effect of human population density, cattle density, percentage of land cover devoted to agriculture, or proximity to a protected area.

Our analysis reveals a conspicuous outlier: Kilosa District had fewer lion attacks than expected from prey scarcity and bush-pig abundance. However, Kilosa had suffered high numbers of lion attacks until people were relocated by the Tanzanian government in 1992. If Kilosa is removed from the analysis, prey scarcity and bush-pig abundance account for 76% of the variance in lion attacks per district ($P < 0.0001$, $n = 16$).

Rising human populations mean that the option of relocating people to reduce the number of lion attacks is no longer feasible. It would also be impractical to increase natural prey populations in agricultural areas. As bush pigs are the most likely maintenance diet of lions in highly disturbed agricultural areas, controlling their numbers might be the best strategy to decrease the lions' attraction to populated areas and would reduce the need for village farmers to sleep in their fields (Fig. 2).

Human population growth has led to encroachment into wildlife areas and depletion of natural prey. However, conservation attempts to sustain viable populations of African lions place the lives and livelihoods of rural people at risk in one of the poorest
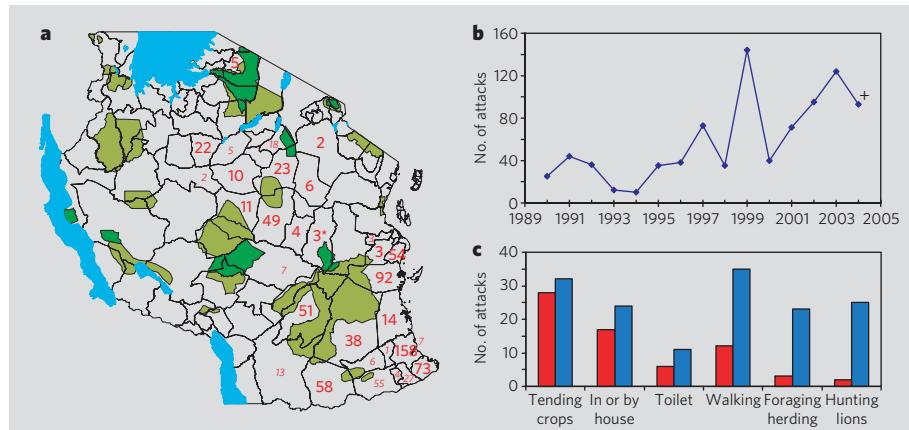

Figure 1 | Analysis of the number of lion attacks on humans. a, Map of Tanzania showing the distribution of 815 lion attacks reported between January 1990 and September 2004. Bold numbers relate to districts where data were evaluated during field surveys; italic numbers derive from incomplete reports to the Wildlife Division in Dar es Salaam. Dark green areas are National Parks; light green areas are Game Reserves. Asterisk marks Kilosa District. **b,** Number of attacks each year. The upward trend is significant ($P = 0.0030$), although data for 2004 are only complete to September. **c,** Principal contexts of attack on females (red) and males (blue), based on 218 attacks for which the context and victim's sex were known.

countries in the world. Mitigation of this fundamental conflict[3,13] must be a priority for any lion conservation strategy in Africa.

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BROWNIAN MOTION

Absolute negative particle mobility

Noise effects in technological applications, far from being a nuisance, can be exploited with advantage — for example, unavoidable thermal fluctuations have found application in the transport and sorting of colloidal particles[1–3] and biomolecules[4–6]. Here we use a microfluidic system to demonstrate a paradoxical migration mechanism in which particles always move in a direction opposite to the net acting force ('absolute negative mobility') as a result of an interplay between thermal noise, a periodic and symmetric microstructure, and a biased alternating-current electric field. This counterintuitive phenomenon could be used for bioanalytical purposes, for example in the separation and fractionation of colloids, biological molecules and cells.

Newton's second law would seem to exclude absolute negative mobility as a response by a system at rest to a static force. However, such paradoxical behaviour has been experimentally observed in semiconductor devices[7] and theoretically predicted in simplified stochastic model systems[8,9]. Nonlinear dynamics are necessary to reconcile absolute negative mobility with Newton's law, and the system needs to operate far from equilibrium to avoid conflict with the second law of thermodynamics.

To provide a proof-of-principle for absolute negative mobility in a lab-on-a-chip, we designed a simple microfluidic device consisting of periodically arranged posts with alternating small and large gaps (Fig. 1; for methods, see supplementary information). The device is filled with negatively charged beads in an aqueous buffer. Electric fields are generated by applying a voltage along the x-axis, so that a positive voltage generates a positive force on the beads along the x-axis. Applying an alternating voltage, $U_{AC}(t)$, that switches periodically between $\pm U_0$, there is no net motion of the beads for symmetry reasons. This set-up represents our unperturbed non-equilibrium system at rest. But what will be the average migration velocity v in the x direction in response to a static perturbation voltage, U_{DC}, superimposed on $U_{AC}(t)$?

To answer this question, we computed the electric field in the microstructure and, including thermal-noise effects, simulated the bead motion by stochastic differential equa-
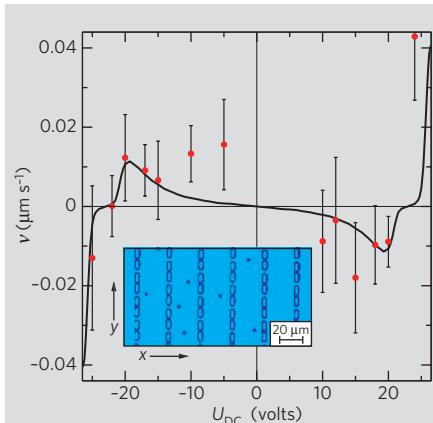

Figure 1 | Absolute negative mobility of polystyrene beads. Movement of 2-μm polystyrene beads in response to a static voltage, U_{DC}, superimposed to an alternating-current voltage that switches between ± 30 V every 25 s. Red dots: experimentally measured velocities, averaged over 40 beads and 200 s. Error bars are of statistical origin, but variabilities in the beads and microstructures also contribute. The line shows the theoretical response characteristics obtained from numerical simulations. Inset: partial view (optical micrograph image) of the poly(dimethylsiloxane) microstructure showing the rectangular posts and migrating beads (dark dots). In both the x and y directions, the gaps between the posts are alternately smaller and larger than the bead diameter. For movie, see supplementary information.

tions, adapted quantitatively to the microstructure geometry and the experimentally determined free diffusion and mobility of the microbeads (see supplementary information). The key feature of the resulting response curve (Fig. 1) is the negative slope that is symmetrical around the origin — a distinct and unambiguous signature of absolute negative mobility. We also measured the average bead velocity by tracking the beads using real-time video microscopy for different values of U_{DC} (see supplementary information) and found that the measured experimental response was in good agreement with theory (Fig. 1).

To explain how absolute negative mobility occurs, we consider the small gaps in the microstructure as 'traps' — electrical field lines can pass through them but the beads cannot. For $0 < U_{DC} < U_0$, the alternating total voltages $\pm U_0 + U_{DC}$ yield a back-and-forth motion of the beads along the x direction. Whenever a bead succeeds in passing through a large gap, it is trapped by the adjacent small gap in the x direction (Fig. 1, inset), unless it thermally diffuses sufficiently far in the y direction to proceed through another large gap. The smaller the voltage, the more time it has to do so and the farther it gets before being trapped. As $|+U_0 + U_{DC}| > |-U_0 + U_{DC}|$, the bead becomes trapped after moving forwards a short distance when $+U_0 + U_{DC} > 0$, whereas it travels backwards for a longer distance when $-U_0 + U_{DC} < 0$, resulting in absolute negative mobility.

We find that this response by a particle is very sensitive to particle size, even to the extent of allowing particles of different sizes to be steered in opposite directions (our unpublished results). Absolute negative mobility therefore holds promise for bioanalytical applications, for example in the sorting of cells, organelles and biochemical compounds.

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