Towards a theoretically informed policy against a rakghoul plague outbreak

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Summary

A long time ago in a galaxy far, far away, the Sith Lord Karness Muur engineered the rakghoul plague, a disease that transformed infected humans into near-mindless predatory rakghouls. At its peak, the disease infected millions of individuals, giving rise to armies of rakghouls on a number of planets. Whether rakghoul populations have persisted until this day is not known, making a rakghoul invasion on Earth not completely improbable. Further, a strategy for defense against an outbreak of the disease on Earth has not yet been proposed. To fill this glaring gap, we developed the first mathematical model of the population dynamics of humans and rakghouls during a rakghoul plague outbreak. Using New South Wales as a model site, we then obtained ensembles of model predictions for the outcome of the rakghoul plague in two different disease control strategy scenarios (population evacuation and military intervention), and in the absence thereof. Finally, based on these predictions, we propose a set of policy guidelines for successfully controlling and eliminating outbreaks of the rakghoul plague in Australian states.

Mathematical model of the population dynamics of humans and rakghouls

To simulate the population dynamics of humans and rakghouls, we developed a model based on the Lotka–Volterra system of ordinary differential equations11 (we refer the curious reader to the online Appendix for full details of the model and its parameters). The model tracks changes in human and rakghoul populations and accounts for their complex interactions. If a human encounters a rakghoul, one of two outcomes is overwhelmingly likely: either the human is killed, or is scratched or bitten (very few individuals have been reported to have escaped an encounter with a rakghoul15,16). In the latter case, the human is then infected with the rakghoul plague and is transformed into a rakghoul within a negligible amount of time; as a result, the human population size is reduced. Rakghoul populations benefit from both killing and infecting humans, but whenever there are few humans around, they become cannibalistic, thus reducing their own population size.

We simulated a hypothetical rakghoul invasion in New South Wales, Australia. The growth rate of the human population (difference between birth and death rates) and the initial population size for humans were based on official 2016 statistics for New South Wales, Australia. The growth rate of the rakghoul population was determined by simulations of our model. The resulting predictions, we propose a set of policy guidelines for successfully controlling and eliminating outbreaks of the rakghoul plague in Australian states.
and insights from only approximately analogous systems (e.g., elks and wolves; see online Appendix) to parameterise our mathematical model.

Examples of the different types of resulting dynamics are depicted in Box 1. The most influential parameter of the model appears to be the time taken by a rakghoul to consume killed prey. The strong correlation in the times to extinction of humans and rakghouls is noteworthy, suggesting that taking advantage of the cannibalistic tendencies of rakghouls alone could potentially be a sufficient strategy for combating the plague.

A variant of the model in which humans are evacuated
We also investigated the feasibility of evacuating the human population as a disease control strategy. To evaluate this option, it is key to obtain estimates of the time required for rakghouls to be driven to extinction through cannibalism in the absence of their primary prey. The analysis of the population trajectories revealed a very weak positive correlation between the initial rakghoul population size and the time until cannibalism-mediated extinction (Box 2 and online Appendix), meaning that cannibalism poses a large threat to rakghoul survival. Extinction times varied from a few hours to more than 2.5 days; a human evacuation strategy for eliminating the disease therefore seems very promising.

Extending the original model to include military action
An alternative strategy for disease control and elimination involves the active extermination of disease hosts by military intervention in the form of armed melee combat, further containing rakghoul population growth. We assumed that when a soldier first detects a rakghoul, the latter will always be killed without inflicting any injury on the soldier. Estimates of parameters for the military intervention (such as the proportion of the population of soldiers in the human population, which was assumed to be constant) were based on the number of Australian Defence Force employees in the state of New South Wales.14 To make sense of the numerical solutions of this model, especially in light of the large number of parameters, we resorted to machine learning and, more precisely, to the construction of a decision tree (see online Appendix for details). The final topology of the tree is shown in Box 3, panel A. The tree broadly suggests that the extinction of the local human population can be averted with the aid of the military if rakghouls take more than 32.4 minutes to consume killed prey, or if the military responds within 21.2 hours of the rakghoul invasion. Panel B shows that the tree almost always predicts the true outcome, and is therefore very reliable.

Crisis evaluation and proposed guidelines
The theoretical investigation in the previous sections suggests that an outbreak of the rakghoul plague will undoubtedly induce crisis conditions, disrupting the orderly functioning of the local community with its cataclysmic rate of progression. As there is no clinically approved antidote that reverses the rakghoul transformation, we consider infected individuals to be de facto removed from the human population. In the absence of any
intervention, the entire local human population will be driven to extinction within hours or a few days at most, so the situation fulfils the criterion for classification as a “major catastrophe” (ie, a minimum of five deaths per 10 000 adults per day).\(^{15}\)

It is therefore essential to devise a detailed plan for defending against an outbreak of the rakghoul plague. Based on the outcomes of the three versions of our model, we propose the following guidelines.

Before the outbreak

To lay the foundations of an efficient and successful response to the rakghoul plague, it is essential that citizens are encouraged to familiarise themselves with the potential threat of a rakghoul invasion. In order to swiftly detect cases of the plague, platforms should be established on which citizens can report rakghoul sightings for further investigation by local authorities.\(^{15}\) Examples of such platforms include websites, Twitter accounts, and a four-digit telephone number via which the public can submit information about rakghoul sightings, together with photos or other media content, if supported by the platform. During an outbreak, operators of these platforms would be encouraged to provide information on the status of the invasion, actions being taken, and official advice. The operation of these platforms would be the responsibility of the state, which should allocate public funding and staff for receiving and responding to user input at any time of day or year.

To ensure optimal combat readiness, soldiers should be aware of the characteristics of the rakghoul plague and be trained in melee combat. The current small arms equipment of the Australian Defence Force, such as the enhanced F88 Austeyr rifle,\(^{16}\) is considered adequate for such operations; no further investment in weaponry is required.

For a successful evacuation strategy to be implemented, it is imperative that numerous high security shelters be constructed. Ideally, these would be subterranean and guarded by armed police during an outbreak, both to limit rakghoul access and to provide safety during any bombardment event undertaken as a desperate means for eradicating remaining rakghouls. Further, the shelters should be able to accommodate the entire population of the state (nearly 8 million people in New South Wales), and should be stocked with non-perishable food and water supplies sufficient for a minimum of 5 days. Finally, emergency communication channels should be established between the shelters and the authorities of neighbouring states to facilitate the exchange of information on the status of the outbreak and decisions that need to be made.

During the outbreak

The proposed algorithm for operation during the outbreak is summarised in Box 4. After confirmation of a rakghoul sighting, it is crucial that the entire local defence force takes immediate action to eliminate the threat; to maximise the probability of success, this must be initiated within 21 hours of the rakghoul invasion. While the military intervention is in progress, citizens should be gradually evacuated to nearby shelters, in compliance with the directives of police and health care professionals, who will ensure that shelters are free from individuals infected with the rakghoul plague. During their time of stay in the shelters, citizens should abide by the orders of public servants, whose duties would include the distribution of food and water rations.

The military operation would be considered successful if the rakghoul population is driven to extinction. Following this, careful examination of each shelter should ensure that the disease had not managed to infiltrate any of them. In such an unfortunate scenario,
The effectiveness of a rakghoul invasion would probably be greatly enhanced if they acquired the ability to infect non-human organisms on Earth, either through evolution or the inspired contribution of a Sith Lord or Lady. Accordingly, the model could be extended to predict the potential consequences of such a change in circumstances.

Further, our current analyses assume a single founder event, consistent with a chance encounter of a small invading population of rakghouls with planet Earth. However, rakghouls may invade relatively nearby inhabited planets that could act as sources of further invasion events. To account for this, as well as to model the spatial interplanetary and intergalactic dynamics of the rakghoul plague, the theoretical model could be extended to include multiple rakghoul metapopulations.19,20

The assumption that human and rakghoul individuals on Earth are evenly distributed in space should also be examined, as heterogeneity in the distribution of either could have important implications for transmission dynamics. The model could thus be extended to account for spatial heterogeneity on Earth.21,22

Finally, a rakghoul outbreak would severely affect the distribution of people in affected areas, as they would all be relocated to underground shelters. The clustering of numerous individuals in small confined spaces would have important implications for any other ongoing epidemic, such as gastroenteritis or lung infections. A sudden increase in population density in a small area could also lead to the emergence of latent anxiety disorders, such as agoraphobia and panic disorder.15,25

Further work should investigate the consequences of population confinement and possible approaches to alleviating these effects.

**Conclusions**

The looming threat of an outbreak of the rakghoul plague on Earth has been passed over in silence in the literature. To rectify this, we focused our analyses on understanding the potential impacts of the plague on the state of New South Wales. Through mathematical modelling, we showed that the extinction of the local human population can be prevented by a combined strategy of human evacuation and swift military intervention. Further, the predictions of our mathematical model can inform guidelines for a successful defence against the rakghoul plague. It is our hope that future studies will build on and expand on our work, so that a thorough understanding of the rakghoul plague can be attained, fuelling the development of effective strategies for controlling and minimising its spread.

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4 Proposed algorithm for successfully responding to a rakghoul plague outbreak, based on the predictions of the three variants of the mathematical model

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**Future work**

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