The Mesopredator Release Effect

Taylor Rhoads
Nonlinear Dynamics
Math 383

Spring 2017

Abstract

In modeling the delicate balance between a superpredator (feral cats), mesopredator (rats), and a prey species (birds), the prey species often reaches extinction when no external control factors are applied to control the superpredator and/or mesopredator populations. In the original paper by Courchamp, Langlais, and Sugihara, without external controls, the bird population must have a large enough growth rate to withstand the effects of the two predators. Then, when eradication controls are placed on the predators one determines the following: when the superpredator control is above a certain level, the superpredator disappears, but if the mesopredator control is not above a certain level also, this results in the disappearance of the prey; if the superpredator control is within some specified region, the prey does not disappear as long as the mesopredator control is high enough. Thus, while controlling both predators is important in maintaining the population of the prey, there is a certain balance needed between the two since the superpredator is important in keeping the mesopredator population down.

Introduction

In many island ecosystems, the introduction of foreign vertebrate species has proved to have a negative impact on many of the endemic species. On island ecosystems specifically, 93% of 176 species of birds have gone extinction. While it may be hard to say what proportion of these have been directly caused by the alien species, there is no doubt that they have affected the situation. Now, numerous endemic species on these islands are endangered and alien species may be the cause.

Amongst the species interactions on island ecosystems, feral cats have proved to be a large threat to some of the endemic bird species on the islands. On over 65 island groups, feral cats have caused bird population decreases or even extinctions. Then, why not just attempt to eradicate the cat populations to save the bird populations? Well, there is more at play than cats preying on birds. The population of rats on these islands actually has an interesting relationship with these populations. It is strongly believed that if mammal species are available to prey on, cats will choose to prey on the mammals (such as rats) over the bird species. Thus, the feral cats keep the population of rats down on the islands. Hence, removal of the cats from the islands may cause the population of rats to skyrocket. Furthermore, the rats also pose a threat to the birds through direct predation, competition for habitats, or competition for food. If the cat population were to be removed or at least decreased, it would allow for the population of rats to increase which could then prey even more on the birds. While the cats pose a threat to the birds, it is possible that the potential population growth of the cats could have an even worse effect on the bird population.

As an alternative, one could try to eradicate some of the rat population to reduce their negative effects on the bird population. However, the rats provide a significant food source for the feral cats, so their removal may cause the cats to prey even more on the birds. Without a lot of field evidence supporting either of these potential solutions, it is difficult to know which, if either, could prevent the bird populations from reaching extinction. Or perhaps a critical point has been reached where the bird populations will die away no matter what is done.

In this interaction, the feral cat is known as a *superpredator*, preying on both the rats and the birds. The rats are a *mesopredator* where they are both a predator and a prey species. Finally, the bird population is the *prey*. The process of eradicating the cats thus resulting in significant growth of the rat population is known as *mesopredator release*. Courchamp, Langlais, and Sugihara have created a model to represent the interaction between these species that can be modified to predict the outcome of potential solutions to save the bird species. One can attempt to find the necessary balance to prevent the negative outcome.

Original Model without Control

In general, the original model describes the interaction between a superpredator (cats), a mesopredator (rats), and a prey species (birds). In developing the model, they first looked at pairwise interactions between each pair of the three species, and then combined these models into a total model for the three species. The pairwise models began as a logistic growth model and then appropriate interaction term was added

For example, the pairwise interaction model between the prey (B) and the superpredator (S) is given by

$$\frac{dB}{dt} = r_b B\left(1 - \frac{B}{K_b}\right) - \mu_b C \tag{1}$$

$$\frac{dC}{dt} = r_c C\left(1 - \frac{\mu_b C}{B}\right) \tag{2}$$

where r_b and r_c are the natural growth rates for the relative populations, K_b is the carrying capacity of the birds population, S is a fixed quantity of non-avian food, η_b is the predation rate of the mesopredator on the prey, and μ_b is the predation rate of the superpredator on the prey. The following variables are used in the models:

Table 1: Parameters used in the Original Model

Variable	Representation
Populations	C, R, B
Intrinsic Growth Rates	r_c, r_r, r_c
Predation Rates of Superpredator	μ_b, μ_r
Predation Rates of Mesopredator	η_b, η_S
Non-avian Food Supply	S
Carrying Capacity	K_b

Combining all of the pairwise interaction models (see original paper for all pairwise models), one obtains the full model that does not include any outside control on the superpredator or the mesopredator.

$$\frac{dB}{dt} = r_b B\left(1 - \frac{B}{K_b}\right) - \frac{B}{S+B}\eta_b R - \frac{B}{B+R}\mu_b C \tag{3}$$

$$\frac{dR}{dt} = r_r R\left(1 - \frac{\eta_b \eta_s R}{\eta_b S + \eta_s B}\right) - \frac{R}{B+R}\mu_r C \tag{4}$$

$$\frac{dC}{dt} = r_c C\left(1 - \frac{\mu_b \mu_r C}{\mu_r B + \mu_b R}\right) \tag{5}$$

In analyzing this model, all parameters are fixed besides the intrinsic growth rate of the bird population to determine how quickly birds must reproduce to withstand the negative effects of having two predator

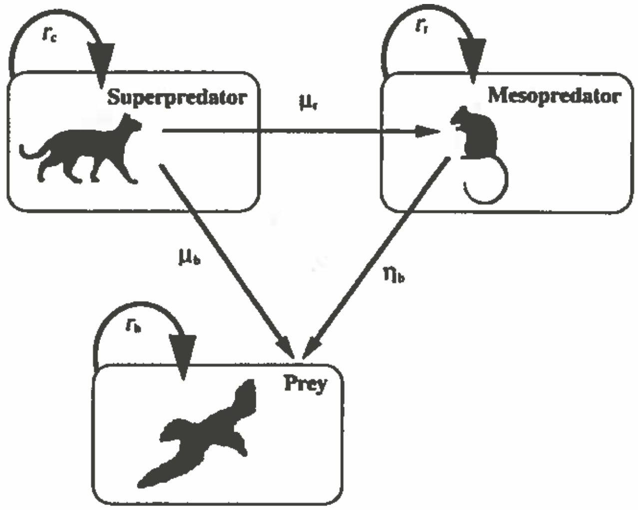

Figure 1: *[1] This graphic directly from the original paper by Courchamp, Langlais, and Sugihara shows the predation interactions between the three species. Arrows from one species to another represents the first species preying on the next. Arrows from a species to itself represents the natural growth rate of that population.*

species. This is a meaningful parameter to change since in this case, no outside controls are being placed on the model. A numerical investigation revealed that the intrinsic growth rate of the birds, r_b must be around 1.3 or greater in order to prevent extinction. This growth rate is fairly high and potentially unrealistic. Thus, it seems reasonable that some control strategies must be put in place to prevent extinction of the bird species.

In order to obtain these results the following fixed parameter values were used: 1.5, 4.0, and 0.75 for r_b, r_r, and r_c, respectively, 100,000 for K_b, 10000 for S, 54 for μ_b, 200 for μ_r, 6 for η_b, and 365 for η_s. For figures (2-5), these parameter values were used and $r_b = 1.5$ as a representative case for the survival of the bird species.

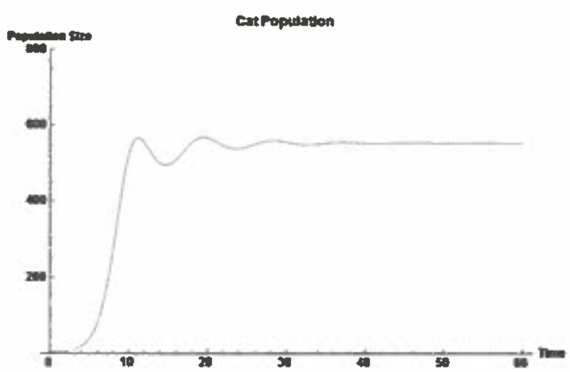

Figure 2: Cat population

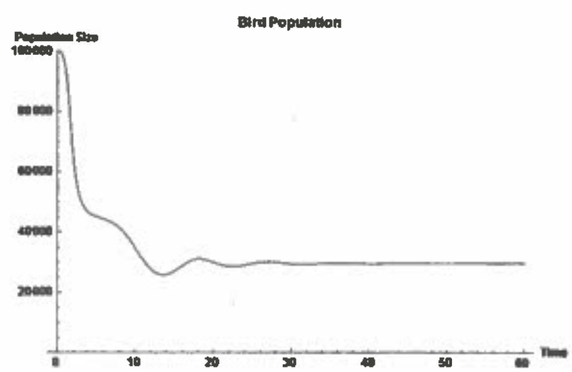

Figure 3: Bird populations

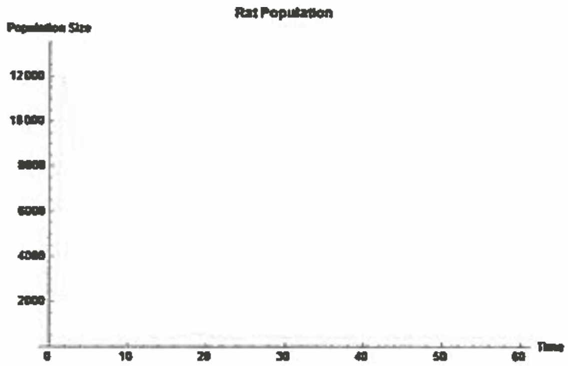

Figure 4: Rat population

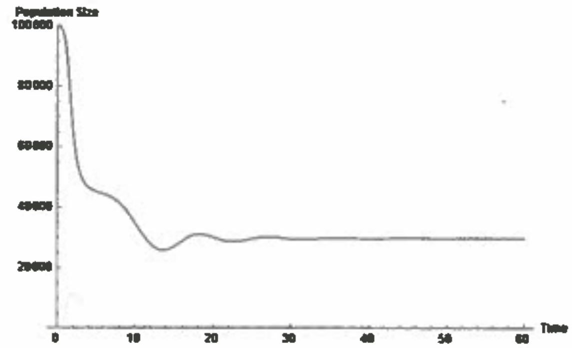

Figure 5: All species populations

These figures represent the populations of the cats, birds, and rats over time when no controls are placed on the cat and rat populations. The natural growth rate of the birds is chosen to be high enough so that all three populations persist at some equilibrium value.

Original Model with Predator Controls

In the previous model, it has been shown that if the birds have a fairly high growth rate, they will be able to withstand the effects of having two predator species. Next, two additional terms are introduced to the rate of change of the rat and cat populations to represent eradication of the rat and cat populations that is proportional to the size of each population, respectively. Two new parameters are introduced, λ_r and λ_c to represent the amount of predator control on the rat and cat, respectively. Thus, the model becomes:

$$\frac{dB}{dt} = r_b B\left(1-\frac{B}{K_b}\right) - \frac{B}{S+B}\eta_b R - \frac{B}{B+R}\mu_b C \tag{6}$$

$$\frac{dR}{dt} = r_r R\left(1-\frac{\eta_b\eta_s R}{\eta_b S+\eta_s B}\right) - \frac{R}{B+R}\mu_r C - \lambda_r R \tag{7}$$

$$\frac{dC}{dt} = r_c C\left(1-\frac{\mu_b\mu_r C}{\mu_r B+\mu_b R}\right) - \lambda_c C \tag{8}$$

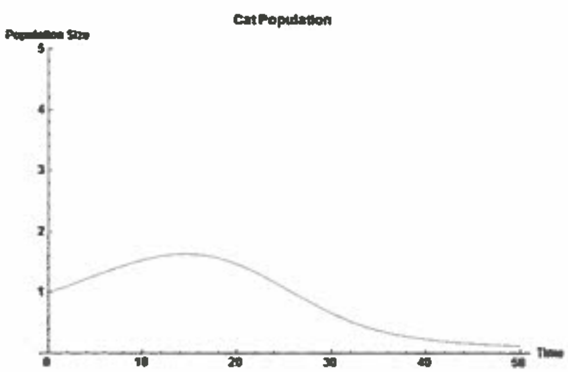

Figure 6: Cat population

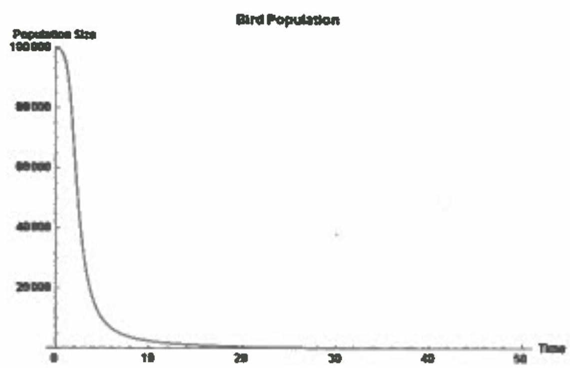

Figure 7: Bird populations

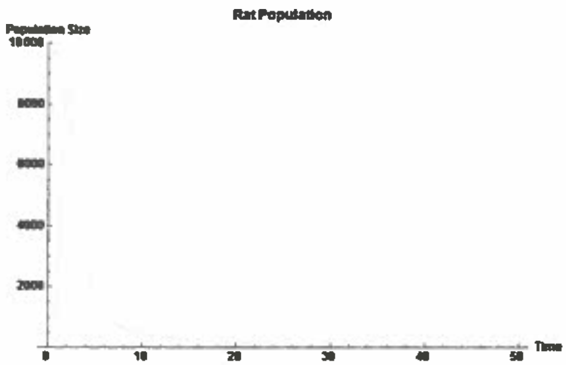

Figure 8: Cat population

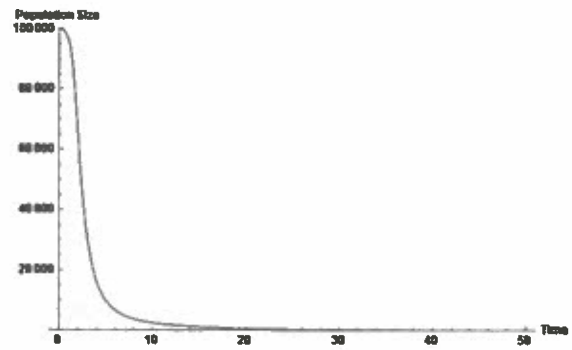

Figure 9: Bird populations

These figures represent the populations of the cats, birds, and rats over time when the control on the cats is high enough for the cats to quickly become extinct, but the control on the rats is not high enough so the birds go to extinction.

Thus, depending on the values of the control parameter, there are various outcomes. If the control on the superpredator is high enough, $\lambda_c > r_c$, and the control on the mesopredator is too low, $\lambda_r < r_r\left(1 - \frac{r_b\eta_s}{\eta_n}\right) < r_r$, then the superpredator will quickly be eradicated, but the mesopredator population will soon increase after the superpredator is going, forcing the prey to extinction. In order to obtain these results the following fixed parameter values were used: 0.06, 4.0, and 0.75 for r_b, r_r, and r_c, respectively, 100,000 for K_b, 10000 for S, 54 for μ_b, 200 for μ_r, 6 for η_b, and 80 for η_s. For figures (6-9), these parameter values were used and the predator control variables, λ_c and λ_r were 0.8 and 0.7, respectively.

Another informative case in this model is when the control on the superpredator within a certain range,$\lambda_r < r_r\left(1 - \frac{r_b\eta_s}{\eta_b}\right) < r_c$, to allow for the superpredator to continue to prey on the mesopredator, but the control on the mesopredator, $\lambda_r > r_r - \frac{\mu_r}{\mu_r}\left(1 - \frac{\lambda_c}{r_c}\right)$, is high enough so that the bird population does not decrease much. In order to obtain these results the following fixed parameter values were used: 0.8, 4.0, and 0.75 for r_b, r_r, and r_c, respectively, 100,000 for K_b, 10000 for S, 54 for μ_b, 200 for μ_r, 6 for η_b, and 80 for η_s. For figures (10-13) these parameter values were used and the predator control variables, λ_c and λ_r were 0.5 and 3, respectively. In this case, one sees that the both the cat and the bird populations reach an equilibrium value, while the rat population dies away.

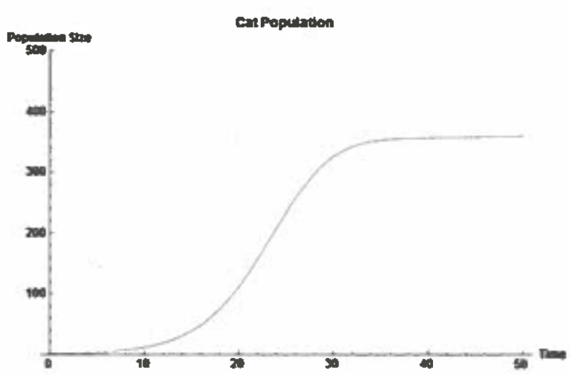

Figure 10: Cat population

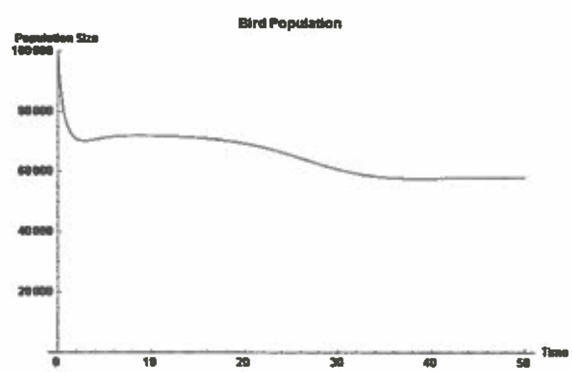

Figure 11: Bird populations

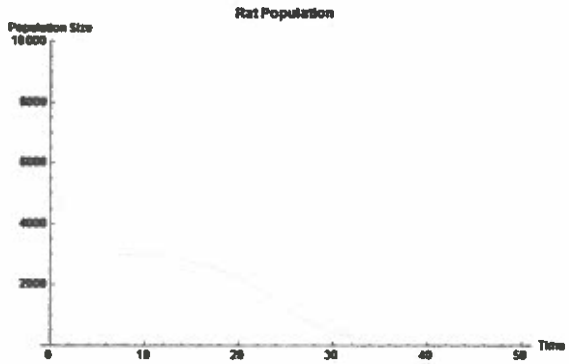

Figure 12: Rat population

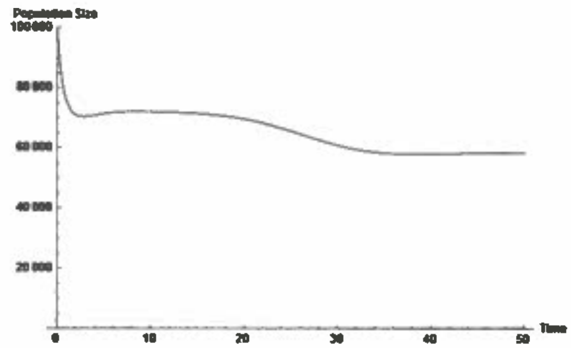

Figure 13: All species populations

These figures represent the populations of the cats, birds, and rats over time when the control on the cats is low enough so that the cats can still control the rat population but high enough so as not to be hurting the bird population as much. Also, the control on the rat population is fairly high in this case to account for the lowered cat population and to reduce the predation on birds.

Conclusion

The intent of this study was to determine the complexities of the interactions between a superpredator-mesopredator-prey relationship. In certain island ecosystems, this study relates to the interplay between alien feral cat species, rats, and endemic bird species. It is believed that the introduction of the cats to the islands has had a negative impact on the populations of certain birds. However, it turns out that simply removing the cats from the island may not actually be the best solution to saving the population of birds. As shown in the model with predator controls factored in, we see that when complete eradication of the cat population occurs, the rat population is able to grow and prey on the birds, causing the bird population to go extinct. This process is known as mesopredator release, and can be even more harmful to the prey species than if the superpredator were allowed to remain in the ecosystems. Thus, we have also shown that if the control on the superpredator (cats) is large, but not too large, some of the cats remain to better control the rat population. While control on the rats is still required in this case, we see that the birds population remains at a stable level significantly above zero.

References

[1] Franck Courchamp, Michel Langlais, and George Sugihara. Cats protecting birds: modelling the mesopredator release effect. *Journal of Animal Ecology*, 68:282–292, 1999.