# Why zombie slugs could be the answer to gardeners' woes

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Slugs are voracious feeders. Credit: Apdency

Slugs and snails are the bane of almost every vegetable planting gardener

and farmer. Slugs in particular have voracious appetites and are relentless in eating stems, leaves and shoots. No wonder gardeners have sought any means to control the spread of this crop killer. Unfortunately, the most common response – slug pellets – can have a terrible effect on other wildlife. One alternative is the parasite *Phasmarhabditis hermaphrodita*, a nematode worm which naturally kills slugs and snails.

Until recently, we had little idea why this parasite was so effective. Our recent research, published in *Behavioural Processes*, shows that after *P. hermaphrodita* infects the slug, it takes control over its behaviour, essentially transforming it into a zombie. By delving further into how this parasite takes control of the slug's behaviour, we can gain a better understanding into the molecular intricacies of mind control and even how to control the behaviour of slugs en masse.

Slugs are notably very hard to control because they can move deep into the soil and produce a tremendous number of offspring. Control methods that have tended to focus on slug pellets can be washed away easily and are highly toxic to a range of other wildlife. For decades, these pellets have contained methiocarb and metaldehyde, both of which can be harmful to the environment. Methiocarb has now been banned and the use of metaldehyde around waterways is under strict regulated use.

The P. hermaphrodita parasite on the other hand is an organic and effective alternative for controlling slugs. When added to the soil the parasites will hunt, infect and kill any slugs they find within 21 days. Then the nematodes reproduce on the cadaver and go in search of any slugs that previously escaped them. There are 108 species of nematodes that infect slugs and snails. But unlike others, *P. hermaphrodita* is highly specific and does not affect other invertebrates such as insects or earthworms.

Our research also showed that the nematode worm *P. hermaphrodita* has the remarkable ability to control the behaviour of slugs. Ordinarily, when in the presence of parasitic worms, slugs sense danger and slither away in fear of being fatally infected. But when slugs are already infected, they seem to be attracted to areas where the parasite is present and will happily remain in an area where they risk further infection.

By directing the slugs towards more parasites, *P. hermaphrodita* lead the slugs to their death, after which the nematodes can feast on the carcass and reproduce. We had previously shown that several slug species avoided *P. hermaphrodita* but were very surprised to see that several other species, when infected, were attracted to the nematodes. This behaviour was caused specifically by *P. hermaphrodita* but not other nematodes.

P hermaphrodita. Credit: Peter Andrus, CC BY-SA

## Its all in the serotonin

To understand exactly how these nematodes were controlling the slug's behaviour, we began a drug-based experiment, in which we fed uninfected slugs the antidepressant fluoxetine (Prozac). Fluoxetine increases the level of serotonin, the chemical signal or "neurotransmitter" that regulates mood in many animals. Amazingly, these drugged slugs were attracted to the nematode-infested soil in the same way as slugs infected by the parasite.

We also found that nematode-infected slugs fed cyproheptadine, a drug which does the opposite of prozac and blocks serotonin, were no longer attracted to the nematodes. All of this suggests *P. hermaphrodita* manipulates serotonin signalling in the slug's brain to change its behaviour.

P. hermaphrodita isn't alone in this behaviour and many parasites have evolved to control the mind and behaviour of their hosts. Protozoa such as Toxoplasma gondii make infected rats lose their fear of cats. A fungus called Ophiocordyceps spp. takes over ants and causes them to climb up trees so the fungus can better disperse its spores. Trematode flatworms are masters of manipulation, with the ability to control the behaviour of a number of organisms.

While the evidence supports the idea that P. hermaphrodita controls its hosts by affecting neurotransmitters such as serotonin, T. gondii interferes with production of another neurotransmitter, dopamine, to change the behaviour of rats. We also know that injecting serotonin into crustacean brains can mimic the behavioural changes caused by

acanthocephalan worm parasites. And the parasite Euhaplorchis, alters the balance of a killifish's serotonin and dopamine, causing it to conspicuously attract the attention of feeding birds. Only by reaching the bird's gut can the parasite lay its eggs.

Our results suggest that by changing the levels of serotonin in healthy slugs, we can replicate the behavioural changes caused by P. hermaphrodita infection. Similarly, we can also reverse the behavioural changes of infected slugs to mimic uninfected members of their species.

Further investigation could lead to a better insight into the molecular intricacies of mind control of not just these nematodes but other parasites too. Ultimately, we could use this knowledge to influence and direct the behaviour of infected slugs. We could make them move en masse to areas of our choosing by manipulating their serotonin levels, and in so doing eradicate their threat and appetite.

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