Who controls who in the world of parasites? Find out how these manipulative organisms are necessary in our lives.

The extraordinary influence of parasites

For organisms that are typically tiny and well-hidden parasites wield considerable power. They’re responsible for considerable human misery and huge economic losses, but they’re a powerful tool to control pests and weeds, and, as UCSB researchers have shown, they’re a tremendously important part of a healthy ecosystem.

About 50 percent of animal diversity is parasites, says Kevin Lafferty, an adjunct faculty
member at UCSB and research ecologist with the U.S. Geological Survey. “There is as wide a range of life-forms inside a fish as there is in an estuary.

“It’s the most popular lifestyle on earth,” he adds.

And it’s one with a great many bizarre variations. There are gawping-jawed parasites that tunnel through the flesh of their hosts, tiny worms that travel through blood vessels, and invaders that consume their host’s reproductive organs then co-opt their body.

“They’re small but it doesn’t make them any less fascinating than what you see on Animal Planet,” says Lafferty.

Lafferty, together with UCSB professor Armand Kuris and researcher Ryan Hechinger—working together as the Ecological Parasitology Laboratory—are studying some of the elaborate strategies that parasites use to manipulate their hosts, and investigating their role in ecosystems. Their research has important implications for how we deal with infectious diseases, how native ecosystems, crops and fisheries can be defended from invaders, and in the monitoring and study of ecosystems.

“We’d like to see full integration of parasites into ecology as a discipline,” Lafferty adds. “Most ecologists stop at the outside of the organism.”

Have parasites? Will travel.

Parasites are found around the globe, from rainforests to kelp beds to crop fields, and they’re actually a hallmark of a healthy ecosystem.

“In places where there’s a lot of action, that’s where you’ll find a lot of parasites,” Lafferty says. “Any place we go we’ll find stuff that hasn’t been found before.”

“Our lab is willing to deal with anything, any ecosystem,” Kuris adds. “We’re not tied to any specific kind of host, we’re not tied to any specific kind of disease. It’s something of a point of pride, that we think we can go anywhere and figure it out.”
Although the UCSB researchers have carried out work on an isolated coral atoll in the Pacific Ocean and in the heart of Africa, some of their most notable research has risen out of the muddy environs of marshes and estuaries on the West Coast of the United States and Mexico. These are excellent laboratories, Kuris explains, because they’re well delineated—you know within a couple of feet whether you’re in an estuary or a salt marsh. That’s not true of a forest or a lake—and not as complex as a coral reef or a tropical rainforest.

“They’re simple enough that we can understand how they work, Lafferty says, and we don’t have to put on a scuba tank.”

**Body of life**

The Carpinteria Salt Marsh, part of the UC Natural Reserve System, is a particularly convenient study site—a short drive south of the UCSB campus—and it’s packed with parasites.

According to a study by Kuris and his colleagues, the total biomass of the parasites in the 70-hectare marsh is more than that of all the top predators—the fish and birds. The total parasite tonnage is equivalent to a few elephants worth, Kuris says, adding, to make the point, they’d be staring at you as you drive by. You couldn’t ignore that. That, to me, says you cannot ignore what they do in food webs.

More recently, the UCSB researchers have examined the place of parasites in estuary ecosystems in terms of their level on the food chain and how much energy passes through them. That work is the subject of a forthcoming paper in the journal Science.

Because parasites are so abundant and so influential—major ecological players, Hechinger says—they have great potential to be used as tools to understand and monitor ecosystems and, more broadly, to gain insights into evolutionary biology.

“It’s much easier to pick up 100 snails and dissect them than to deal with other larger organisms. They’re like little data loggers,” Hechinger says. “We’re getting great empirical evidence that they do reflect the surrounding diversity. The Department of Defense, which manages huge swathes of wetland, is interested in this aspect of the researchers’ work, Hechinger says, and there’s every indication that parasites could be a valuable tool for studying many different ecosystems.

“Similar systems occur throughout the world, not just in estuaries, but also in freshwater and in marine environments,” Hechinger says.

**The good fight**

The delicate balance of these natural ecosystems is easily upset by human impacts, disease, and foreign invaders.

When animals or plants spread beyond their native range, colonizing faraway forests, oceans and estuaries, they don’t bring their full array of parasitic baggage. Without these hangers-on to keep them in check, the invaders are more prone to create problems in their new habitat—proliferating at the expense of the usual inhabitants. Ecosystems can be thrown off balance, species imperiled,
and agriculture and fisheries threatened.

The UCSB researchers have found that parasites slowly accumulate on and in organisms that have expanded far out of their usual habitat, but that can take hundreds of years, Lafferty says. Parasites never catch up entirely.

To understand the problem, the scientists are studying various invaders and the parasites left behind in their home ranges, and investigating ways of redressing the balance.

Parasites can have benefits for us in terms of their impacts on things we don’t like, Lafferty says. Because parasites have this bad connotation, the focus of research has been on how to diagnose and eradicate them. We don’t come at the problem from same direction.

Parasites are already a mainstay of biological control—in particular, parasitoid insects that attack plant pests—and there’s plenty of opportunity to expand the armory. Body-snatching parasitic worms that the UCSB scientists have studied in the Carpinteria Salt Marsh could potentially be used to control invasive snails, wielding the worms’ extraordinarily sophisticated and specific methods of manipulation to fight other invaders.

**Lifestyles of the bizarre and manipulative**

A parasite might seem to have it easy—settled in someone else’s home, freeloading food—but it’s actually a tough life.

Parasites are very successful once they reach a host, but it’s very difficult to do that, Kuris says. They’ve got to find that host amid the bustle of a forest, marsh or reef, then overcome the organism’s defenses in order to establish a home for themselves.

They have to succeed in a hostile environment, Kuris say.

Making it as a moocher calls for a very specialized lifestyle and a delicate balance. The parasite must co-opt sufficient resources to survive, but it can’t do too much damage to the organism it depends on for survival, not unless the parasite is ready to make the hop into another host.

To succeed, parasites have developed remarkably complex lifestyles and sophisticated means of mastering their hosts, methods that range from body-snatching to castration to mind-manipulation.

**Invasion of the body-snatchers: Castes of castrators**

Lurking among the showy egrets and glimmering fish that inhabit Carpinteria Salt Marsh are armies of tiny worms aiming for a takeover, parasites with a sophisticated social order that helps them pull off their nefarious plans.

These flatworms invade the California horn snails that abound in the mudflats, co-opting the snails’ bodies for their own parasitic purposes.

I like to call them body-snatchers, Hechinger says.
The worms begin their takeover by destroying their host’s gonads—parasitic castration is also practiced by barnacles that colonize crabs, protozoans that invade sea stars and fungi that infect plants. Having robbed the snail of the ability to reproduce, the worms then divert their host’s energies to their own growth—unlike most parasites, which are typically tiny relative to their hosts, these worms can constitute up to 40 percent of the weight of the snail—and then pump out multitudes of free-swimming larvae that seek out fish and other hosts.

UCSB undergraduate Sayward Halling demos a vial with hundreds of clonally produced larvae (the white spots in the water) that have left the worm colony in the infected snail to continue their life cycle.

“They castrate, and then they steal the body for themselves,” Hechinger says. “It is now theirs to drive.”

It’s a sophisticated and comprehensive takeover: the body-snatching worm actually messes with the hormonal systems that control the growth and reproduction of its host—changing the snail’s behavior.

“Body-snatchers are extreme specialists,” Hechinger says. “You have to be pretty tied-in to the physiology of a single organism.”

With so much invested in their co-opted host, the worms will fiercely defend their territory.

“If they find another worm in the snail, they kill them. Only one can drive the car,” Hechinger explains.

Inside the body-snatched snail, a colony of worms develops that has two distinct castes: soldiers and reproducers. Like honeybees, which have queens and workers, these parasitic flatworms have a division of labor, Hechinger says.

“It’s actually more radical than honeybees,” Kuris adds.

The soldiers are about 100 times smaller than reproducives, but what they lack in heft, these warriors make up for in tactics and weaponry. Their mouths are just as big as the relatively gargantuan reproducers and they’ll swallow an enemy whole if it’s small enough, or they’ll take on a much bigger opponent by latching onto it and sucking out its insides, Hechinger explains, adding, “They are not without ambition.”

The UCSB researchers were the first to discover such a division of labor in trematode worms—it’s otherwise only known in one mammal, some insects and an anemone—but Hechinger suspects the
The phenomenon is ubiquitous among these kinds of worms and says he’s since noticed it in a number of other species “without really looking for it.”

Trematode worms are tremendously abundant, with about 20,000 species found around the world. The California horn snail that inhabits estuaries like the Carpinteria Salt Marsh plays host to at least 20 different species, the researchers found, and up to 40 percent of all the snails in the marsh are infected, with all the large snails occupied by colonies of trematodes.

Not only could these common parasitic worms prove to be useful tools to study ecosystem functioning and health, they’ll offer new ways of investigating the evolution of sociality, Hechinger says.

“This is just a perfect tool to let us get at basic evolutionary questions,” he says.

**Doing the mind-warp: Parasites on the brain**

Of all the discomforting, disturbing and downright creepy ways that parasites manipulate their hosts, mind-control might just be the most eye-opening—and humans aren’t immune.

Many parasites mess with the minds of animals they inhabit to make them more likely to be gobbled up by a predator—the parasite’s next host.

When worms invade fish, they make them more active and hence an easier target for birds. Crickets infected with a certain parasite seek out a watery suicide by hopping into rivers, where they’re gobbled up by fish. The common protozoan parasite *Toxoplasma gondii* causes infected rodents to become blasé about predators—and it also has eye-opening effects on humans.

*Toxoplasma* makes mice and rats more active and less fearful of cats and cat odors, which otherwise send rodents scurrying away in terror. This bold behavior means infected animals are more likely to wander into the claws of feline predators—cats are *Toxoplasma*’s primary host, although it infects all warm-blooded animals in all habitats, Lafferty says. It’s in the air, in the sea, on land. Toxo’s everywhere. It’s probably the most successful organism on the planet.

Mouse mind-control helps *Toxoplasma* host-hop from rodent to cat, but the parasite also messes with the brains of humans it colonizes.

Free mud treatments are part of the job when researching ecological parasitology in coastal estuaries, as evidenced by principle investigator Ryan Hechinger.

“We’re not the primary targets of *Toxoplasma*’s behavioral meddling—-it’s hardly common for people to be consumed by cats, after all—but rather, incidental victims.”
Humans infected with the parasite from infected meat or contaminated cat feces exhibit various long-term personality changes. They’re subtle, but significant at a population level.

Fascinatingly, the effects vary according to gender. Infected women tend to be more intelligent, conscientious, kind and outgoing, while infected men are apt to be less intelligent and to take more risks. Infected people of both sexes are more prone to worry, self-doubt and guilt.

“It’s fascinating to me that men and women respond so differently,” Lafferty adds. “It’s as good evidence as any of what married folk know—that men’s and women’s brains work differently.”

It’s not known for sure how the parasite manipulates behavior, but it may be by influencing levels of neurochemicals—perhaps as a result of the brain’s immune response to infection.

The result is subtle things, slight shifts in distributions of personality and intelligence, says Lafferty, who in 2006 authored a provocative paper in the journal Proceedings of the Royal Society (B) in which he pondered the implications of human Toxoplasma infection in terms of global cultural differences.

Most healthy people infected with the parasite don’t have any symptoms, although a few experience a mild flu-like illness. Toxoplasmosis can have serious consequences, however, for people with weakened immune systems and for developing fetuses—that’s why pregnant women are advised not to clean cat litter boxes.

At least 20 percent of U.S. teenagers and adults are infected, according to the Centers for Disease Control, and it’s thought that worldwide, a third of the population may play host to Toxoplasma.

The prevalence of the parasite varies greatly around the globe because of factors such as climate, food preparation and consumption practices and the degree of contact with cats. In some areas, such as France, with its tradition of eating raw or lightly cooked meats, most of the population is infected, but in other parts of the globe it’s exceedingly rare. In his 2006 paper, Lafferty found a correlation between this variation and differences in aggregate personalities around the world and concluded that Toxoplasma could be responsible for some of the global variation in human culture.

Lafferty’s work stirred up considerable interest and prompted wide-ranging discussions among scientists and the media. He even received a letter from a convicted criminal who hoped Toxoplasma might be the next Twinkie defense—a means of exonerating him.

Among the many interesting implications of Toxoplasma mind control is its potential for influencing accident rates. Studies have found that people injured in vehicle accidents are more likely to be infected than the general population—a consequence that merits attention, Lafferty says.

If a widespread treatment program was implemented, Lafferty says, making some quick mental calculations, “If you do the math, you can reduce the accident rate by 20 to 30 percent. That’s on the order of seatbelts.”

He’d like to see a major study undertaken—one that tracks the long-term behavioral consequences of treating people infected with Toxoplasma, or a long-term study comparing infected with uninfected groups.

While many scientists are skeptical about the idea of parasites being able to modify the behavior of
their hosts, Hechinger notes, he argues that it’s inevitable in the evolutionary sense.

“It basically has to happen in lots of situations,” he says. “It’s adaptively advantageous, so those individuals will be selected for.”

Behavior modification seems to be common around the world, Hechinger adds. “Many of them do it. If we look closely enough we see that.”

**Misery and mortality**

Parasites are to blame for some of mankind’s most devastating diseases—malaria, African trypanosomiasis (sleeping sickness), Chagas disease and Schistosomiasis—and for scourges that threaten natural ecosystems and offer valuable lessons for understanding and responding to infectious diseases in humans.

Parasitic diseases aren’t a huge problem for people in the first world—Lyme disease and Giardiasis are among the exceptions—but in developing areas they take a tremendous toll that’s marked not only in the tally of lost lives, suffering and loss of productivity and potential.

Schistosomiasis, a disease caused by parasitic worms that is thought to affect more than 200 million people worldwide, contributes to the dulling down of entire nations, Kuris says. “Students’ test scores shoot up after you deworm them.”
Although working in the field or remote laboratories can be long, hard, and dirty, this type of work--in California and Mexico estuaries and other types of ecosystems around the world--plays a major part in the science of the UCSB Ecological & Evolutionary Parasitology group--and the researchers clearly enjoy their work. (Right) It is not just graduate students and faculty that get down and get dirty. Undergraduates also get experience in the world of parasites, getting their hands truly dirty.

Kuris has studied *Schistosoma* worms and their interplay with freshwater snails that play host to them in an area of Senegal that?s one of the epicenters of the disease?and where infection rates have risen sharply since the Senegal River was dammed.

?People are infected very, quickly with a lot of worms and there?s a lot of mortality,? Lafferty says.

The problem, evidently, was that the dam brought down populations of crayfish that feed on snails, leading to a boom in numbers of the mollusks?and in the parasitic worms they host, which can invade humans when they bathe or wade in water.

Kuris and his colleagues, including post-doc Sanna Sokolow, are experimenting with redressing the balance by reintroducing crayfish to the river ?to return that control element to the ecosystem,? he says.

Work like this, he adds, has important implications for how we deal with other infectious diseases?in particular, he says, the importance of looking at the situation from an ecological perspective in order to figure out how to knock down the transmission rate, rather than focusing only on efforts to treat or cure people after they?ve been infected.

?Transmission is an ecological problem,? Kuris says. ?We?re talking about reducing the transmission rate. Then everything gets more possible: the drug gets more useful, the treating of people becomes more feasible, the economics change. The problems gets much more manageable.?

Citing multi-million-dollar vaccine programs, Kuris says a strategy based on the ecological approach could provide a heftier payoff. In the case of Schistosomiasis, ?for $10 million I can deliver a gigantic public health story,? he says.

**Complications of a disease**

One of the few parasitic human illnesses that has a hold in the United States is Lyme disease, which is transmitted by feeding ticks?ectoparasites?that harbor the bacterium *Borrelia burgdorferi*, which causes the disease.

Although it?s rarely fatal?it can be successful treated at the early stages?the illness can be debilitating, with flu-like symptoms and, in advanced stages, neurological and cardiac problems.
The disease is most prevalent in the northeast of the country, even though Lyme disease bacteria, ticks and other host animals like mice are common enough in California. The difference, explains Cheryl Briggs, a UCSB professor and the Duncan and Suzanne Mellichamp Chair in Systems Biology, is that we have a lot of lizards here. They make very agreeable homes for ticks; it's common for a single reptile to be hosting several dozen of the arachnids, Briggs says; but the animals actually help reduce the prevalence of the disease by cleansing feeding ticks of Lyme bacteria thanks to an immune response that sends bacteria-bursting proteins coursing through the lizards' blood.

Any tick that feeds on a lizard comes off uninfected, Briggs says.

Humans produce similar defense proteins but they don't have the same effect on Lyme disease bacteria, and nobody's tried using lizard blood to treat human patients, Briggs notes.

Briggs' investigations into Lyme disease included a study in which lizards were moved out of a particular area, which, rather than leading to an increase in disease prevalence because of the loss of the reptilian disinfectors, actually had the opposite effect because it removed some of the ticks' food source. This discovery added to the understanding of the complex ecology of the disease and underscored the importance of the ecological approach in studying disease.

Scourge of the Sierra

When Briggs began studying populations of native frogs in California's Sierra Nevada, she was focused on the threat they faced from ravenous non-native fish.

Soon, though, an even bigger problem surfaced: the disease chytridiomycosis, which is caused by a parasitic fungus, *Batrachochytrium dendrobatidis*, that colonizes the skin of frogs.

The disease became a more important threat to the remaining population of frogs than the fish were, Briggs says.

People starting noticing it all over the world since the 1990s, she adds. Every time people go to a new place they manage to find it.

The disease has been directly linked to the extinction or serious decline of hundreds of species of amphibians and Over the last decade it's just swept over the Sierra, leading to extinction after extinction after extinction, Briggs says. Now most of the Sierra is pretty much frog-free.

We got tired of watching all these extinctions and we decided to get in there and do something, Briggs says.

Infected frogs can be treated with an anti-fungal agent, which provides a temporary cure, but Briggs and her colleagues are looking for better solutions and examining the complex dynamics of the disease in natural systems. They're investigating why some populations of frogs have a degree of immunity to the disease and studying the interactions between the parasitic fungus and microbes commonly found on the skin of frogs.
Some of these bacteria produce fungus-fighting chemicals, so the researchers are investigating the potential for probiotic treatments: inoculating frogs with strains of bacteria that protect them from the *Batrachochytrium* fungus.

Much of Brigg?s work involves modeling, which is an invaluable tool in studying all kinds of infectious diseases, she says?from severe acute respiratory syndrome (SARS) to foot and mouth to influenza.

Chytridiomycosis, Briggs adds, ?is a model for an emerging infectious disease,? and unlike illnesses spreading through human populations, ?it?s a situation where we can go in and do experiments?manipulate the system,? she says.

Insights from studying diseases in natural systems, she says, can be a great help in understanding infectious diseases that affect humans, and in figuring out how to deal with them?a connection that?s begun to be explored and emphasized only relatively recently.

?It?s at a time when we?re seeing all these emerging diseases both in humans and in wildlife and agriculture and plants,? Briggs says.

**LINKS:**

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