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Invasion of the Flatworms

Easily hidden in imported plants, some land flatworms are conquering the world.

Ronald Sluys

"Probably a million more Americans have heard the word *flatworm* because of me," says my colleague Jean-Lou Justine, who is an expert on these organisms at the National Museum of Natural History in Paris, as he wrote in an email to me last year. In 2014, Justine announced the discovery in France of a land flatworm originally from New Guinea, *Platydemus manokwari*, which is considered by the International Union for the Conservation of Nature to be one of the 100 worst invasive species. It was the first time that *P. manokwari* had been seen on the European continent. This land flatworm is particularly notorious because it spreads easily and eats native earthworms and snails, thereby affecting local ecosystems. In 2015, Justine reported finding *P. manokwari* in the United States. Before these two major continental introductions, the New Guinea flatworm had been a problem on a smattering of Indo-Pacific islands but had not reached any mainland, at least not to anyone's knowledge. But now they seem to be popping up everywhere, and they are not the only species doing so.

Land flatworms, a group of about 910 species, typically live in tropical jungles or temperate wooded areas and can survive only in moist soil environments. Many places in the world are being invaded by land flatworms that have stowed away in the soil of imported ornamental plants. Flatworms may not seem particularly worrisome or threatening, but they are voracious top-level predators of soil organisms, and their presence can change nutrient cycling, endanger native species, and alter an ecosystem's plant community. Indeed, even before *P. manokwari* was found to have invaded France, Europeans already had cause for alarm: Another invasive land flatworm, *Arthurdendyus triangulatus*, was known to have reduced earthworm numbers in the British Isles.

Ancestors of terrestrial flatworms colonized the land, from the sea or freshwater, hundreds of millions of years ago. The current worldwide occurrence of these terrestrial worms is a testament to their remarkable evolutionary success in occupying a new niche on land. Almost nothing appears to eat these flatworms, and they are able to regenerate even when cut in two. A land flatworm also will reproduce asexually by fragmentation: The anterior and posterior halves of its body break apart, and the posterior half crawls around headless until it grows a new head in about 15 days, while the front half grows a new tail.

Until recently, this obscure group of invertebrates had not received much attention, even though a small group of natural historians, including me, had begun monitoring them. Justine's latest discoveries sparked an avalanche of records of land flatworm introductions and have brought attention to the ease with which these organisms spread and acclimate to new places. Although the invasion has apparently accelerated and worsened in recent years, our present knowledge is still limited. The time is ripe for biologists to unravel the diversity, ecology, and natural history of land flatworms, so that the environmental implications of their spread may be understood and curbed.

The First Invasive Land Flatworm

In our shared fascination with these worms, Justine and I have been following in the footsteps of a notable predecessor, Charles Darwin. During his HMS *Beagle* voyage, Darwin was struck by the fact that there is a group of free-living flatworms, or *planarians*, that actually live on land (most planarians live in freshwater or in the sea). He succinctly and appropriately described these land flatworms as follows:

> In general form they resemble little slugs, but are very much narrower in proportion, and several of the species are beautifully coloured with longitudinal stripes.

Darwin took some of the worms that he had collected in Tasmania on board the *Beagle* and managed to keep them alive for two months. Never shying away from experiments, he cut some animals in half and discovered that after 25 days each piece had regenerated to an almost complete animal. About 18 months earlier he had collected other species of land flatworms from forests along the Chilean coast. Always a keen observer, he had noticed that when these worms experience adverse conditions—for example, when they are handled by humans—they may very quickly, before one's eyes, disintegrate into a slimy mass.

Little could Darwin have suspected that 180 years later he would have been able to collect land flatworms in England that originated from the Southern Hemisphere. How could these apparently delicate animals have reached the Northern Hemisphere—and what can we do to stop their continued spread?

A hint at an answer to the first question was presented all the way back in 1878, still during Darwin's lifetime, when a new species of tropical land flatworm was found in the hothouses of the botanical gardens at Kew Park in the London borough of Richmond upon Thames. The species was aptly named *Bipalium kewense* after this site. It was immediately clear that the botanical gardens at Kew represented a curious location, because the native distribution of other species of *Bipalium* covers India, Southeast Asia, and Madagascar. In the following years it became clear that *B. kewense* had actually colonized hothouses and similar artificial environments, such as plant nurseries and gar-

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The first introduced land flatworm discovered, *Bipalium kewense*, was found in the botanical gardens in Kew Park on the outskirts of London in 1878. Native to Southeast Asia and introduced to England via the horticultural trade, this land flatworm has since spread throughout much of the world.

den centers, all over the world. But it has also established itself outdoors—for example, in gardens in California, Louisiana, Florida, and the West Indies.

To a large extent *B. kewense*'s colonizing success can be explained by the worm's ability to propagate itself by fragmentation, an asexual process that Darwin had already noticed during his experiments on the *Beagle*. All species of *Bipalium* are hermaphroditic, having both testes and ovaries. But in temperate regions *B. kewense* animals rarely develop a reproductive apparatus and they therefore are unable to sexually reproduce. However, on rare occasions this flatworm has been known to reproduce sexually as well.

Almost every year *B. kewense* is found in new places—for example, this year they were found on São Miguel Island in the Azores and on São Tomé Island in the Gulf of Guinea. It is presumed that *B. kewense* travels the world as a result of the horticultural trade, transported in pots of tropical plants.

That many Britons are keen horticulturists is well known. Therefore, it is not surprising that over the years other land flatworms, hiding themselves in imported potted ornamental plants, have been introduced into the United Kingdom. From 1963 onward observations of other nonnative land flatworm species from the Southern Hemisphere have been reported in the British Isles. Most of these worms probably originated in New Zealand or Australia and reached the United Kingdom by transport of ornamental plants. Although most introduced flatworms were found in greenhouses early on, by the 1980s their numbers had increased considerably, and the majority of these new flatworm species had also established themselves in outdoor environments. One species, the New Zealand flatworm, *A. triangulatus*, even reached the remote Faroe Islands. To date, 15 species of introduced land flatworms have been found in the British Isles.

As these introductions have continued, we still know little about the myriad of potential ecological effects they could induce. But what we do know does not bode well.

Problematic Eating Habits

Nonnative flatworms can spread quickly and broadly, and their dietary habits can affect local ecology and native species. Darwin thought that land flatworms feed on rotten wood, but he was wrong about that. The animals are generalist carnivores that prey on other invertebrate organisms such as earthworms, snails, slugs, insect larvae, and several arthropods, including isopods and springtails. Land planarians search for, attack, and capture prey much larger than themselves. For example, Peter Ducey of the State University of New York at Cortland found that in North America the introduced flatworm *Bipalium adventitium* may attack earthworms that have more than 100 times its body mass. The worms employ different techniques to subdue their prey. Among these are physical force, adhesive mucus, and the use of an effective digestive secretion over the surface of the live prey—or into it, using a protrusible pharynx. The latter is a muscular, often tube-shaped structure that can be protruded out of a ventral opening about midway down the flatworm's lower body surface. This tube leading to the gut can be inserted into the prey, sucking out its contents by bits and pieces through peristaltic pumping of the pharyngeal muscles.

Recent experimental work by PhD student Piter Boll, from the Universidade do Vale do Rio dos Sinos in Brazil, has revealed that there are even land flatworms that specialize in eating others. The land flatworm that is being preyed upon immediately recognizes the danger when it is touched by the predator or comes across the predator's slime trail and then frantically tries to escape (see: https://youtu.be/-kTUr1t6Z-

The map above of the current distribution of the New Guinea flatworm, *Platydemus manokwari*—which is considered by the International Union for the Conservation of Nature to be among the top 100 worst invasive species in the world—shows how far the organism has ventured from its native range in New Guinea. The flatworm's invasion was thought to be confined to the Indo-Pacific region until 2014, when a study led by Jean-Luc Justine of the French National Museum of Natural History showed that its distribution was much broader and more concerning (*blue dots*). By 2015, Justine had documented additional introductions (*red dots*). In the photograph at left, *P. manokwari* is shown eating a Mediterranean snail by sucking up the prey's contents through its tubelike pharynx on the underside of its body. Because they are top carnivores in soil ecosystems, some species of invasive land flatworms have caused declines in populations of native earthworms and snails. (Figure from J.-L. Justine et al., *PeerJ* 3:e1037; photograph by Pierre Gros, from Wikimedia.)

yU). There are even situations in which one species of land flatworm preys on another species of land planarian that itself preys on still other species of land flatworms.

One of the biggest threats that invasive flatworms present is that they assault native earthworms that maintain soil ecology. Because the so-called Australian flatworm, *Australoplana sanguinea*, feeds exclusively on earthworms, there was legitimate reason for concern in the United Kingdom about the negative impact that this introduced flatworm might have on earthworm populations in agricultural fields. The soil biologist Daniel Dindal from the State University of New York had shown in 1970 that the introduced land flatworm *B. adventitium* had become a pest in North America because of its predations in commercial earthworm beds.

More recent studies by Ducey on the distribution and predatory activities of *B. adventitium* have revealed that the species is most abundant in areas near gardens with exotic and transplanted ornamental plants and that it feeds on many species of earthworms. In this North American setting one could argue that potential eradication or at least a reduction in numbers of earthworms is no reason for panic, because the earthworms themselves are interlopers. In the northern part of the United States and in Canada native earthworms all but disappeared during the last Ice Age, which ended about 12,000 years ago. New earthworm species arrived in the New World with the first European settlers, and later with fishing bait, and these species subsequently spread along with roads and human settlements. Currently in North America as much as 30 percent of the earthworm species are introduced species. Many people and organizations in northern North America try to restrict the spread of the nonindigenous earthworms. In this attempt they probably get some help from invasive land flatworms. Still, native earthworm species left in the southern United States could be negatively affected by predatory flatworms. Even though introduced species, such as *Bipalium pennsylvanicum* and *B. adventitium*, may be ranked as welcome helpers in the battle against nonnative earthworms in North America, another land flatworm that has been introduced there, *Bipalium vagum*, prefers mollusks as prey. So, according to Ducey, *B. vagum* could reduce numbers of rare native snails, although such effects have not yet been studied in detail.

Outside North America, ecologists have identified other negative effects that invasive land flatworms have had on local ecosystems. In several studies published between 1989 and 1995, Rod Blackshaw, who was then at the Department of Agriculture in Northern Ireland, found that the New Zealand flatworm *A. triangulatus* had a negative effect both on population densities and on the species diversity of earthworms in fields in Northern Ireland. That was one of the reasons that Hugh Jones, then at the University of Manchester, and his coworkers launched a national flatworm hunt in 1995, asking gardeners to search for these worms under paving stones, planks, logs, plastic sacks, and so forth. The responses of 318 people revealed that introduced Australian and New Zealand flatworms had infested many regions of the British Isles. It was also clear that their spread was the result of the activities of gardeners, who were transporting potted plants from one place to another.

Early Land Planarian Finds

The current effort to understand and respond to the problem of invasive flatworms began in 1998 with an international workshop on terrestrial flatworms funded by an intergovernmental agency called the Organization for Economic Cooperation and Development (OECD). The conference was held in New Zealand, at the University of

Canterbury in Christchurch. New Zealand ranks as one of the global hotspots of land flatworm diversity and was the country of origin of several of the species introduced into the British Isles.

There are about 86 species known to be native to New Zealand and many more remain to be described. The OECD workshop estimated a land flatworm fauna in New Zealand in excess of 100 species, a number that dwarfs the handful of native species in both Europe and North America. From that perspective, more introductions from New Zealand are to be expected, a fact that prompted Brian Boag of the Scottish Crop Research Institute in Dundee to nickname these invasions the "colonial's revenge" in one of his journal articles.

In addition to estimating the number of species still to be discovered, as well as the number of introductions of alien species, the workshop participants identified other gaps in knowledge about land flatworms and suggested methods for detecting and controlling alien terrestrial flatworms. A volume summarizing the symposium was published later that year, and since then has become a benchmark publication on land flatworms in general and invasive species in particular.

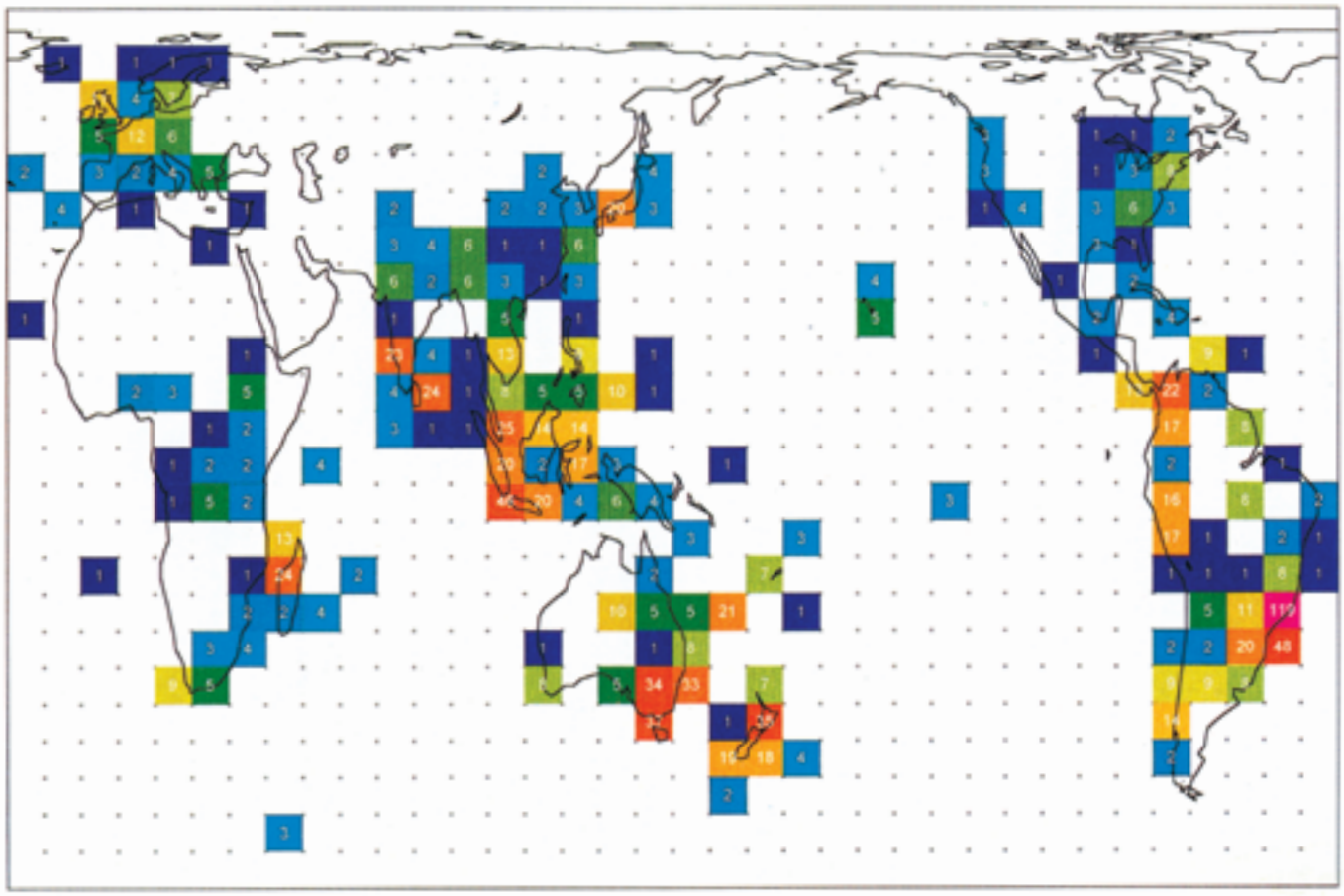
Some workshop attendees from the United Kingdom—Boag and Jones, the latter now at the Natural History Museum in London—continued to monitor the flatworm invasions and their effects in the British Isles. Unfortunately, because of the sparseness of active experts, worldwide efforts to document and manage the invasions tapered off after the 1998 workshop.

Outside the United Kingdom, little action or research was undertaken, probably because of the highly restricted number of special-

Selected Invasive Flatworms

	species	common name (if applicable)	native range	nonnative range
	*Arthurdendyus triangulatus*	New Zealand flatworm	New Zealand	Faroe Islands, Ireland, United Kingdom
	*Artioposthia exulans*		New Zealand	United Kingdom
	*Australoplana sanguinea*	Australian flatworm	Australia	United Kingdom
	*Bipalium adventitium*		unknown	United States
	*Bipalium kewense*		Indochina	All over world, including the United Kingdom and United States
	*Bipalium multilineatum*		Japan	France, Italy, and maybe South Korea
	*Bipalium pennsylvanicum*		unknown	United States
	*Bipalium vagum*		unknown	Bermuda, United States
	*Caenoplana bicolor*		Australia	Italy, Spain, the Netherlands, United Kingdom
	*Caenoplana coerulea*	Australian blue garden flatworm	Australia	Argentina, France, New Zealand, Norfolk Islands, Spain, United Kingdom, United States
	*Dolichoplana striata*		Indomalaysia	Spain, United Kingdom, United States
	*Kontikia andersoni*		New Zealand	United Kingdom
	*Marionfyfea* sp.		New Zealand	France, the Netherlands, United Kingdom
	*Obama nungara*		Brazil	France, Guernsey, Italy, Spain, United Kingdom
	*Parakontikia ventrolineata*		Australia	France, Ireland, Mexico, New Zealand, South Africa, United Kingdom, United States
	*Platydemus manokwari*	New Guinea flatworm	New Guinea	France, Japan, New Caledonia, Puerto Rico, Singapore, the Philippines, Tahiti, the Maldives, the Solomon Islands, United States, various other islands in the southeastern Pacific

This selection of species of introduced land flatworms, including some of the most pernicious invaders, shows their widespread distribution.



On this 1998 grid map, the number of species of land planarians is shown by location. Colors range from the maximum in red to the minimum in dark blue. Over the past 18 years new discoveries have added to the number of native species recognized as well as the number of invasive species discovered in new places. The current pattern of biodiversity remains similar to the one shown here. Still, it should be noted that, for example, about 20 new native species are now recognized in Europe, 40 in southeastern and southern Brazil and northeastern Argentina, 9 in the Australian territories, and 6 in New Zealand (Figure from R. Sluys, *Pedobiologia* 42:492).

ists and the fact that thus far only a small number of alien land flatworms had been observed. At the time of the workshop a few alien species of land flatworms had already been found on the European continent, and they were likely inadvertently introduced by 19th-century horticulturists via the transport of potted plants. These species included *B. kewense* and also the Indo-Malayan species *Dolichoplana striata*, the latter having been reported for the first time in 1943 in North America. Three years earlier *Parakontikia ventrolineata* was reported in Texas, taken from shipments of flowers from Mexico. Clearly, this Australian species was not an original member of the North American fauna. The species is now established in gardens in California. The originally Australian species *Caenoplana coerulea* now also lives in gardens in Florida, Georgia, and California and is frequently found together with *P. ventrolineata*.

Before the workshop, we biologists knew that *B. kewense* also inhabits many places in North America, where it may be found outdoors as far north as North Carolina. There are three other nonindigenous species of *Bipalium* in North America: *B. adventitium* (found in 12 states), *B. pennsylvanicum* (thus far only in Pennsylvania), and *B. vagum* (recorded in Florida, Texas, and Bermuda).

Because only a smattering of species were known to have been introduced to places outside the United Kingdom, few people were on the lookout for them and fewer still were concerned about preventing their spread.

New Introductions of Land Flatworms

As a result of the increasing number of records of land flatworm introductions, some new workers recently became interested in these creatures, including Justine, who made the discovery that the New Guinea land flatworm had arrived for the first time on two mainland continents, Europe and North America. The flood of new European records of invasive land flatworms started off in 2014 with Justine's reports on the occurrence in France of the Australian blue garden flatworm, *C. coerulea*, and then the New Guinea flatworm *P. manokwari*. In particular, the finding of the latter set alarm bells ringing among ecologists. This flatworm may reach a length of 45 millimeters, or occasionally even 70 millimeters, and a body width of about 5 millimeters. Its natural range is indeed presumably New Guinea, but it currently has a much broader distribution in the Indo-Pacific region. It has been accidentally introduced, probably again via the horticultural trade, to a large number of islands, such as Guam, Palau, Hawaii, Micronesia, French Polynesia, Samoa, Rotuma, and the island continent Australia.

At other Pacific locations (Bugsuk, Philippines; Yokohama, Japan; and the Maldives) *P. manokwari* was deliberately introduced to control another problematic invasive species—the giant African snail, *Achatina fulica*. This snail is native to East Africa but has been introduced to many other parts of the world as a food resource, through the

pet trade, or just by accident. The snail feeds voraciously on all kinds of plants and thus outcompetes rare, endemic species of snails that are found only on remote Pacific islands. The fact that the New Guinea flatworm will feed on giant African snails may seem a reason for optimism in places where both species now live together. But, alas, the worm does not care what it eats, giant African snails or endemic snails. So far it has failed to eradicate the invasive species while at the same time causing declines in populations of native snails.

The finding of *P. manokwari* in France, far outside its known Indo-Pacific distribution, kindled a worldwide interest. As a result, information on new findings of *Platydemus* poured in. It turned out that this invasive land flatworm was also present in, for example, Singapore, New Caledonia, and the Solomon Islands. Clearly, these new records fell within its already known Indo-Pacific range of distribution. But there were also new findings way outside that range, in Florida and Puerto Rico. In France, *Platydemus* was found only in a hothouse, but in Singapore, New Caledonia, Florida, and the Solomon Islands, it occurs in the wild.

Over the past two years the European continent has been quickly catching up with the United Kingdom, as findings of introduced species of land flatworms have continued there. Species that were already known to be in the United Kingdom, such as *P. ventrolineata* and *D. striata,* have now been found in Spain, and the former has also been sighted in France. The Australian blue garden flatworm, *C. coerulea*, already known to be in the United Kingdom, has been found not only in France, but also in Spain. Another species from this genus of flatworms, *Caenoplana bicolor*, has been sighted in Italy, Spain, and the Netherlands. And *B. kewense,* that notorious world traveller, now has company in Europe from *Bipalium multilineatum*, a species native to Japan that has been found in France and Italy.

Although one may be inclined to ascribe this upsurge in sightings of alien land flatworms to better communication between natural historians because of the Internet or to the participation of citizen scientists—and these factors may indeed partly explain this increase—flatworm researchers believe that these factors do not fully explain it. We believe that the increasing speed and amount of travel as globalization progresses has made the spread of the worms accelerate in recent years.

The largest South American land flatworm, *Obama eudoximariae*, from the Rio de Janeiro forest in Brazil, can reach lengths of 29 centimeters, but most land flatworms are no more than several centimeters long. It is coincidence that the flatworm has the same name as the current President of the United States: *Obama* means "leaf animal" in the extinct Tupi language of Brazil. Although this species is not found outside its native range, a closely related Brazilian species, *Obama nungara*, which was previously unknown to science, was recently found in several locations in Europe. (Photograph by Fernando Carbayo.)

Recent invasions not only concern already known species, but also may involve animals completely new to science. During the 12th International Symposium on Flatworm Biology in Stockholm, Sweden, in 2012, Jones and I discovered that we had independently obtained specimens of a land flatworm from the United Kingdom and the Netherlands, respectively, that externally looked very much alike. So we decided to join forces and to find out which species they might be. Through examination of microscope preparations it became clear that the animals that Jones had obtained were taxonomically the same as the ones that I examined. But it also became clear that the animals could not be assigned to any species of land flatworm currently known to science. It turned out that

Some land flatworms not only prey on soil invertebrates but also may eat other species of land flatworms. Above, a neotropical land flatworm, *Paraba multicolor*, swallows a land flatworm belonging to another species, *Endeavouria septemlineata*, from Hawaii and Brazil. The arrow points to the clear pharynx, a tube that the flatworm can protrude to consume prey. (Photograph by Piter Boll).

Jason Bazzano/Alamy Stock Photo

Some land planarians, such as this *Bipalium* species from Southeast Asia, are quite colorful. Others are harder to spot, but the dark, wet corners of greenhouses and gardens are a good place to start looking for them.

If You Find a Land Flatworm. . .

If you happen to have a close encounter with a critter resembling a possible alien land flatworm, I suggest three actions. The first is to take a picture (preferably including a scale of some sort) and post it to an appropriate portal, such as iNaturalist (http://www.inaturalist.org/), together with information about the precise geographic location and the date of the observation. In many countries there are additional local portals for uploading natural history records and observations. The second action that you may want to take is contacting the relevant biosecurity agencies in the country where you found the flatworm and pointing them to the records you submitted to the website(s).

Third, it may be useful to collect the animal(s) for further investigation, because external appearances can be deceptive. The best and simplest method is: Pick up the animal with a soft artist's paint brush or with a leaf, and put it into a container. When the animal undertakes its normal gliding movement and is as fully stretched as possible, quickly pour hot water over it. This kills the worm immediately and also minimizes contractions. After that, put the worm in a well-sealed tube or a small jar with 70-percent ethanol (or, if ethanol is not available, surgical spirit or rubbing alcohol). Place a label, written in pencil, *inside* the tube, specifying the date, location, and collector.

they belong to the genus *Marionfyfea*, the name that Leigh Winsor, of James Cook University in Australia, has coined for a species of land planarian from subantarctic Campbell Island, New Zealand. (The name acknowledges the previous research of zoologist Marion Fyfe on New Zealand land flatworms.) So, with respect to the origin of this new introduced species of *Marionfyfea*, all we can say is that its original area of distribution probably is somewhere in the New Zealand territories. Understanding the nature of the invasion is complicated by the fact that biologists still do not have a complete picture of the flatworm taxa, and often invaders show up before anyone even knows their original point of origin or what their ecology is.

These new alien species in Europe are all from the East—that is, from Southeast Asia, Australia, or New Zealand. But that does not hold true for a species of the genus *Obama* that recently has been found in the British Isles, Spain, France, and Italy. The name of the genus *Obama* was not coined in honor of the current president of the United States. It is instead derived from two words in the extinct Tupi language, which was spoken by the native Tupi people of Brazil: *oba* for "leaf" and *ma* for "animal." This genus of land flatworms is native to Brazil and includes the largest South American land flatworm—the impressive and colorful species *Obama eudoximariae,* which may reach a length of 29 centimeters.

Spread of a new species may go unnoticed because externally a flatworm can very much resemble another species. That is, the external appearance of an animal usually gives insufficient information to reliably determine which species it is. The finding of an *Obama* species in Europe exemplifies the fact that in flatworms looks can be deceiving. At first, these European animals were thought to belong to the species *Obama marmorata*, which is confined to Brazil. But examination of their microscopic anatomy and also their genetic composition revealed that these European specimens are different from *O. marmorata* and all other known species of *Obama*. But that was not all. The same species was found in Brazil, where the newly discovered organisms possibly occur alongside *O. marmorata*. So, recently, this new form of *Obama* from Europe and South America was described under the name *Obama nungara*. In both Europe and Brazil *O. nungara* is found in human-modified environments, such as parks, garden centers, plant nurseries, earthworm farms, grassy fields, and ornamental plant pots.

Most of these recent new findings of alien land flatworms in Europe are from outdoor localities such as gardens and orchards. Some species thus far have only been reported from plant nurseries, but that is no reason to think that they will not spread. Everything we know about their adaptability and ease of transport suggests that in the longer term many of these species will establish themselves outdoors and over a much vaster area, through human agency. This exact phenomenon has already happened in the United Kingdom with the New Zealand flatworm, *A. triangulatus*, and the Australian flatworm, *A. sanguinea*.

Control Measures

It is critically important to undertake control measures to stop the spread of land flatworms, but the animals are so prolific, adaptable, easily hidden, and poorly understood that curbing their spread will be enormously challenging. Bioinvasion may have unpredictable and adverse effects on local plants and animals. But thus far, most countries have not developed clear or stringent enough legislation to prevent

continued and increasing introductions of land flatworms. Best practices to prevent spread of introduced land flatworms have been suggested by private and public agencies in Europe, including governmental departments responsible for agriculture in Northern Ireland, Wales, and the United Kingdom as a whole; Dove Associates, a horticultural consultancy company based in the United Kingdom, and the European and Mediterranean Plant Protection Organization (EPPO).

For some organisms that have established themselves in the wild, such as the New Guinea flatworm, biological control methods are unknown and probably nonexistent, because these organisms are top-level predators that have little to fear from other predators in the soil ecosystem. In other words, under natural conditions there are no—or only very few—animals that feed on terrestrial flatworms. Part of the reason may be that they do not taste good, which has been vouched for by Winsor. He devoted his life to the study of Australian land flatworms, and he did not hesitate to gather such esoteric information, writing in a journal article that he found the taste of *Platydemus* "astringent."

Several flatworm experts have already commented on or explored the plausibility of using sanitation measures on imported plants to kill land flatworms and prevent their spread in potted plants. Immersing potted plants in water heated to 34 degrees Celsius for at least five minutes (after sealing the portion of the plant contained within the soil in a plastic bag), is fully effective, killing within one hour any New Zealand flatworm individuals present inside the pot. Similar simple methods, such as heating the soil, might be equally effective to prevent further spread of the worms. The New Guinea flatworm appears to be a hardier species in that it is killed only after immersion for five minutes in hot water of at least 43 degrees Celsius, as reported in 2008 by Shinji Sugiura, then at the Forestry and Forest Products Research Institute in Japan. The flatworms generally are attracted to dark and damp places, and therefore one may also actively hunt them down in garden centers and plant nurseries, or in one's own garden, by looking under objects such as loose pieces of turf, plant pots, rocks, and nontransparent plastic on the soil surface.

In several countries, legislation and regulations have been designed to control harmful invasive species, but for the most part these still largely overlook land flatworms. Such regulations are important because the problem with invasive, alien species is that one never knows which of them will develop into a major disaster and cause great economic damage or extinction of native species.

In the United Kingdom it is illegal under the Wildlife and Countryside Act to knowingly distribute *A. triangulatus*, *A. sanguinea*, *Kontikia andersoni*, and *P. ventrolineata*. For other countries, suggested control measures, such as the EPPO standard on *A. triangulatus*, are merely guidelines and recommendations that as yet have not led to European Union legislation. Although the E.U. Regulation on Invasive Alien Species entered into force on January 1, 2015, and a list of invasive species has been drawn up, so far it does not include any land flatworms.

In Australia the new Biosecurity Act and its associated regulations came into force on June 16, 2016. One of its objectives is to control the movement of plants and animals, but it does not single out land flatworms as focal organisms. Similar legislation is in effect in New Zealand.

The United States has a body of laws and regulations controlling the transport of animals and plants under the jurisdiction of the federal agency Animal and Plant Health Inspection Service (APHIS), which is within the U.S. Department of Agriculture. Each state also has its own regulations regarding the import and transport of animals and plants. The Code of Federal Regulations does not mention flatworms specifically, but a representative from APHIS pointed out to me in an email that the agency nevertheless considers flatworms to be a general predator that is subject to their regulation of biological control agents. This representative also pointed out that land flatworms can be considered an indirect plant pest because they feed on earthworms.

Bioinvasion effectively homogenizes the world's biodiversity. Flatworm aficionados can get excited about new findings of exotic, introduced land flatworms, but all of us would prefer to see them restricted to their natural surroundings. Sanitation measures for imported plants might prevent or reduce the spread of nonnative flatworms, but limited inspection of imports into Europe and open trade within Europe will inevitably lead to more alien species being found and distributed. Even if more countries include invasive flatworms in their quarantine pest lists and legislation, enforcement may be complex, as is the case in the United Kingdom, where adherence to the regulatory code is patchy. Therefore, realistically, at best we may be able to minimize new introductions and to contain those species that already have invaded.

So, I, along with my colleagues around the world, continue to keep a close watch for new flatworm invaders. Earlier this year a new intruder from New Zealand was discovered in the United Kingdom, *Artioposthia exulans,* illustrating that we have not yet seen the last of the invaders.

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