BLOSSOMING TREASURES OF BIODIVERSITY

In defence of the world’s most reviled invertebrate ‘bugs’

Ernest Small

Science and Technology Branch, Agriculture and Agri-Food Canada, Ottawa, Canada

ABSTRACT
Species of invertebrate animals, notably insects, are undergoing an alarmingly high rate of extinction, coupled with minimal support for their protection, even from the world’s leading conservation organisations. This is intolerable, as invertebrates constitute over 95% of the world’s species, have indispensable economic values and provide ecological services without which life on earth would virtually cease. Much of the lack of public and governmental support for invertebrate conservation is due to the abhorrent tiny pests that have persuaded most people that ‘bugs’ are bad and consequently the only species worthy of support are the charismatic superstar mammals like pandas and tigers that currently are the mainstays of biodiversity fundraising. Just as these respected, highly attractive icons are effective ambassadors of biodiversity conservation, so certain detested pests have poisoned the public image of invertebrates, and indeed have made it seem to many that most wildlife is hostile. The ‘dirty dozen’ bugs that particularly are a hindrance to improving public investment in biodiversity are: bedbugs, clothes moths, cockroaches, fleas, houseflies, leeches, lice, locusts, mosquitoes, spiders, termites and ticks. Except for spiders, these species, admittedly, are responsible for enormous damage to health and economic welfare. Nevertheless, this paper shows that most have at least some compensating values, their harm has often been exaggerated and all have related species that are good citizens. Six of the dozen ‘least wanted’ invertebrates highlighted are blood parasites of humans, and these ‘bad apples’ are very hard to defend since parasitism seems abhorrent. Remarkably, however, at least half of the world’s tens of millions of species are also parasites, and without them most ecosystems would be in danger of collapse. To improve invertebrate conservation, it is advisable that efforts be made to educate the public regarding their importance. Since prejudices against ‘bugs’ are primarily acquired during childhood, special attention is needed to persuade the young that most invertebrates are harmless, valuable and entertaining. Recent advances in genetic engineering (‘synthetic biology’, ‘genetic drives’) have led to very serious consideration of deliberately eliminating the world’s worst pests of humans. While these extermination technologies could greatly increase support for invertebrate conservation by annihilating their most despised representatives, the dangers of unforeseen damage to ecosystems and hence to biodiversity are substantial.

Introduction
The most pressing issue facing humankind is the expanding degradation of our planet and the consequent growing threat to the welfare of the world’s species, including ourselves (Food and Agriculture Organization 2019; IBPES 2019). Human-caused climate change (‘global warming’), perhaps the most obvious symptom of the problem, has captured the interest of many because it demonstrably has the potential to harm health and economic welfare. This is good for biodiversity (the animate part of the environment), because concern for the inanimate environment is likely to improve the habitats that sustain living things, and climate change is one of the great threats to biodiversity. But there are other, debatably greater threats to biodiversity, particularly habitat degradation and elimination, and overexploitation of natural resources (Textbox 1). Conservationists have bemoaned the fact that while climate remediation has been identified as an issue of predominant concern that has attracted international political and financial support, by contrast support for species conservation is alarmingly limited (Textbox 2). Numerous scientists have analysed the frightening rate of extinction of species (IBPES 2019), and the substantial associated costs to human society, but quite unlike the climate change threat, both public and governmental support for biodiversity conservation have been disappointing (Legagneux et al. 2018). However, there is in fact considerable support for a small, privileged set of species, but decidedly not for the vast majority. A chief if not the leading cause of this lack of support is the subject of this paper.

CONTACT Ernest Small Ernie.Small@agr.gc.ca Science and Technology Branch, Agriculture and Agri-Food Canada, Ottawa, Canada © 2019 Her Majesty the Queen in Right of Canada, as represented by the Minister of Agriculture and Agri-Food Canada
Conservationists are keenly aware that the key strategy to improve support for biodiversity conservation, just as has been the case for the climate change issue, is the generation of greater public and governmental concern. Towards this goal, the most successful tactic has been the adoption of charismatic iconic species – Giant Pandas, whales, spectacularly gorgeous butterflies (Figure 1) and towering trees – whose survival people spontaneously support (Bennett, Maloney, and Possingham 2015; Jepson and Barua 2015; Thomas-Walters and Raihan 2017; Macdonald et al. 2017; Albert et al. 2018). The public relations value of these ‘flagship’, ‘surrogate’, or ‘ambassador’ species has proven to be immense, and happily their conservation is necessarily achieved by preserving their habitats, which coincidentally conserves many other species (Yamaura et al. 2018). However, the approach often fails to adequately support many other partially associated species (e.g. Fourcade, Besnard, and Secondi 2017; Kramer et al. 2019), and of course ignores the vast majority of species that occur outside the geographical ranges and habitats of conservation icons.

In the noble quest to address the biodiversity extinction crisis by highlighting the world’s most attractive, loveable and charming species, a key consideration has been tacitly ignored: the world’s most harmful, offensive, disgusting and despised species, which regrettably have been allowed to greatly lower respect for the living world. Advocating on behalf of biodiversity’s most reviled species is not an easy exercise – how do you defend mosquitoes, bedbugs, cockroaches, fleas, vermin and other harmful, ugly, offensive pests? A simple statistic illustrates the magnitude of the problem: more than half of the world’s tens of millions of species are parasites (Morand 2015). Parasitism is a life form that is repugnant to most people – even most biologists and conservationists – who have limited if any sympathy for such species. Nevertheless, as will be reviewed, parasites are indispensable components of biodiversity, and indeed have values that deserve to be identified. Most importantly, the widespread fear and disgust associated with the world’s most despised species needs to be tempered with a realistic understanding of and respect for their useful roles in nature, in order to minimise the disrespect for biodiversity that they generate.

Over 95% of the world’s animals are invertebrates (Scanes 2018; note Figure 2). Of the tens of millions of animal species, the average person is particularly aware

**Textbox 1. The importance of climate change for biodiversity should not subordinate the relevance of other major determinants.**

During the past 25 years, more than 85% of published scientific studies that have explored the responses of biodiversity to future environmental changes – i.e. the so-called ‘biodiversity scenarios’ – have relied on simulations that only project changes in climatic conditions. Although we do not intend to downplay the future impacts of climate change on biodiversity, we are concerned that too strong a focus on climate change in biodiversity scenarios may discourage scientists from examining the effects of other, at least equally important issues. For instance, the destruction and modification of natural habitats resulting from land-use change are among the most important and immediate threats to biodiversity.

– Titeux et al. (2016)

**Textbox 2. Support for species conservation is alarmingly limited.**

The negative impact of biodiversity loss on ecosystem functioning and services, and ultimately on human well-being, has been unequivocally established; however, despite all efforts, biodiversity is still declining worldwide. It is widely accepted that biodiversity awareness is crucial for its conservation. Nevertheless, after many initiatives to alert society about the consequences of losing biodiversity, biodiversity loss is still perceived as a minor environmental risk compared to others such as climate change.

– Arroz et al. (2016)

![Figure 1. Beautiful butterflies, the only invertebrates that receive universal approval. Source: publicdomainpictures.net.](image-url)
of the 12 groups highlighted here. These are the antithesis of the charismatic, photogenic, adorable species that are employed as conservation icons to evoke sympathy for biodiversity. Unlike the very large ‘mega-fauna’ such as pandas, tigers and elephants, they are all miniature animals occurring in vast numbers. Most alarmingly, with the exception of spiders, they negatively affect huge numbers of people. Most significantly in the context of biodiversity, these are the creatures most responsible for generating hostility to nature and the living world, because they are so ubiquitous, familiar, hated and the subjects of constant vilification.

So what can be done? As reviewed in the following, efforts at rehabilitating the reputations of the principal pests are required. The worst of the worst – parasites and pests – need to be correctly identified and not mistaken for the millions of their innocent relatives. Moreover, their destructiveness should be clearly understood but not exaggerated, and control measures adopted that are targeted but not harmful to nature and biodiversity in general. Our invertebrate enemies have remarkable behavioural and anatomical adaptations that make them efficient competitors with humans, and while it is difficult to admire society’s worst biological foes, a measure of respect is desirable, since most play significant positive roles in nature, which are emphasised in this paper. Most people are unaware that the vast majority of life forms are harmless invertebrates, particularly insects, and that they contribute in critical ways to the orderly functioning

Figure 2. Educational illustration contrasting vertebrate and invertebrate animals. Although the two groups are given equal prominence in this plate, in fact invertebrates constitute more than 95% of all animal species, and are much more diverse than indicated here. Source: Siyavula Education (CC BY 2.0).
of ecosystems, and indeed to human welfare. The principal goals of this presentation are to correct the widespread impression that the invertebrate world is validly characterised by its most offensive representatives, and to point out that even the most despicable have redeeming values and innumerable related species that play indispensable roles in nature.

**Visibility: a basic necessity for finding creatures despicable**

Human psychology determines what species are likeable or detestable (Small 2011, 2012). The vernacular derogatory, pejorative noun ‘bug’ when applied to living things may denote both pathogenic microorganisms (‘germs’) and small, relatively unattractive animals (mostly insects and spiders). However, attitudes towards these two classes of bug differ. A minimum size is an essential criterion, because if something can’t be seen, it’s hard to hate. Pathogenic microorganisms that are invisible to the naked eye, notably viruses, bacteria and protozoans, generate diseases that are greatly feared (excessive, unreasonable fear is ‘germophobia’), but the causal species per se are not really detested like the invertebrates discussed here. Most of the especially despised species examined in this paper are terrestrial (leeches are more often aquatic, and so are mosquito larvae), reflecting the fact that the majority of human encounters with biodiversity are on land. Almost all terrestrial invertebrates are small, but at least large enough to be noticed, especially insects. Possibly the most detestable of small animals are internal parasites, such as tapeworms and botflies (see Scanes and Toukhsati 2018 for a review). These are not discussed here because, at least in Western countries, they rarely occur today in humans (although a considerable problem in Developing Countries and for livestock), and can be managed by hygiene and modern medicine. Many invertebrates are serious agricultural pests. These are not discussed here because, in Western countries where biodiversity conservation requires popular public support, agriculture is carried out by a remarkably small proportion of the population. There are many invertebrates whose stings are occasionally fatal, notably certain ants, wasps and scorpions, but these are relatively rarely encountered. (Ants in residences, gardens and picnic areas are greatly disliked, but on the whole they are viewed by the public as hard-working, respectable super-athletes.) Remarkable invertebrate diversity occurs in the marine environment, but because the majority of these species are infrequently viewed and most do not threaten humans (jellyfish are an exception), they are largely ignored by people. Indeed, the vast majority of invertebrate species are hidden from human view, and in accord with the old proverb ‘out of sight, out of mind’, they are not of concern to most people. Unfortunately it is the common pests that are, by a considerable margin, most evident and influential.

The animal kingdom is classified dissimilarly by different authorities. Some recognise about 3 dozen comprehensive groupings termed phyla, the majority of which are completely unknown to most people. Vertebrates (a subgroup of the phylum Chordata) are animals with a spinal column or backbone, and include mammals, birds, amphibians, reptiles and fish. Invertebrates (an artificial grouping defined by lack of a spinal column or backbone) are all other animals. Most of the noxious animals examined in the following presentation are classified in two subdivisions of the phylum Arthropoda: Insecta (the insects) and Arachnida (including spiders, ticks and others). The leeches are in the phylum Annelida (best known for earthworms).

**Bedbugs**

The Hemiptera or ‘true bugs’ may contain as many as 80,000 species, most of which feed on plants. The bedbugs (also spelled bed bugs and bed-bugs) represent only a little more than 100 of the described Hemiptera. Bedbugs are ectoparasites – parasites feeding on the outer surface of animals. Recent literature assigns them to two families, the Cimicidae, which live on birds and mammals, including humans, and the Polycyrtidae, which live on bats and are called bat bugs (Reinhart and Siva-Jothy 2007). However, ‘the taxonomy of bat-associated bugs is currently in a state of transition’ (Hornok et al. 2017), and all bedbugs are often included in the Cimicidae. Bedbugs are small nocturnal insects which feed on the blood of humans and other warm-blooded hosts, primarily mammals (often bats) and birds (including poultry). The Common Bedbug, *Cimex lectularius* (Figure 3), occurs in temperate climates throughout the world. For the most part, the unqualified word ‘bedbug’ refers to this species. *Cimex hemipterus* (also called ‘Bedbug’) is a more significant pest of humans in tropical regions. Bedbugs are one of the most familiar of insects, as reflected by the popular saying ‘Good night. Sleep tight. Don’t let the bedbugs bite’, the origin of which is obscure (Bologna 2018). Bedbugs may be familiar, but one of the reasons that infestations rapidly expand before they can be eliminated is that most people cannot identify the insect (Romero et al. 2017). Adult bedbugs
are seemingly wingless (actually their wings are vestigial, represented by short, non-functional wing pads) and cannot fly. They are reddish brown (more reddish after a blood meal), flattened, oval, banded and about 4 to 5 mm long. As noted by Berenbaum (2010), ‘their sexual practices are bizarre even by insect standards: because the female bedbug has no genital opening, the male inseminates her by using his hardened, sharpened genitalia to punch a hole through her abdomen. With no elaborate courtship ritual, males in a frenzied pursuit of sexual congress often blunder into and puncture the bodies of other males, occasionally inflicting fatal wounds.’ Bedbugs usually feed at night, piercing skin with two hollow tubes (Figure 3(b)). The saliva, containing anticoagulants to facilitate blood flow, is injected through one tube, while blood is withdrawn through the other tube (Figure 3(b)). Victims of these tiny vampires are unaware that they are donating blood because of anaesthetics in the bedbug saliva. Often bedbugs produce a distinctive linear group of three bites (macabrely referred to as ‘breakfast, lunch and dinner’). Another disturbing clue to their presence is that bedbug faeces stains bedding black while blood from bites results in brown stains. Flea bites are mainly around the ankles, but bedbug bites may occur on any area of skin that was exposed while sleeping. Another distinction is that flea bites tend to have a red spot in the centre.

Common Bedbugs (*C. lectularius*) are extremely well adapted to cohabit with humans, and are thought to have parasitised people since ancient times. It has been believed that they transferred from cave-living bats to humans, possibly in the Pleistocene epoch (Talbot, Keyghobadi, and Fenton 2019), but recent evidence suggests that bedbugs evolved much earlier (Roth et al. 2019). Bedbugs are small and flat, capable of hiding in tiny crevices, and also avoiding light which would reveal them to people. They often take refuge in mattresses, furniture, carpets, baseboards and clutter. Bedbugs prefer humans, but will also parasitise pets and rodents in homes. When blood is unavailable, they can remain dormant for months. As with mosquitoes, a blood meal is necessary for egg production, and females can produce hundreds of eggs in their lifetime. Bedbugs can travel short distances, but rely on humans to move between buildings. These insects are exceptional hitchhikers, travelling on clothing, bedding, luggage, furniture and boxes. For centuries, people have made efforts to remove or kill bedbugs in their sleeping quarters before retiring (Figures 4 and 5). Use of the insecticide DDT for pest control in the 1940s and 1950s reduced bedbug frequency, but subsequent increased international travel and exchange of goods have made them very widespread (Borel 2016). Bedbugs are extensively found in apartment complexes, dormitories, hotels, cruise ships, trains and busses. Crowded living quarters where control measures are difficult, such as homeless shelters, and refugee camps, tend to attract bedbugs. Although often thought to be associated with lack of sanitation, bedbugs show up in immaculate homes.

**Harmful aspects**

With the recent world-wide increase in bedbugs, the cost of their removal from commercial and private buildings has become enormous (Scarpino and Althouse 2019). Although bedbugs can harbour pathogens in their bodies, such as plague and hepatitis B, they have not been linked...
to the transmission of any disease and are not regarded as a particularly dangerous medical threat (Goddard and deShazo 2009; Delaunay et al. 2011; Pospischil 2015; Lai et al. 2016). However, for sensitive individuals the welts and swelling produced are more itchy and longer-lasting than mosquito bites. Additionally, some people develop skin infections and scars from scratching bites. Frequently the discovery of bedbugs produces considerable stress, and sometimes even a paranoia (‘delusional parasitosis’) that bedbugs are present when they are not. The misguided stigma that bedbugs indicate uncleanliness also causes psychological stress for many. Occasionally, respiratory symptoms, dermatitis and allergic reactions result from secretions produced by bedbugs. Sometimes serious poisoning has occurred as a result of incompetent usage of pesticides to control bedbugs. Unfortunately, resistance has developed to common pesticides (Romero and Anderson 2016). All bedbugs are blood parasites, and as such are scorned by virtually all people (Figure 6).

**Beneficial aspects**

What can be said in defence of bedbugs? Doggett et al. (2012) suggested the possibilities that extracts from bedbugs might be useful to inhibit the growth of bacteria, prevent germination of pathogenic fungal spores, and that they might be a potential resource for the discovery of new drugs. Most of their relatives in the huge insect order Hemiptera do not harm people, although admittedly some are significant pests of crops. Bedbugs are food for some predators, notably spiders. They provide employment for professional pest control companies, since most infestations need to be treated by experts. Bedbugs have become the basis of million-dollar lawsuits, providing work for lawyers (another form of parasite, some would unkindly remark). Bedbugs also stimulate research, for example into their genome, which was intended specifically to find ways of killing them (Nield 2016). Bedbugs also are useful subjects of ethical debate, for example regarding why Noah brought them aboard his ark.
Conservation aspects

The bedbug family, like most parasites, generally does not threaten the very existence of host species, which have usually evolved adaptations to survive the attacks. However, when the population of a host species has become reduced to the point of endangerment, parasites can be the straw that broke the camel’s back. For example, bedbugs appear to threaten the survival of the Crowned Eagle (*Harpyhaliaetus coronatus*), a large raptor of southern South America, currently considered a globally endangered species, with a world population under 1000 (Santillán et al. 2009). The bedbug species specialising on humans have not been found to have beneficial properties (at least to date), and their extinction would likely not trouble conservationists (The Guardian 2013).

Clothes moths

The Lepidoptera constitute one of the largest orders of insects, with about 200,000 species. The larvae (‘caterpillars’) of many species are significant pests of crops, and some are toxic or allergenic (Mullen and Zaspel 2018). On the positive side, many Lepidoptera are important pollinators, and most serve as food for birds, mammals, amphibians, other insects and spiders (Perveen and Khan 2018). Some moth species are specialist feeders on weeds, which makes them good biological control agents for harmful plants. Silk cocoons prepared by larvae of the domesticated Silkworm Moth (*Bombyx mori*) are the chief source of silk, perhaps the most familiar economic product of the Lepidoptera. The larvae of numerous wild lepidopterans, as well as of the domesticated Silkworm Moth, are widely employed as food in some countries.

Butterflies and moths are somewhat arbitrarily distinguished groups. Butterflies usually have thin antennae with small balls or clubs at the ends, while moths lack the club ends. Most butterflies are diurnal (active during daylight, inactive at night), while most moths are nocturnal (active during nighttime, inactive during daylight) or crepuscular (active at dawn and/or dusk). Most butterflies and many of the moths that fly during daylight have brightly coloured wings, while nocturnal moths are usually brown, grey, white or black, and drab compared to most butterflies. Because colourful Lepidoptera are much more attractive than plain species, and the dull ones are reminiscent of harmful clothes moths, there are very dramatic preferences for most butterflies, and distaste for moths (Figure 7). Only about 10% of lepidopteran species are considered to be butterflies, the rest are moths, so most adult Lepidoptera are not viewed favourably, and almost all immature stages (especially the caterpillars) of all species are considered suspicious at best.

![Figure 6. Bedbug cartoon (public domain) from Clipart Panda.](image)

**Figure 6.** Bedbug cartoon (public domain) from Clipart Panda.

![Figure 7. Contrast of attractive ‘butterflies’ and drab ‘moths’ (public domain plates). For better or worse, much of human judgement is based on appearance, and flying insects lacking impressive colouration are disadvantaged. (a) Butterflies. Source: Hewitson (1856–1876). Credit: biodiversitylibrary.org/page/12839744. (b) Moths. Source: South (1907).](image)
Clothes moths are just a few species of the large moth family Tineidae. The most unwelcome species is *Tineola bisselliella* (Figure 8), best known as the Common Clothes Moth, but also often called Cloth Moth, Clothing Moth and Webbing Cloth Moth. Adults have a body length of 6–7 mm and a wing span of 9–16 mm. The larvae are creamy-white caterpillars up to 15 mm long. The Common Clothes Moth has been speculated to have originated in Africa (Pfarr and Krüger-Carstensen 2011), but has been distributed to many countries by humans. The larvae (caterpillars) are feeding machines, but the adult moths do not feed. Several other pest moth species are also economically significant ‘clothes moth’, most notably *Tinea pellionella*, the Case-making Clothes Moth or Case-bearing Clothes Moth (Figure 9), so-named because the larvae feed and move about in a silken case. Adult Common Clothes Moths are a uniform, buff-colour, with a small tuft of reddish hairs on top of the head (less evident reddish hairs may also be on the Casemaking Clothes Moth). The two moths are similar, but Case-making Clothes Moths have dark specks on the wings (less evident in stored museum specimens). Curiously, clothes moths develop more slowly or not at all on clean wool, because they require Vitamin B and various salts as essential nutrients, and these are lacking in well-cleaned wool. However, perspiration and other kinds of fabric soiling can provide vitamin B and salts, and the larvae focus their feeding on patches of cloth soiled with sweat, oil, urine, beverages or other materials. Clothes moths are rarely observed because they avoid light. Because clothes moth are frequently in heated buildings where conditions are favourable, they can reproduce year-round, typically producing two generations annually.

**Harmful aspects**

True to their name, clothes moths are notorious for damaging garments (Figure 10). The larvae feed mostly on natural fibres employed by humans, particularly animal hair such as wool, silk and fur, but also plant fabrics like cotton and linen, and synthetic fibres blended with natural fibres. Apparel, bedding, blankets, carpets, curtains, drapes, feathers, leathers, piano felts, rugs, upholstery, animal bristle brushes and many other valued objects are in danger (Hodgson, Trina, and Roe 2008). Even paper and wallpaper may be consumed. Expensive and irreplaceable materials (such as tapestries and stuffed animals maintained in museums) that are stored for long periods are often damaged beyond repair. The larvae can also feed on other dry protein-rich animal materials, including fishmeal, dried meat extracts, drugs containing albumin, and insect remains (Cox and Pinniger 2007). Occasionally the larvae damage stored grains and seeds,
ground seeds like soya bean meal, spices and tobacco (Stejskal and Horák 1999), but other moths are more harmful agricultural pests. Sometimes Carpet Beetles (Anthrenus species) are responsible for the damage attributed to moths. Chemical control measures have been extensively employed to control moths. Mothballs or moth flakes (with naphthalene or paradichlorobenzene) are toxic to humans and pets, and their use is now discouraged. The traditional storage of garments in cedar-lined closets and chests to deter clothes moths has proven to have limited value.

Beneficial aspects

In nature, Clothes Moths contribute significantly to the recycling of dead animals, concentrating on the epidermal tissues that most other species find to be indigestible. The larvae are specialist feeders on the exterior of carcases of birds and mammals. They are adapted to consuming animal fibres, especially fur, silk, feathers and leather. These materials contain the protein keratin, which cannot be digested by many other animals, but is to the taste of the larvae (Cox and Pinniger 2007). Pests that cause considerable economic damage, like the Clothes Moth, attract research funds, not just for control measures, but to understand their basic biology, and the resultant knowledge is of great scientific and practical value for utilising and protecting biodiversity.

Conservation aspects

As noted by New (2004) ‘Moths have long been regarded as the ‘poor cousins’ of butterflies in Lepidoptera conservation, and have lagged well behind butterflies in popularity and in the attention given to their conservation status and needs. Only rarely do they gain greater prominence, despite the enormous taxonomic and biological variety they display.’ Unfortunately the harmful Clothes Moth does little to promote the cause of moth conservation.

Cockroaches

There are about 4,400 species of cockroaches (Brenner and Kramer 2018), which are now considered to be allied with the termites (Djernæs 2018). The main household pests, shown in Figure 11, are the German Cockroach (Blattella germanica) and the American Cockroach (Periplaneta americana), both actually
from Africa, (the former is far more prevalent in buildings). Pest cockroaches are reputed to have extraordinary survival skills, and a study of the DNA of the American Cockroach suggested that this is because of the acquisition of genes that enhance the insect’s abilities to detect bitter (toxic) substances and to detoxify poisonous substances that are ingested (Hernandez 2018; Li et al. 2018). Cockroaches were so common in the Carboniferous (late Paleozoic era) that this geological period is sometimes referred to as ‘The Age of Cockroaches.’

**Harmful aspects**

Ants, termites, fleas, houseflies and bedbugs are among the candidates for the title of ‘worst household pest’, but most surveys give the title to cockroaches. According to a Neapolitan folk saying, ‘Every cockroach is beautiful to its mother’ (Arruda and Pomés 2013), but most people find them repellent, if not extremely ugly. They carry bacteria (and sometimes protozoa and viruses) which can contaminate food and spread disease, especially gastroenteritis (such as food poisoning, dysentery and diarrhoea). They can also serve as intermediate hosts of parasites that affect domestic animals and potentially humans (Brenner and Kramer 2018). Cockroaches produce protein faecal matter and decaying moulted skeletons, releasing foul odours, and causing allergic rhinitis and asthma. Roaches like starchy food like cereals, sugary substances and commercial meat preparations, all of which can be contaminated by their faecal droppings. They also feed on books and their bindings and on paper. Cockroaches can even chew through electrical wiring and short-circuit electronics. With considerable justification, cockroaches have come to epitomise poor sanitation (Figure 12). The mere appearance of cockroaches causes considerable emotional distress in some individuals, and some develop an irrational fear of them (katsaridaphobia). Cockroaches are the most common pests of indoor dwellings (Lai 2017), causing damage to reputations when found in cruise ships, hotels, restaurants and supermarkets. Broad-spectrum insecticides employed to control cockroaches are increasingly ineffective because of the development of insecticide resistance, necessitating increased dosages which in turn can expose humans, pets and livestock (Fardisi et al. 2019).

**Beneficial aspects**

As pointed out by Bell, Roth, and Nalepa (2007), more than 99% of the thousands of cockroach species have never set foot in a kitchen! Indeed, as with mosquitoes, most cockroaches are not troublesome. Only about 30 species are associated with human habitats, and only about four are significant pests. Many cockroaches are important members of ecosystems as recyclers of decaying plant and animal matter, upon which they feed. They are thought to particularly contribute to recycling nitrogen in forests, making this normally scarce element available to the trees. Some cockroaches are kept as pets, particularly the Madagascar Hissing Cockroach, Gromphadorhina portentosa (Figure 13). Cockroaches are a source of food for many birds and small insectivorous mammals such as mice and rats, and some parasitic wasps specialise on cockroach eggs. A few cockroaches are also used as food for humans or livestock (Figure 14). Some cockroaches pollinate plants (Suetsugu 2019; Vlasáková et al. 2019). Because cockroaches are adapted to filthy conditions, they may have the ability to produce antimicrobials of potential value to humans (Mosaheb, Khan, and Siddiqui 2018). Cockroaches serve as laboratory models for scientific studies of metabolism, insecticide resistance, chemical communication and neurobiology.

**Conservation aspects**

The 1997 science-fiction movie *Men in Black* featured a struggle of one of the heroes with a gigantic extraterrestrial cockroach who acquired the name Edgar. During a confrontation, the hero remorselessly crushed
cockroaches underfoot in order to attract Edgar’s attention. In the film, Edgar demonstrated admirable respect for Earth’s insects by killing a bug exterminator for doing his job, and a clerk who was swatting flies. However, the indifference of audiences of the film for the welfare of cockroaches demonstrates how difficult it is to seek financial support for their conservation, even the innocent species. Indeed, several cockroach species are threatened with extinction (e.g. Carlile, Priddel, and O’Dwyer 2018). Another conservation issue that involves cockroaches is the fact that they are an important food source for some rare species. For example, roaches make up half the diet of the endangered Red-cockaded Woodpecker (Leuconotopicus borealis; Figure 15) of the Southeastern U.S. (The Guardian 2013).

As with mosquitoes, most informed entomologists and ecologists are strongly opposed to the prospect of driving all cockroaches to extinction, since the vast majority are harmless to humans and serve important roles in sustaining ecosystems. However, also as with mosquitoes, the idea of totally eliminating the chief pest species is not unattractive to many, on the theory that the possible harm to the ecology of the world would pale in comparison to the benefits for people.
Nevertheless, there are many for whom deliberate extermination of even species as objectionable as pest cockroaches is wrong in principle (Textbox 3).

Textbox 3. A view opposing all specicide, even of pest cockroaches.

You should never wish for the extinction of an entire species, especially insects as they always play an important role in the food chains of an ecosystem, typically being at the bottom of the food chain. Even if a creature is a ‘pest’ to us humans, it still had reasons to evolve the way they have and a niche within the environment they evolved in. A lot of larger species prey on insects and while they may annoy you, even cockroaches have their place in the environment. Wiping them out would mean a decline in population for any species that prey on them. Cockroaches also feed on dying/dead organic and plant material and release nitrogen through their faeces which helps fertilize soil and plants to grow.

– Hurricane Matthew (2015)

Fleas

Fleas are any of about 2500 species of small, flightless insects classified in the order Siphonaptera. (Some so-called fleas are not true insects, but have jumpy movements like those of fleas; ‘water fleas’ are tiny crustaceans, mostly found in fresh water; ‘snow fleas’ are springtails, which typically feed on decaying matter in moist soil). Fleas inhabit all continents and a very broad range of habitats. They are external parasites, adapted to suck blood from their hosts, about 95% of which are mammals, the remainder birds (Durden and Hinkle 2018). Adult fleas are 1–8 mm long, usually brown, with flattish bodies facilitating movement through their host’s fur or feathers. These insects possess strong claws to hold onto their hosts, and well developed hind legs for jumping. Fleas often bite in a cluster or line of three wounds (reminiscent of bedbugs). Although many fleas occur predominantly on one host species, most flea species are capable of living off a variety of hosts. The Cat Flea, Ctenocephalides felis, is the most common flea on both cats and dogs, as well as numerous other mammals, including humans and several species of livestock (Rust 2018). The Dog Flea C. canis (Figure 16(b)), is particularly fond of dogs but also occurs on other species. The Human Flea, Pulex irritans, parasitizes a range of mammal species as well as humans (Ziegler 2016).

Figure 17 suggests that there are fleas parasitising fleas, but there is no known case of this (although fleas have their own parasites).

Harmful aspects

Flea bites are usually just a nuisance to people, but can remain itchy and inflamed for weeks, which in turn causes both humans and other animals to scratch, sometimes damaging the skin. Scratching can result in hair loss in wild and domestic animals. Blood loss from large infestations may result in anaemia. Occasionally an allergic skin reaction occurs. More seriously, fleas are vectors of diseases caused by viruses, bacteria and rickettsias (a bacterial group), as well as protozoan and helminth parasites. The most potentially serious conditions include murine typhus, tularaemia, cat scratch disease and bubonic plague. The Chigoe Flea or Jigger (Tunga penetrans) causes tungiasis, a skin disease which is widespread in tropical countries. (Jiggers should not be confused with chiggers, which are mites [members of the Arachnida, which also includes spiders and ticks], a group of tiny parasites attaching and feeding on the skin of animals, including humans, causing itching.) The Oriental Rat Flea,

Figure 16. Examples of flea species. (a) Oriental Rat Flea (Xenopsylla cheopis). Photo by Olha Schedrina, The Natural History Museum (CC BY 4.0). (b) Dog Flea (Ctenocephalides canis). Source: Shaw (1813). Photo enhanced by rawpixel.com (CC BY 4.0).
Xenopsylla cheopis (Figure 16(a)), is credited with transmitting Yersinia pestis, the bacterium causing the bubonic plague, to rodents, which in turn spread the disease to humans, resulting in devastating plagues, notably the black death (ca. 1350). During World War II, the Japanese army employed the insects as a biological weapon, dropping plague-infested fleas in China. At least in most industrialised countries, flea-borne diseases are a limited threat today. However, fleas are a constant threat to household pets. Veterinary care to prevent or cure flea infestations represents a considerable cost. While mature adults are short-lived (typically 2 or 3 months), other stages of flea development (young adults, nymphs, eggs) have been known to survive in a dormant state for a year in a house.

**Beneficial aspects**

Unlike the adults, flea larvae are not parasites. After emerging from their eggs the larvae feed on organic materials such as dead insects, faeces and vegetable matter, and so contribute to organic recycling. While it is hard to accept that spreading parasites by adult fleas is a good thing, this does benefit the parasites, and also regulates populations of the hosts, and so keeps them in balance with the remainder of the ecosystem (Textbox 4).

Although one of the world’s best known pests, fleas are sometimes treated with respect. They are a common subject of fairy tales and fables, and in the past they were shown in paintings as a routine part of life (Figure 18). Because of their extraordinary jumping and athletic abilities, fleas came to be popular in flea circuses from the nineteenth century onwards (Figure 19). Craftspeople dressed fleas as humans or prepared them to tow miniature carts. The well-known expression ‘flea market’, referring to a small marketplace, is not considered pejorative.

**Textbox 4. What are fleas good for?**

If you think about the benefits of fleas regarding the food chain, environment and so on, it could be argued that fleas (like all species) are merely filling an available ecological niche. All organisms are part of the food chain; whether they are consumed by animals, microorganisms or fungi, fleas help keep nutrients flowing through the system of life. You could (controversially) argue that bloodsucking parasites help to re-balance populations that are out of control by being vectors for disease. That’s all well and good until it’s your species that’s under the threat of disease and death!

– Bungay (2018)

Conservation aspects

Fleas that are specialists on endangered animals are in danger of going extinct when their host does so (Platt 2018). Indeed, numerous species of fleas are known to have become extinct and many others may do so (Kwak 2018). However, most biologists, like most other people, are not sympathetic to fleas. The Black-footed Ferret

---

The vermin only tease and pinch
Their foes superior by an inch.
So, naturalists observe, a flea
Has smaller fleas that on him prey;
And these have smaller still to bite ‘em.
And so proceed ad infinitum.
– Jonathan Swift, 1733. On Poetry: a Rhapsody

**Figure 17.** A hierarchy of flea parasitism, conceived by Anglo-Irish satirist Jonathan Swift (1667–1745). Illustration by B. Brookes.

**Figure 18.** Humorous painting entitled ‘A monkey physician examining a cat patient for fleas.’ Source: Wellcome collection (CC BY 4.0).
Mustela nigripes), once common on the Great Plains of North America, is highly endangered. Prairie Dogs constitute over 90% of their diet, and the ferrets often occupy their burrows. Conservation organisations protect the Prairie Dogs from outbreaks of lethal sylvatic plague (which kills both the Prairie Dogs and the Ferrets) by eliminating fleas that carry the plague bacterium (World Wildlife Fund 2014; U.S. Fish and Wildlife Service 2018).

Houseflies

‘True flies’ are insects of the order Diptera, which probably contains about 1 million species, although only about 150,000 have been described to date (Gerhardt and Hribar 2018). Many insects with ‘fly’ in their name, such as butterflies, mayflies, stoneflies and whiteflies, are not true flies. Mosquitoes, discussed later, are the most harmful of all dipterans to humans, followed by the Common Housefly, examined here. Many dipteran species are important pollinators, assist in organic decomposition, serve as food for other animals, and some make excellent subjects for genetic studies. Forensic post-mortem pathologists sometimes employ certain flies – mostly flesh-flies (Sarcophagids) and blowflies (Calliphorids) – to estimate the time of death (Harvey, Gasz, and Voss 2016). These insects are quick to visit a fresh corpse. The eggs they lay hatch between 8 and 24 hours later, and their subsequent development provides an estimate of how long the body has been dead. Unfortunately, numerous true flies are significant pests of livestock and crops, and ‘no other group of insects has as much impact on human and animal health’ (Gerhardt and Hribar 2018). ‘Of all the insect groups, the flies (Diptera) most frequently play negative roles in human symbolism. Flies typically represent evil, pestilence, torment, disease and all things dirty. This association is likely a result of the fact that those flies most familiar to people have a close association with filth’ (Hogue 2009).

Although several species of flies commonly occur in houses, the predominant housefly (also spelled house fly and house-fly) is Musca domestica (Figures 20 and 21), thought to have originated from the savannas of Central Asia before it spread throughout the world.

![Figure 19. Advertising poster (public domain) for ‘Rollof’s Floh-Circus’ (German for Rollof’s flea circus). Originally published by Adolf Friedlaender, Hamburg, Germany, in 1906.](image1)

![Figure 20. Housefly (Musca domestica). (a) Adult. Public domain photo by U.S. Department of Agriculture. (b) Close-up of head. Photo by Sanjay Acharya (CC BY SA 4.0).](image2)
Adults are usually 6–7 mm long. Females lay batches of about 100 eggs on decaying organic matter such as food waste, carrion and faeces. The eggs hatch into legless, white maggots up to 12 mm in length (Figure 21). These transform into adults in 2 to 6 weeks. Adults usually live 2 to 4 weeks, but can hibernate overwinter. Adult houseflies cannot bite humans, and are adapted to a moist diet. They feed on liquid and semiliquid substances, and solid materials softened by their saliva. Houseflies are attracted to garbage, manure, sewage, compost and other wastes. The housefly is closely associated with humans and it has been claimed that it is the most widely distributed insect in the world. Certainly it is the most widespread dipteran in buildings. Houseflies are truly at home in homes. They can walk on vertical window panes or hang upside down on a ceiling, because of the surface-tension properties of a secretion produced by their feet. Houseflies rest at night, but are active when illumination is good and humans are also awake. Houseflies have extremely rapid responses to movement, and so can usually avoid being swatted.

**Harmful aspects**

Houseflies transport pathogens on and in their bodies, constantly defaecating and salivating on food, thereby depositing bacteria, viruses and other disease-causing organisms (Iqbal et al. 2014; Figure 22). The contaminated food may in turn result in the transfer of serious illnesses such as...
anthrax, cholera, diarrhoea, dysentery, eye infections (conjunctivitis, trachoma), poliomyelitis, salmonellosis, tuberculosis, skin infections (yaws, leprosy) and typhoid fever (Malik, Singh, and Satya 2007; Khamesipour et al. 2018). Houseflies can occur in large numbers, and are often annoying, distracting and a significant nuisance during work and leisure as they buzz around faces. Fly defaecation soils human belongings. Accordingly, the presence of houseflies is viewed with justification as an indicator of poor sanitation and unhygienic conditions, and this can have a negative psychological impact. To date, pesticides have been the most effective control measure, but houseflies have acquired pesticide resistance (e.g. to DDT), and the use of chemical controls remains ecologically and medically problematical.

**Beneficial aspects**

What good are houseflies? They feed many predators, including amphibians, birds, insects, reptiles and spiders. Houseflies (especially the maggots) contain large amounts of protein, and are beneficial to the many birds, reptiles and other insects that prey on them. Maggots are even used as a source of protein in commercial fish and livestock feed, called ‘magmeal’, which has as much as 60% protein. By feeding on decaying matter, maggots hasten the recycling of elements that eventually become incorporated in plants and nourish the animals that feed on them. ‘Maggot debridement therapy’ is the use of maggots (especially of the Housefly) to clean wounds and bone infections. The maggots consume and remove the dead tissue, and disinfect wounds. Houseflies contribute to commerce, providing work for pest control specialists, and manufacturers of flyswatters, fly sprays, flypaper and electrocution grids.

**Conservation aspects**

Diptera are among the species that are especially endangered (Sánchez-Bayo and Wyckhuys 2019). Unfortunately, houseflies have so sullied the reputation of this large group of insects that conservation attempts specifically targeted at endangered flies (or any species that has ‘fly’ in their name) are likely to face ridicule (Textbox 5). As is obvious, ‘Houseflies are highly abundant and not threatened or endangered’ (Doctor 2013).

**Textbox 5. The difficulty of conserving endangered flies.**

Maybe some endangered species should be endangered. Take, for instance, *Rhaphiomidas terminatus abdominalis*, the scientific name for a great big fly that calls some 45 acres of California sand dunes home. This fly is a pest in more ways than one. Already, builders of a hospital have lost about $4 million because part of their construction was going to encroach on the fly’s habitat. The federal government required a change in plans, and it is also holding up a project in the area that some believe could lead to 20,000 new jobs over time. The fly is getting this kind of special treatment, of course, because it is thought to be the last of its kind. Under the government’s interpretation of the Endangered Species Act, this creature, which no one even knew about until a relatively few years ago, is due privileges few human beings can claim. But what would its extinction cost anyone or anything? Some sadness on the part of a few entomologists, maybe. Nothing else. Its preservation, meanwhile, is costing the Endangered Species Act its credibility and a number of Californians economic opportunities. Our view is that this is an ugly, stupid, worthless bug. Squash it.

— Scripps Howard News Service 1997

(Note: This species, the Delhi Sands Flower-loving fly, is one of very few fly species on the U.S. Endangered Species List, and its protection has been extremely controversial.)

In addition to houseflies, there are other, highly undesirable Diptera. Tsetse Flies (genus *Glossina*), are large biting flies of tropical Africa that feed on the blood of vertebrates. These ‘flies of death’ transmit trypanosomes (pathogenic protozoans), which cause human sleeping sickness and animal trypanosomiasis. Because of the enormous health and economic effects of Tsetse Flies, their deliberate extinction has been considered (Textbox 6). However, Tsetse Flies protect many of the native large mammals in Africa (which have evolved with these flies) by preventing the encroachment of Humans and their invasive cattle. The eradication of Tsetse Flies could potentially doom the last remaining strongholds of large African mammals.
Leeches

Leeches are segmented worms, classified as subclass Hirudinea of the phylum Annelida. The most familiar annelid is the earthworm (one of the very few invertebrates that people welcome on their land). There are about 500 freshwater, 100 marine, and 100 terrestrial species of leeches. Most leeches have a sucker at each end, the anterior one with the head used for both feeding and anchorage, the posterior one to assist in anchorage. About 25% of leech species are predators of small invertebrates, usually feeding on worms, snails and insect larvae (Aloto and Eticha 2018). Some leeches are scavengers. The diverse kinds of leeches have jaws adapted to different feeding strategies (Aloto and Eticha 2018; Kuo and La 2019). However, about three-quarters of leeches are blood suckers. Many absorb blood from their hosts through their anterior (head-end) sucker (Figures 23 and 24), within which is a mouth equipped with a set of razor-sharp jaws. After the host is wounded, a muscular pharynx (part of the gut behind the mouth) pumps the blood into the leech’s digestive tract. A group of ‘jawless’ leaches employ a proboscis to pierce skin and extract blood. Leeches inject anticoagulants to prevent blood clotting, and are suspected of also anesthetizing the wound so that they can remain undetected while feeding. Most leeches feed on a variety of hosts, but may specialise on certain groups, such as frogs, fish or birds (Sawler 1981). The majority of leeches stay on their hosts for short times while feeding, but some marine leeches remain attached for long periods.

Harmful aspects

Rarely, leech bites produce significant allergic or anaphylactic reactions. Leeches can transmit viruses and bacteria, but there are very few examples of disease transfer to humans (Al-Khleif et al. 2011). Very rarely, leeches can get inside eyes, ears, noses, digestive systems and urinary organs, and cause significant harm. Leeches also damage livestock. An attack by 100 or more leeches can produce significant blood loss. Many people avoid outdoor activities, especially swimming, because of fear of leeches. Some individuals become quite hysterical when they find a single leech on their body, although the blood loss is trivial. Of the many parasites attacking humans, the leech has been adopted in the phrase ‘social leech’ as representing this reprehensible character flaw (note Figure 25). However, the widespread fear and loathing of leeches is far out of proportion to their potential to harm humans.

Beneficial aspects

The best known leech species is the medicinal leech, Hirudo medicinalis, but at least five other species are

Textbox 6. Should the ‘fly of death’ be exterminated?.

Humans have developed the technical capacities to purposefully eradicate undesirable species, such as insect vectors of a variety of pathogens. Policymakers are now tasked to determine whether and to what ends such technologies should be used. The moral seriousness of this decision cannot be overstated. We suggest a full ethical evaluation of tsetse fly elimination is essential to support sound decision-making around the usage of new technologies, to assess whether or under what conditions elimination of an endemic species harmful to humans might be justified... We suggest there is a good case to be made against the global eradication of tsetse fly species.

– Bouyer et al. (2019)
often employed medically (Saglam 2018), and it appears that in recent times these other species are the primary ones employed (Sket and Trontelj 2008). The practice of bloodletting using leeches was common in medicine from ancient times to the 19th century (Figure 26). Leeches also used to be widely employed to draw blood from areas swollen by poisonous stings and bites. Today, leeches are sometimes used to treat joint and vein diseases, black eyes, and as a substitute for stitches in microsurgery (Whitaker et al. 2004; Porshinsky et al. 2011; Zaidi et al. 2011). Leeches are also employed to maintain circulation after microsurgery, such as after the re-attachment of ears (Soucacos et al. 1994). The anticoagulant hirudin from leeches is employed as a drug to treat some blood-clotting disorders, and leeches have been found to have many other pharmacologically significant compounds (Sig et al. 2017). Fish and birds widely consume leeches, which are a natural component of food webs.

Conservation aspects

‘Leeches are indispensable organisms of the aquatic ecosystem’ but ‘they are largely ignored in many ecological and environmental research projects’ (Saglam 2018). Regrettably, ‘Leeches are most affected by agricultural activity, excessive collection, dangerous chemical compounds in water, increasing urbanization and global climate change’ (Saglam 2018). Analysis of DNA accumulated in blood-feeding leeches has potential to monitor the conservation status of wild vertebrates that the leeches fed on (Kampmann et al. 2017; Tessler et al. 2018).

In the past, leech collection for medical usage was a popular trade (Figure 27). The medicinal leech has been

Figure 25. ‘Social leech’ (always a guest, never a host), prepared by B. Brookes.

Figure 26. The use of leeches in bloodletting. (a) Vase for medicinal leeches. Photo by Paulo O (CC BY 2.0). (b) Humorous painting with three physicians in the form of leeches recommending bloodletting to treat a grasshopper patient. Photo of 19th century painting from Wellcome Collection (CC BY 4.0).
overcollected for therapeutic usage in some countries, leading to shortages and the need to import other leech species (Elliott and Kutschera 2011). The traditional medicinal leech, *H. medicinalis*, is now protected and/or listed as endangered in many European countries (Sket and Trontelj 2008). Leeches are a popular live fishing lure, and some concern has also been expressed about overharvesting of local wild populations for bait. There are several quite rare leech species that are of conservation concern. For example, the European Land Leech, *Xerobdella lecomtei*, discovered in 1868, is one of the rarest animals on Earth and is badly in need of protection (Kutschera, Pfeiffer, and Ebermann 2007). Unfortunately for leeches, they are particularly despised.

**Lice**

Lice include about 5,000 wingless species of the insect order Phthiraptera, about 4,000 of which are external parasites of birds, while about 800 species parasitise mammals. ‘Chewing lice’ (also known as biting lice) occupy hair or feathers, feeding on skin and debris on the body of the host, while ‘sucking lice’ absorb blood and sebaceous secretions. Less than 1,000 species are classified as sucking lice, all of which are specialists on placental mammals, and these are the principal species of economic significance to humans (Durden 2018). ‘Most species of mammals and birds are infested by at least one but up to six species of lice’ (Barker 1994). Lice paste their eggs, called nits, to hairs or feathers. True lice should not be confused with a variety of other so-called lice. For example, ‘plant lice’, better known as aphids, are sap-sucking small insects that cause considerable damage to cultivated plants; and ‘sea lice’ are parasitic crustaceans which damage fish.

Three kinds of lice are found on humans (Bonilla et al. 2013; Figure 28): the Human Head Louse (*Pediculus humanus capitis*), the Body Louse (*Pediculus humanus humanus*, commonly called the ‘Cootie’ and also known as the Clothes Louse), and the Pubic Louse (*Pthirus pubis*, also known as the Crab Louse). The Head Louse and Body Louse can interbreed, but rarely do so (Durden 2018). These three groups are usually found only on people, although sometimes companion animals such as dogs acquire short-lived infestations (Durden 2018). While Body Lice feed on the human body, they live on clothing, which they must have access to in order to survive. Clothing Lice evolved from Head Lice ancestors (Leo and Barker 2005), after modern humans adopted clothing, perhaps about 170,000 years ago, which coincidentally corresponds to the rapid onset of an ice age when garments would have been necessary for survival (Toups et al. 2011). Pets such as dogs and cats are not responsible for transmitting lice among humans. Lice can only crawl, and cannot jump, hop or fly. In the past, people accepted lice as a problem to be addressed regularly (Figure 29).

**Harmful aspects**

The derogatory word ‘lousy’, applied in many ways, reflects human disdain for these tiny insects, and learning that one is infested usually results in fear and embarrassment. Lice are capable of vectoring microbial
diseases and helminths (parasitic worms), but most spend their lives on a single animal, limiting their capacity to infect many individuals. Blood-sucking lice inject saliva into their host to prevent blood from clotting, and this can result in an allergic reaction. Occasionally, scratching lice bites result in secondary bacterial infections. Lice are very significant parasites of livestock, pets and wild animals (Durden 2018). They cause considerable anaemia in cattle in the northern United States (Peek and Buczinski 2017). Some dangerous chemicals have been employed in the past to get rid of lice infesting humans, and some authorities question the safety of some of the preparations conventionally applied today.

The Human Body Louse is the chief health hazard to humans. It is a transmitter of typhus, trench fever, louse-borne relapsing fever and other diseases. In the past, the Body Louse was a constant companion of people, but today it is chiefly found in less developed nations and in unsanitary conditions such as associated with war, famine, natural disasters and homelessness. Severe infestations of more than 30,000 lice on some people have been recorded.

Head lice infestations are a worldwide problem with prevalence between 1–3% in elementary school aged children (Sneath and Toole 2010). Head Lice are far more likely to be encountered in Western nations than Body Lice. Head-to-head contact among people is considered the most common way that Head Lice are transmitted, with girls being infected much more often than boys. Lice on the scalp are often not detected until itching starts, 2 or 3 months following colonisation. Lice nits (eggs; Figure 30) historically were removed with lice combs (Figure 31(a)), now considered obsolescent (Mumcuoglu 2008). Medical shampoos are now usually used to kill lice, although genetic resistance to some of the treatment chemicals is developing. Head Lice are
detested, especially when found on children, and their presence normally results in frenzied attempts to get rid of them. However, unlike Body Lice, they (as well as Pubic Lice) are not known to vector infectious diseases, although they can transmit bacteria causing skin infections (Durden 2018). Large infestations of Head Lice can result in severe irritation and consequent scratching leading to secondary infections. Head lice are not considered to be a significant health hazard or an indication of poor hygiene (a widespread misconception).

The Crab Louse or Pubic Louse is mostly attached to pubic hair, but may occur on coarse hair elsewhere, such as eyebrows, eyelashes, beards, chest and armpits. It typically transfers during human copulation, and in France, Crab Lice are sometimes charmingly described by the ambiguous phrase ‘papillons d’amour’ (butterflies of love). Transfer from bed linens, sofas and toilet seats can occur, but Crab Lice can survive only a few hours off the host. Crab Lice cause intense itching.

**Beneficial aspects**

It has been suggested that infestations by Head Lice might promote a natural immune-increasing response that defends against the more dangerous Body Louse (Rozsa and Apari 2012). Conversely, it has been demonstrated that lice can exert an immune-suppressive effect on their hosts, a phenomenon which may have practical application for treating auto-immune diseases (Jackson et al. 2009). Because it has the smallest known insect genome (Kirkness et al. 2010), the Body Louse has proven to be useful as a model research organism. Moreover, studies of the comparative genomes of lice and their hosts are useful in assessing their evolutionary and ecological evolution (Toon and Hughes 2008).

**Conservation aspects**

‘Co-extinction’ occurs when a species that is indispensable to another species (such as in obligate parasitism and mutualism) goes extinct, causing the dependent species to also become extinct. When the species essential to the other is endangered, the dependent species is ‘co-endangered’. Several species of lice are known to have died out because their hosts went extinct, and dozens of other lice species have...
been identified that are in danger of going extinct because their hosts are in danger of going extinct (Rózsa and Vas 2015). The case for saving endangered lice species is made in Textbox 7.

Textbox 7. Why should lice species in danger of extinction be protected?

There are several reasons why conservationists should care about threatened parasites. They not only constitute a large proportion of global biodiversity but also exert selective pressures to increase host diversity, and therefore harbouring a unique parasitic fauna can increase the conservation value of the host. Furthermore, parasites carry phylogenetic and population genetic information about the evolutionary past of their hosts. On the other hand, the preservation of parasite species that pose considerable medical or veterinary threats would not be widely accepted. Not all parasites are equally important. For example, the critically co-endangered Gorilla Louse *Pthirus gorillae* is of particular value because it is closely related to the human Pubic Louse *Pthirus pubis*, thus its loss would deprive us of a unique possibility to study the evolution and ecology of a human pathogen... The potential costs and benefits of reintroducing infested vs. non-infested animals are open to debate. As far as we are aware no practical work has been carried out to conserve any species of louse.

– Rózsa and Vas (2015)

Locusts

Locusts and grasshoppers are not assigned to different taxonomic groups. Locusts are simply certain species of grasshopper that have a swarming phase. The insect family Acrididae has over 10,000 species, of which about 500 (both grasshoppers and locusts) can cause damage to pastures and crops; about 50 of these are considered major pests (Zhang et al. 2019; Figure 32). The word ‘locust’ derives from the Latin *locusta*, meaning grasshopper (certain plant species of the pea family are also known as locusts). Normally, locusts are solitary, occur in low numbers, and are innocuous. However, when exposed to drought followed by abundant availability of vegetation, they reproduce rapidly, and swarm as winged adults. A large swarm can number in the billions, and densities on the ground can exceed thousands per square metre (Zhang et al. 2019). Locusts can strip crops, both as the immature stage (when they are called hoppers) and during their winged phase.

Harmful aspects

Plagues of locusts (Figure 33) have occurred since prehistory, and have produced extreme damage on all continents where crops are grown (Latchininsky 2013). They have caused famines and human migrations. The use of insecticides to control them has had some deleterious effects on biodiversity, but in recent times better monitoring, biological control and improved agricultural practices have decreased the significance of locusts. Nevertheless, large locust outbreaks, often promoted by climate change and shifts in land usage, continue to be a major, albeit sporadic

Figure 32. Some locust species. (a) Garden Locust (*Acanthacris ruficornis*) in Ghana. Photo by Charles J. Sharop. (CC BY SA 4.0). (b) Migratory Locust (*Locusta migratoria*) in Germany. Photo by H. Crisp (CC BY 3.0).
problem in many parts of the world (Lomer et al. 2001; Lecoq 2010; Zhang et al. 2019). Locust swarms often devastate natural vegetation cover, and this can result in soil erosion, increased runoff and habitat alteration that is deleterious to native plants and animals (albeit, such cycles have been occurring for millennia, and native species have survival adaptations).

Grasshoppers, including locusts, have been regarded since the dawn of agriculture as crop pests. The historical disrespect for these insects probably is the basis for well-known fables in which a dislikeable grasshopper spends the summer making music while ants work industriously to store up food for winter (Figure 34). When winter arrives, the grasshopper starves, providing the lesson that idleness is sinful.

**Beneficial aspects**

In nature, locusts and grasshoppers are, except in years of great abundance, desirable components of healthy ecosystems, controlling plant densities and participating in nutrient cycling and the food chain, both as consumers and consumables (Latchininsky et al. 2011; Figure 35). From the human perspective, locusts are edible insects, and indeed considered a delicacy by many cultures, especially in African, Middle Eastern and Asian countries (Figure 36). Their consumption is permitted both in Judaic and Islamic dietary practice, unlike many other animal...
foods. As a source of animal protein, locusts are far less damaging to the planet than conventional livestock, and represent a potential alternative. Locusts are an important source of food for many animals.

**Conservation aspects**

Most major agricultural crops are grown in large, concentrated monocultures, and while this has deleterious consequences for biodiversity, at least the application of pest control measures, particularly insecticides, can be localised to the cultivated area. However, locust swarms are mobile, migrating among crops and natural areas such as deserts or semi-deserts, steppes, savannas and grassland biomes, and so pesticides are often applied in very large amounts to natural areas, potentially endangering ecosystems and biodiversity (Textbox 8). There is obviously a need for guidelines to avoid damaging natural areas (Wiktelius, Ardö, and Fransson 2003). ‘Chemical pesticides applied for locust control represent a risk for humans, terrestrial non-target fauna and aquatic ecosystems’ (Everts and Ba 1997).

Locusts typically occur in such vast numbers that it is difficult to contemplate their possible extinction. Nevertheless, this happened to the Rocky Mountain Grasshopper (or Locust), Melanoplus spretus, which once was widespread over the Great Plains from Canada to Texas, periodically devastat-

**Textbox 8. The critical conservation issue in locust control: bombarding natural habitats with insecticides.**

In contrast to pests developing in close association with a particular host crop, locusts and grasshoppers are often controlled in natural or semi-natural landscapes, exposing structurally and functionally diverse communities to agrochemicals, chemicals to which they are not adapted. This suggests that insecticide-induced perturbations may be severe... Few insect taxa raise such controversial, and often irrational, views and feelings as acridids. In Central Europe, many grasshoppers are nowadays considered as indicators of biodiversity and ecosystem quality, and sometimes even as flagship species, i.e. ‘popular, charismatic species that serve as symbols to stimulate conservation awareness and action’. In other parts of the world, however, they remain feared pests of crops and pastures, and may trigger control campaigns of considerable scale and intensity. While the status of both locusts and grasshoppers as pests of rangeland may presently be questioned, status as pests of crops is certainly not. The potential to bring havoc to crops is generally acknowledged, and the debate is rather on control strategies than on whether acridids are worth controlling.

– Peveling (2001)

**Mosquitoes**

Mosquitoes (also spelled mosquitos) are members of the fly family Culicidae, of which about 3,500 species have been described, and many more await discovery (Foster and Walker 2018). Mosquitoes begin life as eggs, laid in water. Hatched eggs develop into motile larvae (Figure 37), which feed on algae and detritus. Adults – both males and females – feed on plants, particularly on nectar. Adult males (and sometimes females as well) feed only on plant juices. Some female adults eat other insects, and do not suck blood. However, in order to produce eggs, female adults of many species require a blood meal, which they obtain by extracting blood from the surface of animals by employ their proboscis (tube-like mouth-part), as shown in Figure 38. Mosquito saliva has anticoagulants to keep blood flowing freely, so the
proboscis does not become clogged with blood clots. Females of blood-sucking mosquito species feed on the blood of all classes of vertebrates (even fish if they are temporarily above water), and some invertebrates. Some species specialise on certain hosts, others are less selective. Adults rarely live for more than 2 weeks, the males often less than 1 week. Most blood-sucking mosquitoes are crepuscular (feeding at dawn or dusk). Mosquitoes are attracted to human hosts by CO$_2$ and other compounds expelled during breathing, and by sight. They exhibit preferences to sweat and other body odours, and body heat, so some individuals are much more attractive than others to the insects.

**Harmful aspects**

Mosquitoes are responsible for annoying, itchy, irritating bites, which are usually a mild irritant (Figure 39). However, people differ in their responses, and sometimes some individuals experience life-threatening allergic reactions. The chief threat from mosquitoes is that they transmit deadly diseases such as malaria, chikungunya, West Nile virus, yellow fever, Zika fever (named for the Ziika Forest of Uganda), dengue fever, various forms of encephalitis and filariasis. These diseases kill millions annually, and debilitate many more, especially in developing tropical countries. Malaria, the world’s most significant infectious disease, harms over 250 million people worldwide and may kill more than one million annually (World Health Organisation 2014). Because they are extraordinarily efficient at removing blood from one animal and transmitting it along with pathogenic microbes into another, mosquitoes are widely considered to be the most dangerous of all animals. ‘Half of the global population is at risk of a mosquito-borne disease. They have had an untold impact on human misery’ (F. Hawkes, cited in Bates 2016). Mosquitoes also ‘strain the resources of health

![Mosquito larvae (genus Culex) hanging upside down at the surface of water.](image)

*Figure 37. Mosquito larvae (genus Culex) hanging upside down at the surface of water. Photo (public domain) by James Gathany, U.S. Centres for disease control and prevention.*

[Figure 39. ‘The American Mosquito’, painting (public domain image) by José Guadalupe Posada (Mexican, 1851–1913), housed in The Metropolitan Museum of Art.](image)

[Figure 38. Progress of a mosquito sucking blood. (a) Mosquito identified as ‘probably Ochlerotatus vittiger’ of NSW Australia, just beginning to extract blood. (b) Same mosquito at left, after several minutes of feeding. Photos by John Tann (CC BY 2.0).](image)
services and reduce human productivity, thereby perpetuating economic hardship’ (Foster and Walker 2018). The average mosquito weighs only about 2.5 milligrams and its meal amounts to just approximately 5-millionths of a litre of blood, but these insects are capable of generating huge numbers, and have proven extremely difficult to control. Not only are mosquitoes threats to people, they also harm livestock, pets and wildlife. Swarms in Alaska have been thick enough to asphyxiate Caribou (Fang 2010). Very extensive efforts have been made to eliminate mosquitoes, and in the past DDT has been a principal weapon (Figure 40).

‘Blood sucker’ is an insulting phrase reflecting the disgust that humans have for ‘sanguivores’ (animals that feed on drawn blood). Numerous species, such as ticks, fleas, lice, mites, bedbugs, lampreys, leeches and some bats and birds engage in this vampire life style. Of all of these, mosquitoes are the most hated creatures everywhere, with few exceptions such as Antarctica and Iceland which are just too cold to support significant populations.

**Beneficial aspects**

Despite their blood-thirsty reputation, some species of mosquito do not feed on blood at all. Of the several thousand species, only about 200 bite or bother humans, and only about half of these are serious vectors of human disease. Mosquitoes are vegetarians most or all of the time (Figure 41). Although females of most species need blood protein as a prerequisite to develop eggs, at other times, like the males, they employ their long proboscis to feed on the nectar of flowers or juice from fruit or stems. Some orchids (notably *Platanthera* species) rely on mosquitoes for pollination. Other plants, such as Goldenrods (*Solidago* species), and some aquatic or semi-aquatic plants also benefit from pollination by mosquitoes that reproduce in nearby waters. Mosquitoes are a valuable source of food for many species, especially fish, amphibians, birds, bats and spiders. Some mosquito larvae (notably of *Toxorhynchites*, ‘elephant mosquitoes’, so named for their large size) even eat the larvae of other mosquito species, and so have been considered as potential control agents of harmful mosquitoes (Focks 2007). Adults of *T. speciosus* (Figure 42) are believed to be the world’s largest mosquitoes, reaching a length of over 3.4 cm; fortunately, the adults are entirely herbivorous. Aquatic larvae of some insects, such as dragonflies and damselfly nymphs, also feed on mosquitoes. Mosquitofish (*Gambusia* species) are particularly effective predators of...
mosquito larvae, and are often introduced into ponds and pools to control mosquitoes. ‘Wiping out a species of mosquito could leave a predator without prey, or a plant without a pollinator’ (Fang 2010). However, not all species that benefit from mosquitoes evoke sympathy from humans. ‘The bottly depends on mosquitoes to carry its larvæ to hosts. The bottly lays eggs on the mosquito, which hatch and jump off when the mosquito lands on a mammal. The bottly larvae then burrow into the mammal and develop there’ (Shelomi 2016a).

**Conservation aspects**

‘The romantic notion of every creature having a vital place in nature may not be enough to plead the mosquito’s case’ (Fang 2010). Not all arguments in favour of maintaining mosquitoes in nature are convincing. Some of the microbes that cause diseases would go extinct were it not for mosquitoes transmitting them to hosts, although few would mourn such losses of biodiversity. Another defence on behalf of mosquitoes is that fear of them has slowed the destruction of tropical rainforests, where they can make life intolerable for people. In a similar vein, malaria and other mosquito-borne diseases have protected the people of some malaria-endemic regions from military and cultural colonisation. For example, in 1892, after 11 years of effort to construct the Panama Canal, the French abandoned the project after one-third of their workforce died from yellow fever. Mosquitoes have killed many people, thereby limiting the growth of the world’s population, and so indirectly have limited the damage caused to the planet and its inhabitants. And, controlling mosquitoes and treating their destructive effects stimulates employment, research and technological developments. It’s also satisfying to know that many parasitic microorganisms only infect and cause diseases in mosquitoes. However, mosquitoes that get sick are often the most effective transmitters of diseases, because numerous microbes have reproduced in their bodies and are available for injection into their victims. The preceding arguments are, of course, insufficient to allay concerns about the harm that mosquitoes cause. The quotations in Textboxes 9 and 10 are representative of the common view that at least selective elimination of the most deadly mosquito species is warranted and would not result in disastrous harm to ecosystems. There are proposals to employ genetic engineering to infiltrate wild mosquitoes with ‘extinction genes’ (LaFrance 2016; Plummer 2016; Kyrou et al. 2018; Shrivastava et al. 2019). Mosquitoes are the chief target of attempts to eliminate harmful species employing genetic modification, and because of concern about the potential harmful effects on biodiversity, guidelines for experimentation have been developed (World Health Organization 2014). Unfortunately, there are potential unforeseen consequences. For example, ‘The removal of an entire species, such as a mosquito, could have effects on other organisms in the ecosystem, which could in turn lead to unwanted changes, such as an increase in the population of another insect disease vector as it fills the ecological niche opened by suppression of mosquito populations’ (National Academies of Sciences, Engineering, and Medicine 2016).

**Textbox 9. The viewpoint that eradicating deadly mosquito species is justified.**

Say we eliminate *Aedes aegypti* and a salamander species and an orchid are eliminated along with it; that is a trade we can live with, and by ‘we’ I mean the millions who will no longer die from yellow fever. The other extinctions will be a tragedy, yes, but the loss of yellow fever will be a triumph worthy of the Nobel Peace Prize. Compared to the losses of the Dodo and the Tasmanian Tiger, which came with no benefit to society and are thus completely unfortunate, the benefits of the loss of *A. aegypti* [an important vector of dengue, yellow fever, Zika, chikungunya, West Nile, and La Crosse viruses] or *Anopheles gambiae* [the chief transmitter of malaria] would outweigh even the most pessimistic estimates of costs.

– Shelomi (2016b)
The word ‘bug’ to most people means an insect or other similarly small animal, and this would include spiders. However, spiders and insects are distinctly different, although both have jointed legs and a hard external skeleton. Unlike insects which have a three-part body (head, thorax and abdomen) and six legs, spiders (and their relatives, ticks, discussed next) have a two-part body (cephalothorax and abdomen) and eight legs. Spiders are arthropods, (‘phylum’ Arthropoda) a very large group of invertebrate animals (almost two-thirds of all species that have been described are arthropods), which includes insects, daddy-long-legs, crabs, lobsters, shrimp and others. Spiders belong to the arachnids (‘class’ Arachnida), a subgroup of arthropods with over 100,000 named species, but which may prove to include over 500,000 species. Mites, ticks, scorpions and other creatures are also placed within the arachnids. Spiders are often classified as a subgroup of the Arachnids, the ‘order’ Araneae, with over 45,000 known species (possibly another 75,000 species remain to be catalogued). Spiders are extremely diverse, occupying many habitats, and occurring in much of the world (Marusik and Koponen 2000). Except for Bagheera kiplingi, which is mainly vegetarian, all other known spiders are predators (Meehan et al. 2009). Spiders mostly feed on insects and other spiders, but a few large species can capture small or immature vertebrates such as birds, lizards, snakes and mice. Most species of spiders are relatively small, about 2–10 mm in body length. Tarantulas (a thousand or more species of the family Theraphosidae) are the largest and heaviest spiders, the bodies of some as long as 9 cm, and despite their scary appearance, they are frequently kept as pets. Like most arthropods, there is much research needed to identify the many species not yet discovered (Coddington 1991).

**Spiders**

Only a few dozen spider species, mostly in the Tropics, are considered to be dangerous to humans (Mullen and Vetter 2018; Figure 43). Diaz (2004) reported that in the entire 20th century, only about 100 deaths from spider bites were reliably reported. In discussing the world’s most dangerous spiders, Kularatne and Senanayake (2014) wrote: ‘About 12 species of spiders stand out as clinically important. These include Widow Spiders, Recluse Spiders, Banana Spiders and Australian Funnel Web Spiders. The most dangerous are the female Widow Spiders of the genus Latrodectus, e.g. Black Widow (L. mactans), Grey Widow (L. geometricus), American Loxosceles causing cytotoxin-mediated local cutaneous damage, and the world’s most toxic, Australian Funnel Web Spiders. In Brazil, three groups of spiders are found: Banana Spiders (genus Phoneutria; phoneutrisim), Recluse or Violin Spiders (genus Loxosceles; loxoscelism) and Widow spiders (genus Latrodectus; lactroductism). Widow spiders are widely distributed in all continents including Australia.’

‘Chelicerae’ of spiders are mouthparts made up of a basal portion containing venom glands and hollow fangs that inject venom (chelicerae are often called fangs or jaws). Almost all spiders use their fangs to inject venom, and while most cannot bite through human skin, some can inject dangerously toxic doses into people (also into pets and livestock), and some people are allergic to small amounts. Some scientists hypothesise that harmful spider bites during the evolution of humans may have resulted in genes favouring instinctive fear of spiders (a similar situation may exist regarding fear of snakes). The amygdala region of the brain appears to play a role in the fear response, and experiences with dangerous spiders and snakes may have sensitised this region to fear these animals (Spitzer 2005).

Many people find spiders to be spooky, but for a minority they are terrifying. Significant fear of spiders is widely known as arachnophobia, but some authorities employ the term araneophobia for fear of spiders, while employing the word arachnophobia to also include related arachnids such as scorpions, ticks and

---

**Textbox 10. What would happen if all mosquitoes were eliminated?**

This is where the opinions of many scientists differ. Some say that it would actually be alright, because another species would simply take their place in the ecosystem. (We just don’t know if that other species would be better or worse for us than mosquitoes). Others say that every animal plays an important role in the ecosystem, so removing them entirely could have a lot of negative effects. Mosquitoes are a source of food for a lot of birds, fish, and even plants, so many animals would actually suffer from their extinction. So currently, scientists are working on ways to kill only the species that carry deadly diseases like malaria – or genetically modify them, so that they either can’t carry the disease anymore, or die before they can infect humans with it.

– Sirwinchester (2016)
mites. Fear of spiders ranks with fears of snakes, heights and public speaking as the leading phobias (Curtis et al. 1998). Studies of responses to different classes of arthropods have shown that people show relatively high fear of spiders (Gerdes, Uhl, and Alpers 2009). Women have been found to have a greater fear of spiders than men (Cornelius and Averill 1983), consistent with the same observation for fear of snakes. A survey in Sweden reported that 5.5% of adults and children have snake phobias and 3.5% have spider phobias, and that these phobias are suffered by about four times more women than men (Fredrickson et al. 1996; Figure 44). This might indicate that women have superior genetic adaptation to avoid dangerous animals that could harm their relatively susceptible infants, or alternatively, that men are adapted to greater risk behaviour (Bower 2009). It is important to understand that arachnophobia and indeed other fears of animals are psychological illnesses that can be treated (Bouchard, Wiederhold, and Bossé 2014), and those suffering from such medical conditions should not be condemned as haters of biodiversity. Irrational fear of spider bites has been known since ancient times. In the Middle Ages, a hysterical condition called tarantism (for the Italian province of Taranto, where the mania was first reported), involving

Figure 43. Examples of extremely toxic spiders. (a) The Sydney Funnel-web Spider (*Atrax robustus*) is a native of eastern Australia. Males (above) wander more than females (below), and so tend to be involved more in biting humans. Deaths of humans have not been reported for decades, thanks to the use of anti-venom since 1981. Photo of a display at the Australian Museum, Sydney by Sputniktilt (CC BY SA 3.0). (b) The Brazilian Wandering Spider (*Phoneutria nigriventer*) is native to South America. Several other species of *Phoneutria* are also called Brazilian Wandering Spider, and the name ‘Banana Spider’ is also used because they are often found in shipments of bananas. These large, aggressive spiders are responsible for serious poisonings in South America, but also in other countries when found in exported bunches of bananas. Photo by João P. Burini (CC BY SA 3.0). (c) The Western Black Widow (*Latrodectus hesperus*) of western North America. Photo by Marshal Hedin (CC BY 2.0). Spiders of the genus *Latrodectus* occur on several continents, and are known as black widow spiders and brown widow spiders (‘widow’ in the name is based on the female’s habit of often eating the males following sex). Female widow spiders have relatively large venom glands and, unlike the males, their bite can be harmful to humans, although death or serious complications are rare. The three North American black widow species are considered to be the most poisonous spiders on the continent.
mass frenzied dancing, was claimed to arise from spider bites, although the cause is unclear (Donaldson, Cavanagh, and Rankin 1997).

Dislike of spiders is likely not only because a small minority of species are actually dangerous. In terms of human preferences, most people find spiders unattractive physically. However, some spiders are quite beautiful, rivalling butterflies in their brilliant combination of colour (Figure 45). Nevertheless, the behaviour of spiders does not endear them to people. Spiders are literally ‘creepy’ in the way they move. And, their hunting and feeding style – ambushing and/or laying sticky traps, paralysing their prey and sucking them dry – are gruesome in human terms. Cobwebs in houses, sometimes with the remains of insect corpses, need to be cleaned away regularly, generating additional resentment of spiders.

**Beneficial aspects**

Spiders do not deserve their bad public reputation as dangerous. Frequently, bites blamed on spiders came from mosquitoes, biting flies or fleas, and indeed undiagnosed skin irritations are often termed ‘spider
bites’ (spider bites may show two puncture marks from the fangs). Almost all spiders, including venomous species, are timid, avoiding confrontation with humans and biting only in self-defence, typically when handled, cornered or injured. Most spider bites are less painful than a bee sting. Spiders are not transmitters of diseases.

Spiders play a critical role in controlling insect pests (Maloney, Drummond, and Alford 2003; Ndava, Llera, and Manyanga 2018), their primary food, although they occasionally eat plant material (Nyffeler, Olson, and Symondson 2016). In turn, spiders are food for some insects and for many vertebrates, including birds, reptiles, amphibians and mammals. Fried spiders are a delicacy in Cambodia (Figure 46), and the practice of consuming spiders (‘arachnophagy’) by indigenous peoples is well known (Meyer-Rochow 2004). Spiders are deliberately employed as biological control agents to reduce pest insects (Riechert and Lockley 1984; Young and Edwards 1990; Marc, Canard, and Ysnel 1999; Sunderland 1999). Spider venom is being explored for its potential medicinal properties (Matavel, Estrada, and De Marco Almeida 2016; Ting et al. 2019), and pesticide possibilities (Ikonomopoulou and King 2013; King and Hardy 2013). Spider silk also has possible medical applications (Harvey et al. 2016a), and it has been speculated that spider silk genes could be inserted into bacteria, other insects and plants to transform them into silk sources (Liu, Wang, and Li 2011). Spiders are key components of many ecosystems, and are potentially useful indictors of ecosystem health (New 1999; Textbox 11).

Conservation aspects

‘The IUCN Red List of Threatened Species is the most widely used information source on the extinction risk of species ... Spiders currently comprise over 47,000 species described at the global level. Of these, only 200 species (0.4%) have been assessed’ (Seppälä et al. 2018). Unfortunately, the negative view of spiders by most people makes their conservation a challenging endeavour (New 1999; Skerl 1999; Textbox 12), and their image is in need of rehabilitation. Most illustrations of spiders make them seem quite threatening (but note Figure 47).

Textbox 11. Spiders as climatic indicators.

When the French chemist Quatremere-Disjonval was imprisoned in Utrecht after being banished from France by Napoleon, he reputedly learned to predict the weather by observing spiders and their webbing behaviour. Consequently, he was able to predict a period of freezing weather when Utrecht was under siege by the French in 1795; his message smuggled to the French general was instrumental in the successful capture of the city. Quatremere-Disjonval, released in gratitude, was perhaps the first person to utilize spiders directly as a climatic indicator.

– New (1999)

Figure 46. Spiders as food. (a) The Edible Spider (*Haplopelma albostriatum*) of Southeast Asia. Photo by www.universoaracnido.com (CC BY SA 2.5). This palm-sized tarantula is quite venomous, but the toxin is believed to be neutralised by frying. The spider occupies burrows in the ground, from which it is collected, but it is also often reared in holes in the soil for later harvest and marketing. (b) Fried spiders for sale at a market in Skuon, Cambodia. Photo by Mat Connolley (Matnkat) (CC BY SA 3.0).
Textbox 12. Conservation challenges facing spiders.

Spiders, like many invertebrates, receive little attention from the conservation community. This may be due to fear and dislike of their appearance, behaviour or venomous nature; the fact that most spiders are probably widely dispersed and not presumed to be threatened; or because relatively little is known about the distribution and abundance of these creatures... There are many reasons to conserve spiders, even without considering that all species have intrinsic value in and of themselves. Spiders are clearly an integral part of global biodiversity since they play many important roles in ecosystems as predators and sources of food for other creatures. Spiders also have utilitarian value. For many years spiders have been model organisms for research in ecology, behaviour and communication. They may also be important as biological control agents in agro-ecosystems, providers of silk for materials science, and suppliers of venom for both medical and insecticide research... Many threats to spider diversity have been documented. The primary threat is habitat loss and degradation, as with many other elements of biodiversity. More specifically, some spiders have become imperilled due to urban development, land-use management techniques, air and ground water pollution by pesticides and fertilizers, the introduction of alien species, and in some cases, collection and trafficking due to the pet trade. For a few species, these threats have pushed them to the threshold of extinction.

– Uniyal (2004)

Termites

Termites are a group of about 2300 insects closely related to cockroaches (Inward, Beccaloni, and Eggleton 2007). Most are 4 to 15 mm in length, although queens of Macrotermes bellicosus are over 10 cm. Termites are very successful, occurring on all continents except Antarctica. There are about 1000 species in Africa, and about 400 in each of Asia, South America and Australia. Relatively few species are in North America and Europe, as termites are generally not cold-adapted. Termites divide labour among reproductive males and females (‘Kings’ and ‘Queens’), and sterile ‘workers’ and ‘soldiers’ (Figure 48(a)). This social structure is reminiscent of the organisation found in some bees and wasps, and especially in ants. Termites are not ants, although they are sometimes called ‘White Ants’. The Kings and Queens have a brief winged phase (at which time they are called ‘alates’; Figure 48(b)), while the sterile forms are wingless and are mostly blind. Worker termites are usually the type found in infested wood, as in many species they have the role of digesting cellulose in wood, and feeding the other castes. Some termites are remarkable. The Queens of some species live for as long as 50 years, a record among insects. Some termites build huge, elaborate mounds (Figure 49), considered to be the greatest architectural achievement in the insect world. Most termites construct nests, often underground (Eggleton 2011).

Harmful aspects

Several hundred termite species significantly damage wooden buildings (Su and Scheffrahn 2000; Figure 50) and crops, both herbs and trees (Rouland-Lefèvre 2011). In some countries, damage to buildings amounts to billions of dollars annually. Extremely toxic pesticides are often used to control termites, and if not applied professionally, damage to biodiversity and humans may result. ‘They are the most problematic pest threatening agriculture and the urban environment... especially in the semi-arid and sub-humid tropics’ (Verma, Sharma, and Prasad 2009). Termites are thought to be responsible for producing as much as 11% (some estimates are as high as 40%) of the greenhouse atmospheric gas methane as a result of the digestion of cellulose (Zimmerman et al. 1982; Thakur, Hooda, and Jeeva 2003; Ritter 2006). While termites can be beneficial to nature, ranchers often find them objectionable.

More than 2 dozen termite species are considered to be invasive (Evans, Forschler, and Grace 2013). The Formosan Subterranean Termite (Coptotermes formosanus, Figure 48), actually a native of China, may be the most destructive of all termites. It is often called the super-termite because it is invasive in many areas of the world, producing huge colonies (some with millions of insects) and consuming wood at an alarming rate (sometimes an individual eats 400 g/day). It is one of North America’s most serious insects pests, estimated to cause over 1 billion dollars in damage annually in the southern U.S. Several

Figure 47. “Friendly spider’, a late 19th century advertising image (public domain) for the Merrick Thread Company, which suggested their thread was as strong as spider silk.
other termite species are also considered extremely destructive (Govorushko 2019).

**Beneficial aspects**

Termites primarily consume dead plant material, such as wood, litter and animal dung. Their recycling of organic matter is of huge ecological significance in subtropical and tropical areas, particularly improving tropical soils (Donovan et al. 2001; Mokosesse et al. 2012). They also play an important constructive role in temperate forests (Maynard et al. 2015). Termites are food for numerous predators, including insects, especially ants, also spiders, lizards, frogs, toads, many birds and numerous mammals including some specialists such as aardvarks, aardwolves, anteaters (Figure 51) and pangolins. Termites are eaten and employed as folk medicine by some ethnic groups (Figueirêdo et al. 2015).

**Figure 48.** Formosan Subterranean Termites (*Coptotermes formosanus*). (a) Most of the termites are workers; the soldiers present have larger (orange) heads with large jaws. (b) Winged (alate) stage. Public domain photos by Scott Bauer, Agricultural Research Service, U.S. Department of Agriculture.

**Figure 49.** African elephants next to a termite mound (constructed by *Macrotermes* sp.) in Tanzania. Photo by Whitney Cranshaw, Colorado State University/Bugwood.org (CC BY 3.0).

**Figure 50.** Termite damage (from *Reticulitermes* sp.) to a house in Mississippi that was less than 5 years old. Photo by Wood Products Insect Lab, USDA Forest Service, Bugwood.org (CC BY 3.0).
Conservation aspects

Termites play a surprisingly significant role in supporting ecosystems and maintaining habitat for many other animals. Their mounds provide living quarters for many species, especially ants (Dejean and Durand 1996; Dejean, Bolton, and Durand 1997). Termite mounds also appear to play a valuable role in stabilising climates and biodiversity (Bonachela et al. 2015; Textbox 13).

Textbox 13. The value of termites for stabilizing climate, biodiversity, and food production.

Termites might not top the list of humanity’s favourite insects, but new research suggests that their large dirt mounds are crucial to stopping the spread of deserts into semi-arid ecosystems and agricultural lands... In the parched grasslands and savannas, or drylands, of Africa, South America and Asia, termite mounds store nutrients and moisture, and – via internal tunnels – allow water to better penetrate the soil. As a result, vegetation flourishes on and near termite mounds in ecosystems that are otherwise highly vulnerable to ‘desertification,’ or the environment’s collapse into desert.

– Kelly (2015)

Worms and termites are not likely to win hearts and minds, but they, along with lichens and microbes, are vital to food security... Worms, termites, lichens and soil microbes may well be the heroes of food production as without these species land-based biodiversity would collapse and food production cease... Safeguarding the underlying ecological foundations that support food production, including biodiversity, will be central to feeding seven billion inhabitants, climbing to over nine billion by 2050.

– Jena (2012)

Ambivalency about the values of termites

As for many of the invertebrates discussed in this paper, from a human perspective, termites may be both harmful and useful (Ibrahim and Adebote 2012; Govorushko 2019; Textbox 14). ‘Termites are viewed as both beneficial and destructive in many ecosystems. In some instances they are thought to be important in nutrient cycling and soil formation, whereas in others they are regarded as major factors in range deterioration and soil erosion’ (Bodine and Ueckert 1975).

Textbox 14. Ambivalency about the values of termites.

Although termites are excellent decomposers and have a positive impact on numerous ecological functions, they become serious issues when they attack crops and constructions. Consequently, the positive roles played by termites are often overshadowed by their status as pests threatening agriculture in the tropics where billions of US$ are annually spent on their prevention and extermination... more effort has been spent on eradicating termites than on understanding their environmental impacts, and/or how to use their impacts for improving specific ecological functions in agro-ecosystems. Hence, it appears that the role of termites, as ecosystem service providers, is clearly under-appreciated and that more research is needed to better evaluate the importance of termite activity and diversity in tropical agro-ecosystems.

– Jouquet, Chaudhary, and Kumar (2018)
Ticks

Ticks include about 1000 species of small (usually 3–5 mm long) relatives of spiders, discussed previously (Sonenshine and Roe 2014; note Figure 52). They are distributed worldwide, from the Arctic to tropical regions, occurring especially in countries with warm, humid climates. Ticks have been assigned to subclass Acari of the arthropod class Arachnida. There are two major families of ticks, about 80% of species in the Ixodidae (hard ticks, so-called because of their hard dorsal shield) and 20% in the Argasidae (soft ticks, with a flexible leathery cuticle). A third family, the Nuttalliellidae, has just one species. The classification of ticks requires study (Mans et al. 2019). Ticks are blood parasites, feeding on mammals, birds, and to a much lesser extent on reptiles and amphibians. Ticks cannot fly or jump. They crawl up on low vegetation, awaiting animals to which they adhere. They feed by cutting a hole in the skin of their hosts, attaching by a harpoon-like barbed structure (the hypostome) near the mouthparts, while injecting an anticoagulant or clotting inhibitor to keep the host’s blood flowing. Males and females tend to be distinctive (Figure 53(a,b)). Some ticks are capable of consuming 100 times their weight in blood, and they can become quite swollen after feeding for some time (Figure 53(c)). Migrating birds can carry ticks, along with the diseases they harbour, for long distances (Cohen et al. 2015).

Figure 52. Paintings (public domain) of ticks, by Wilhelm Döntz in Schultze and Döntz (1910). Original identifications: 1 – Hyalomma hippopotamense (female), 2 – (male); 3 – Amblyomma marmoreum (male); 4 – Amblyomma variegatum (male); 5 – Amblyomma variegatum (female); 6 – Amblyomma hebraeum (male); 7 – Amblyomma hebraeum (female); 8 – Dermacentor rhinocerinus.
Harmful aspects

Ticks transmit diseases among animals, including humans, livestock, pets and wild species (Magnarelli 2009; Asebe, Hailu, and Basu 2016). ‘Among arthropod vectors of disease, ticks transmit the most diverse array of infectious agents and ticks are the most important arthropod vectors, globally, of pathogens to humans and domestic animals’ (Kikel 2018). Bloodborne infectious agents may be bacteria, viruses and protozoa. The bacterium *Rickettsia* can cause typhus, African tick bite fever, Rocky Mountain spotted fever and other serious conditions. Additional diseases carried by ticks include Colorado tick fever, tularaemia, Lyme disease and many more (CDC 2018). The venomous Australian Paralysis Tick can cause paralysis. Many other ticks that attach and suck blood near the spinal cord can also produce a condition called ‘tick paralysis’ in humans and other animals. ‘Tick toxicosis’ is a condition that causes sickness and death in animals (Nicholson et al. 2018). Livestock production around the world suffers enormous losses due to ticks (Narladkar 2018). Tick-caused wounds promote secondary microbial infections and reduce the value of the hides of livestock. As blood parasites, ticks in large number can cause anaemia. Climate change is affecting the distribution of ticks, sometimes warmer, more humid conditions extending the range of diseases (Dantas-Torres 2015; Oliveira, Gazeta, and Gurgel-Gonçalves 2017). Enormous research efforts are underway to control ticks, but some pessimism has been expressed about the prospects of success (Pfeiffer 2018).

Lyme Disease (named after Old Lyme, Connecticut, where the disease was first diagnosed), caused by bacteria of the genus *Borrelia*, is the most common and the most widely feared tick-transmitted disease in the Northern Hemisphere (Figure 54). It has been estimated that about 300,000 new cases of infection are occurring annually in the U.S. (Kuehn 2013). Lyme Disease is carried by ticks belonging to the genus *Ixodes*, notably the Deer Tick (*I. scapularis*) of eastern North America, the Western Black-Legged Tick (*I. pacificus*) of the West Coast of the U.S., the Sheep Tick (*I. ricinus*) of Europe, and the Taiga Tick (*I. persulcatus*) of China.
Fear of ticks, unfortunately, discourages people from enjoying the outdoors. It encourages the use of pesticides. It also raises distrust of wild animals, especially birds, deer and rodents, which may be carriers of tick-borne diseases.

**Beneficial aspects**

Ticks are consumed by birds (Figure 55), reptiles, amphibians, insects, nematodes and mites, and so contribute to the orderly cycling of food energy in ecosystems. Like all parasites, ticks regulate the population sizes of their hosts, preventing excessive expansion that might disturb ecosystem functioning. There is evidence that tick diversity can serve as an index to local animal biodiversity (Esser et al. 2019).

**Conservation aspects**

Ticks that are obligate parasites of a given host species are of course dependent for survival on that species. For example, the Sambar Deer (*Rusa unicolor*) has four specifically associated ticks, which would become extinct if the deer were extinguished. In fact, dozens of ticks are in danger of extinction (Durden and Keirans 1996; Mihalca, Gherman, and Cozma 2011), and ticks have been identified as being especially subject to extinction because of climate change (Carlson et al. 2017a). Because these blood-sucking parasites are despised and can transmit viruses, bacteria and pathogenic protozoans to a variety of hosts, it is difficult (perhaps virtually impossible) to promote their welfare.

**What are invertebrates good for?**

This paper has examined the most disliked of invertebrates, which have contributed to the very poor image of invertebrates in general. It is important to educate the public about the importance of invertebrates, and the following contributions to human welfare have been advanced as their chief values. (1) The principal importance of invertebrates is their indispensable values in contributing to ecosystem functions (New and Yen 1995; Kellert 1996; Cock et al. 2012). Soil invertebrates (including arthropods, mollusks, nematodes, protozoa and especially worms) are essential to the health of soil. Invertebrates are also necessary to decompose waste and recycle organic matter, and indeed without their contributions we would be living in a world of dung. (2) Most pollination is conducted by insects, without which agriculture and indeed civilization would be in dire straits (Basu and Cetzal-Ix 2018; Figure 56). (3) Invertebrates directly or indirectly provide food for humans, livestock and harvested animals. Wild game animals, particularly fish, have frequently fed on invertebrates, so indirectly food is made available to people. Invertebrates also furnish food directly to humans (e.g. shrimp, clams, crabs, lobsters, oysters, honey). (4) Invertebrates provide a variety of non-food economic products (e.g. pearls, dyes, shellac, silk; Figure 57). (5) Invertebrates are occasionally employed medicinally (e.g. leeches for stitching wounds) and have great potential as sources of pharmaceuticals (Textbox 15). (6) Invertebrates are also

---

**Figure 55.** Red-billed Oxpeckers (*Buphagus erythrorhynchus*) feeding on ticks infesting Cape Buffalo (*Syncerus caffer*) at Kruger National Park, South Africa. Photo by Derek Keats (CC BY 2.0).

**Figure 56.** Bee visiting a rose. Pollinators, particularly insects, are essential for many crops and for reproduction of numerous wild plants. Photo by Debivort (CC BY SA 3.0).
widely employed in laboratory research. (7) So-called ‘beneficial insects’ are predators of other insect species that are detrimental to humans, especially agricultural pests. Some invertebrates are useful as biocontrol agents, because they feed on pests (either animals or weeds). (8) Some invertebrates provide habitats for other, economic species. Coral polyps build coral reefs, the home of a quarter of all ocean species, including many consumed by humans (9) Invertebrates are often displayed in educational and amusement exhibits (such as aquaria and insectaria). (10) Invertebrates are excellent bioindicators of the health of habitats (McGeoch et al. 2011). Although invertebrates make up as much as 97% of all animal species, they receive far less biodiversity research than vertebrates (Titley, Snaddon, and Turner 2017). ‘Despite their high diversity and importance for humankind, invertebrates have largely been neglected in conservation studies and policies worldwide’ (Cardoso et al. 2011).

Textbox 15. The potential value of invertebrates as sources of invaluable medicinals.

Infectious diseases pose a serious threat to humankind, accounting for an estimated 17 million deaths. These statistics comprise a daily toll of 50,000 men, women, and children dying, despite advances in antimicrobial chemotherapy. Contrary to the wide belief that infectious diseases have been largely alleviated, malaria, cholera, and tuberculosis alone remain significant threats, while HIV/AIDS, Ebola, dengue, and Zika pose a major risk to human health. Hence, there is an urgent need to discover novel and effective antibiotics. This has sparked the antibiotic hunt from natural sources. Plants and marine algae have often been acclaimed for their beneficial antimicrobial properties. However, instead of focusing on an extinguishable antimicrobial source from the flora, it would be interesting to consider the fauna as well. Since invertebrates represent a staggering 95% of the fauna and have existed for millions of years in hazardous environments, they are promising candidates. These creatures are believed to have developed antimicrobials to protect themselves from the pathogenic microbes.

– Mosaheb, Khan, and Siddiqui (2018)

Ethical welfare issues in relation to biodiversity conservation

One of the significant uses of invertebrates is as experimental animals. Fruit flies and nematodes, for example, have been mainstays of genetic studies. Generally, regulations demand humane treatment of vertebrates in laboratories, farms, zoos and in nature, a reflection of how similar humans are to other vertebrates, and how we consequently have compassion, empathy and pity for our nearest animal relatives. In contrast, except occasionally for the largest cephalopods (particularly octopuses), invertebrates are not protected from infliction of pain or tissue damage of any kind by humans. Key to this ‘animal rights’ philosophical issue is whether invertebrates are capable of experiencing pain and suffering, or even if they experience consciousness and stress in ways comparable to humans. (Horvath et al. 2013). If ‘lower animals’ are no more capable of experiencing pain than plants, then humane treatment of them seems irrelevant to many. This is a much-discussed and unsettled issue for invertebrates, and indeed there are ongoing debates regarding the humane treatment of all animals.

Kind treatment of animal species and biodiversity conservation of animal species are different ethical issues. However, there is some overlap, because promoting sympathy for the welfare of animals (especially if they are cute and cuddly) is a very effective way of increasing support for...
biodiversity. Moreover, although concern for inflicting pain on invertebrate species and concern for their extinction are different issues, it is probably true that conservation-oriented people – indeed many who love animals or nature in general – also tend to support humane treatment of sentient creatures. But most people, however much they strongly object to causing pain to vertebrate animals, are much less generous to invertebrates, and it does seem that, at least in Western societies, the majority are substantially or completely indifferent to the possibility of invertebrate suffering. This lack of concern is a substantial barrier to enlisting support for biodiversity conservation, and this paper argues that it is due in considerable part because the most familiar invertebrates are mainly reviled pests. Some Asian religions, notably Jainism, accept even the tiniest of invertebrates as genuinely sentient creatures meriting considerable human respect and protection (Rankin 2018). Ancient Jain monks had such respect for all forms of life that as they walked they would sweep the ground in front of them to avoid stepping on even the humblest of insects. Even some modern Jains wear cloth over their nose to avoid accidentally inhaling small flying insects like gnats! Spiritual and religious movements have important roles to play in persuading society that invertebrates deserve much more consideration than they currently are afforded.

What are parasites good for?

Half of the invertebrates discussed in this series are parasites (bedbugs, fleas, leeches, lice, mosquitoes and ticks), which are perhaps the most despised of all reviled creatures, responsible for huge investments to eliminate them (e.g. Figure 58). Parasites are by no means limited to invertebrates: they also occur in vertebrates and flowering plants, and especially in fungi and microorganisms. Indeed, it is commonly estimated that about 50% or more of all species are parasitic (Jones 2015). Nevertheless, the very high incidence of blood parasites of humans has contributed to the very poor image of invertebrates in general. It is important to educate the public about the importance of parasites, which as explained in the following is mainly as major regulators of animal populations.

Parasites are organisms that live in or on individuals of another species (the hosts), deriving nutrients at the hosts’ expense. (A more expansive definition of biological parasite would broaden the meaning to include reliance of one species on another species for existence or support without adequate compensation. For example, ‘brood parasites’ are species that rely on others to raise their young, as illustrated by cuckoo species.). As noted earlier, to be judged as ‘despicable’ species need to be visible, and ‘microparasites’ such as viruses and some bacteria are too small to evoke this judgement, while ‘macroparasites’ that are at least the size of lice and ticks are the ones that evoke hatred.

Parasites keep populations of their hosts in check, and stimulate their hosts to evolve more efficient protective adaptations. Almost certainly the world would have far less interesting biodiversity were it not for parasites. As people, our human values and personal experiences with parasites leads us condemn their life styles on moral (‘parasites are evil’) and aesthetic (‘parasites are repulsive’) grounds, but Nature makes no such judgements, and those who advocate on behalf of biodiversity need to strive to keep an open mind. Many of mankind’s most hated parasites have some significant medical uses, as pointed out earlier. Numerous parasites are used in ‘biological

Figure 58. Advertisement for Buchan’s Carbolic Disinfecting Soap, featuring two children giving a large dog a bath using the soap. Product information claimed that the medicine ‘kills all parasitic life on man or beast.’ Public domain photo from the U.S. National Library of Medicine.
control’ as natural predators to eliminate introduced pests of natural and agricultural landscapes (illustrating the maxim ‘the enemy of my enemy is my friend’). Particularly important in this regard are ‘parasitoids’, species that live on or in a host, eventually killing it (Figure 59). About 10% of described insect species are parasitoids, mostly in the Order Hymenoptera (which includes bees, wasps and ants).

The ‘hygiene hypothesis’ holds that ‘Decreased exposure to infectious agents early in life increases susceptibility to allergy (and perhaps autoimmune diseases) by limiting immune system development’ (Kerkosiek 2008). Intrinsically in this idea is that many parasites are actually beneficial to the immune system of some humans, and have therapeutic potential (Capron 2011; Dhingra, Sharma, and Dwivedi 2013; Tunnessen and Hsieh 2018). Autoimmune diseases such as arthritis, asthma, diabetes and multiple sclerosis are caused by the body excessively reacting to its own constituents, especially T-cells attacking proteins. But what may be an excessively active immune system today could have been adaptive for our ancestors, who had to endure a far greater load of parasites than today’s people. Some physicians have reasoned that deliberately infecting autoimmune patients with parasites may serve to channel the immune system’s attack towards the parasites, and away from the patients’ bodies. Another hypothesis deals with intestinal parasites that remain for very long periods within the body. In this case, it has been reasoned that such parasites deliberately weaken the immune system so they will not be attacked, and if so, this may benefit autoimmune patients by also weakening the attack on their bodies. Although it seems disgusting, some autoimmune patients today are deliberately swallowing intestinal parasites to improve their overall health. It has been claimed that some people in the early 19th century consumed tapeworm eggs so that the resulting tapeworms would cause them to lose weight; this extreme form of dieting appears to be mythical, and is certainly dangerous. There is some interest in exploring the medical application of parasites to relieve some conditions (Sobotková et al. 2019). It also needs to be noted that while parasites take advantage of other species, they themselves are subject to very extensive predation by other species, and thereby contribute to food chains and webs (Orlofske, Jadin, and Johnson 2015). When all is said that can be found in defence of parasites (Textbox 16), they are perhaps the hardest creatures to defend (Textbox 17).

**Textbox 16. In defence of conservation of parasites.**

A growing body of work has shown that parasites are a critical part of ecosystems, acting as regulators of food webs and host populations, and serving an important role in energy flow through trophic levels. The increasingly apparent benefits of parasites make a case for their recognition as an important neglected target for conservation, especially given that parasitic life cycles are already known to be particularly extinction-prone due to cascading co-extinctions with hosts... While institutions such as the IUCN have spent decades developing centralized frameworks for prioritizing the conservation of free-living biodiversity, parasites are rarely included in mainstream assessments; for example, only two animal macroparasites are listed on the IUCN Red List (Hematopinus oliveri, the pygmy hog louse, and Hirudo medicinalis, the medicinal leech). The under-representation of parasites speaks to... the comparative bias against parasites in conservation.

– Carlson et al. (2017b)

Parasites, particularly the host-specific species, are perhaps the most imperilled group of organisms on Earth. Specialized parasites are at the mercy of their host species, which actually makes them more prone to extinction than their hosts... this cryptic loss effect means many parasite species are at risk of extinction, even if they are not currently recognized as such. For every threatened vertebrate species listed on IUCN Red List, there is a number of unrecognized co-threatened parasites waiting to go extinct should their host decline... Why should we worry about conserving parasites? It turns out that despite the negative connotations of the word, most parasites don’t kill their hosts, and they play some important roles. We certainly know that parasites play key roles in food chains, nutrient cycling and in helping their host’s immune system stay strong and effective.

– Platt (2018)
Textbox 17. Equal rights for parasites?.

An important issue in conservation biology is lying dormant. The term biodiversity seems to be used almost entirely for free-living animals and plants. Parasites seem to be ignored or regarded as a threat to the conservation of endangered species… Parasitology is usually taught from a medical or veterinary perspective in which parasites are nasty critters to be eliminated. Informing most people, even most biologists, that parasites are going extinct is sure to bring a response such as ‘good riddance.’… Parasites are part of our biosphere and we, as biologists, must accord them the same respect we exhibit for their hosts. If we truly appreciate biological diversity, we must advocate that all species are precious, even parasites… My concern for this matter was expressed in my slogan ‘Equal Rights for Parasites!’ Apparently, this slogan is not as catchy as I had hoped, because it has not caught on.

– Windsor (1995)

Insect conservation challenges

Textbox 18. Challenges to the conservation of insects.

An estimated 11,200 species [of insects] have gone extinct since the year 1600. Some estimates are that half a million insects may go extinct in the next three hundred years, while some projections suggest that perhaps a quarter of all insect species are under threat of imminent extinction… Only about 10% of all insects have scientific names, with many taxonomic revisions still required… Describing all unknown species before they become extinct is the taxonomic challenge. Another great challenge for insect conservation is the perception challenge. Even among some general conservation practitioners, insects are often considered insignificant or given scant attention. This lack of appreciation of insects can reach major proportions among some sectors of human society, who may only recognize the dirty cockroach and the nuisance fly.

– Samways (2007)

Biodiversity loss has become a major global issue, and the current rates of species decline – which could progress into extinction – are unprecedented. Yet, until recently, most scientific and public attention has focused on charismatic vertebrates, particularly on mammals and birds, whereas insects were routinely underrepresented in biodiversity and conservation studies in spite of their paramount importance to the overall functioning and stability of ecosystems worldwide… At present, about a third of all insect species are threatened with extinction… The pace of modern insect extinctions surpasses that of vertebrates by a large margin… Because insects constitute the world’s most abundant and speciose animal group and provide critical services within ecosystems, their… cannot be ignored and should prompt decisive action to avert a catastrophic collapse of nature’s ecosystems.

– Sánchez-Bayo and Wyckhuys (2019)

Textbox 19. ‘The only good insect is a dead insect’.

In recent decades, there is no mistaking the fact that Western attitudes towards the natural world have changed markedly. Protecting endangered species, preserving wilderness areas, moderating global warming and sustaining fragile ecosystems are common themes of modern life… Unfortunately, however, this apparent newfound love for and connection to the natural world has not pervaded the insect world. How is it that we have come to embrace the preservation of and a deep affinity with whales, wolves, polar bears, cats, dogs and gerbils, to name just a few, while at the same time kill without hesitation any and all creeping, crawling things that have the misfortune of crossing our paths? For all the progress the human species has made in recent decades towards finding its way back to nature, the language of war, loathing and eradication still informs our attitude towards insects. We seem locked in an engrained specicide that sanctions the wholesale extermination of insects – as if by doing so the world would be a much better and safer place for everyone. When it comes to insects, it seems our mantra is ‘Kill often, kill on sight, and kill mercilessly’.

– Ryan (2014)

Perhaps gene drives could be used to suppress or modify populations of insects merely on the grounds that they are nuisances.

– National Academies of Sciences, Engineering, and Medicine (2016)
Why do so many people hate bugs?

Biodiversity fallout of the commercial campaign against household pests

In times of war, exaggerated, unrealistic and ugly visual stereotypes and vicious propaganda have been commonly created to eliminate respect for the enemy, so that they can be eliminated without guilt. Traits that are emphasised include dangerousness, ugliness, prevalence and horrible, disgusting behaviour. Indeed, ethnic groups were commonly labelled as the insect groups discussed here (Rafles 2010). In modern times, a propaganda and chemical war is being waged against invertebrates that ‘invade’ the domain of humans (Figure 60). The chief exposure to invertebrates by most people is the ceaseless advertisements for insecticide sprays and repellents, which depict ‘bugs’ as maliciously as possible. ‘Insect bombs’ and electric ‘zappers’ often boast of killing everything in the vicinity, omitting any mention of harm to beneficial species. The fear of disease factor is typically highlighted, emphasising for example that mosquitoes carry Zika virus and ticks transmit Lyme disease. Additionally, housekeepers are often warned that their domicile won’t be ‘clean’ or smell good if insects are present. Often, it is suggested that a chemical barrier needs to be laid down to prevent surreptitious entry into the home of any form of creepy-crawly. And, since household pests usually remain hidden, pest control companies offer inspections to relieve homeowners’ anxieties. The result is not just that most people do not hesitate to kill invertebrates that appear in their homes and gardens, but that they view almost all insects and spiders that they encounter with suspicion, if not indeed with contempt. The harm that this does to the cause of biodiversity preservation is immense, because public
attitudes and values are the ultimate drivers of investment in biological conservation.

The psychology of entomophobia

Wilson (1993) defined ‘biophilia’ as ‘the innately emotional affiliation of human beings to other living organisms’ (cf. definition in Wilson 1984), and suggested that most people instinctively like most other life forms. In reality, most humans are biophobic, i.e. dislike the majority of species they encounter. Earlier, arachnophobia (defined either as fear of spiders or, more generally fear of all arachnids) was discussed. ‘Entomophobia’ has been defined as fear of insects (all or just particular groups), more generally as fear of arthropods, or more vaguely as fear of bugs. There has been much academic and some experimental analysis of whether phobias to animals are learned or instinctive (see earlier discussion of arachnophobia). Lockwood’s (2013) book (available online), The Infested Mind: Why Humans Fear, Loathe, and Love Insects, is perhaps the best analysis of why people dislike bugs. He wrote:

Entomophobia is rooted in six ‘fear-evoking perceptual properties.’ Insects can: (1) invade our homes and bodies; (2) evade us through quick, unpredictable movements, to which it might be added that the furtive skittering of a cockroach, for example, with its head lowered as if slinking out of the room, evokes a sense that the creature is guilty or ashamed; (3) undergo rapid population growth and reach staggeringly large numbers, threatening our sense of individuality; (4) harm us both directly (biting and stinging) and indirectly (transmitting disease as well as destroying woodwork, carpets, book bindings, electrical wiring and food stores); (5) instil a disturbing sense of otherness with their alien bodies – they are real-world monsters associated with madness (e.g. ‘going bugs’); and (6) defy our will and control through a kind of radical mindless or amoral autonomy.

Improving the public image of bugs on behalf of invertebrate conservation

Guiney and Oberhauser (2008) recommended that conservation efforts for insects be focused on charismatic insects, endangered insects and insects that provide important ecological services. Unfortunately there are very few charismatic insects (notably butterflies), and very many endangered insects, and those most in danger of extinction often make their last stands in foreign, hostile, or isolated locations of little relevance to most people. A survey of the use of local charismatic insects to promote conservation among children had mixed results (Schlegel, Breuer, and Rupf 2015).

New (2007), noting the difficulties of garnering support for conservation of insect species specifically, recommended that efforts be directed to campaigns that support communities of organisms, so that invertebrates present would also benefit. In a similar vein, Simaika and Samways (2018) also noted the lack of support for insect conservation, and recommended that this could be improved by efforts to educate the public about the values of nature in general. These approaches, at least, could contribute to the cause of invertebrate conservation.

Education of the public regarding ecological services is certainly in order. Since health has become a major concern of most people, it is important to emphasise the value of insects as sources of natural compounds of medicinal value (Cherniack 2010, 2011), and the fact that since most insect species have not yet even been discovered, their extinction could greatly compromise human welfare. People need to be made aware that ‘Of all insect species, over 97% of those usually seen in the home landscape are either beneficial or are innocent bystanders’ (Stewart and Coverstone n.d.).

Children are frequently naturally curious and sympathetic to many insects (Lockwood 2013), but fear of insects and spiders usually begins in childhood (Hardy 1988), so it is clear that early education is a critical period to generate appreciation of, and diminish fear of bugs. Illustrated children’s books, prepared by nature-friendly authors, are invaluable (Figure 61). Libraries should have such a category prominently displayed. Since children increasingly pass their time in front of electronic screens, carefully prepared digital presentations are needed. Most importantly, contact with living insects is critical. Ideally, teachers and parents should introduce their children to the local fauna, but given the widespread negative attitudes to insects, it may be preferable to leave this task to specialists. Exhibits by museums and zoos, featuring living invertebrates explained by skilled teachers and guides, are likely to be very impressionable on children. Religious professionals also can be extremely helpful, stressing that living things are spiritual creations meriting respect. Regardless of theological tradition, teaching children to respect all species is helpful in generating respect for all people.
Historically, most artists have depicted insects as hostile, ugly, alien and utterly lacking in relatable human qualities. The best children’s books anthropomorphise insects, giving them charm, character and human qualities that serve to emphasise that they are valued citizens of the world (Figure 61). In the cause of increasing support for biodiversity, one cannot underestimate the persuasive value of art featuring animals (Small 2016).

**Synthetic biology and the future of undesirable bugs**

“Synthetic biology’, a catchall term for which a universally accepted definition does not exist, refers to genetic engineering science that attempts, much more substantially than in previous times, to modify the genetic makeup and biology of species, populations and organisms, alter the components and metabolism of natural living systems, and even create artificial life-like systems, all for practical purposes (for background, see Secretariat of the Convention on Biological Diversity 2015; European Commission 2016). The relevance of the diverse synthetic biology possibilities to biodiversity has been recently extensively reviewed (National Academies of Sciences, Engineering, and Medicine 2016; Redford et al. 2019), and analysts foresee both extremely promising advantages and very dangerous hazards for conservation. In the context of this paper, synthetic biology offers possibilities of modifying or even totally eliminating parasites, organisms that produce or vector diseases, and indeed any species considered deleterious, employing a technique termed ‘gene drive’. A gene drive is a ‘system of biased inheritance that enhances the ability of a genetic element to pass from an organism to its offspring through sexual reproduction’ (National Academies of Sciences, Engineering, and Medicine 2016). This technology allows engineered genes to very rapidly infiltrate a population or species, even if the altered genes are detrimental or deadly. (The use of such technology as bioterrorism is a concern. However, not all species are easily susceptible.)

Earlier, the objectives of eradicating cockroaches, mosquitoes and tsetse flies were discussed, and certainly these and some other ‘bugs’ are among the principal candidates under consideration for deliberate extinction (Leftwich, Bolton, and Chapman 2016). This issue is of course a slippery slope, with potentially disastrous unanticipated consequences for ecosystems and biodiversity. The ‘precautionary principle’ (when human activities may lead to unacceptable or irreversible harm, proceed only if or when risk is established to be minimal) has been discussed in relation to synthetic biology (Holm 2019), and the U.N. recently recommended cautions (COPD 2018; noteTextbox 21). However, there are urgent social and economic pressures to reduce the harm of the world’s major pests, and experimentation to eliminate them is proceeding (e.g. McFarlane, Whitelaw, and Lillico 2018; Moro et al. 2018).

Figure 61. Art from children’s stories, sympathetically illustrating insects. (a) The hookah-smoking caterpillar from Lewis Carroll’s ‘Alice’s Adventures in Wonderland’, drawn by John Tenniel, published in 1865. Coloured by MrWalletPants (CC BY 2.0). (b) Cover of ‘The Butterfly Ball and the Grasshopper’s Feast’, a vintage children’s book published in 1800 in Great Britain. Illustrator unknown. Photo by Paul K (CC BY 2.0). (c) Beetle carrying a grasshopper, dragonflies and a gnat flying above, from ‘The Butterfly Ball and the Grasshopper’s Feast.’
Textbox 21. Genetic technologies to eliminate unwanted species are premature because there are uncertainties and unevaluated potential dangers.

Molecular biology has developed at an increasing speed in the last years and now offers the possibility to generate artificial gene drives (GD) to alter or eliminate wild populations. There are now concrete research projects seeking to utilise GD as a ‘silver bullet’ to combat invasive alien species… We consider the technology not to be fit for practical use at present. Because of the potential of GD to alter ecosystems and to eliminate species we recommend adjusting the legal framework and increasing biosafety research, especially on ecological consequences. In addition, ethical and societal questions need to be addressed before the application of GD technology.

– Simon, Otto, and Engelhard (2018) (from the English abstract)

Research on gene drive systems is rapidly advancing. Many proposed applications of gene drive research aim to solve environmental and public health challenges, including the reduction of poverty and the burden of vector-borne diseases, such as malaria and dengue, which disproportionately impact low and middle income countries. However, due to their intrinsic qualities of rapid spread and irreversibility, gene drive systems raise many questions with respect to their safety relative to public and environmental health. Because gene drive systems are designed to alter the environments we share in ways that will be hard to anticipate and impossible to completely roll back, questions about the ethics surrounding use of this research are complex and will require very careful exploration.

– National Academies of Sciences, Engineering, and Medicine (2016)

Most humans respect nature, but when our welfare is at stake, we modify the world to suit our needs. Indeed, far exceeding all other species, we have created our own artificial habitats and ecosystems while sacrificing other species, their habitats, and the world’s natural resources. Environmentalism and the goal of sustainability offer hope of preserving biodiversity but, as argued in this paper, human attitudes to other species is a key determinant that has been insufficiently addressed. As pointed out earlier, more than half of the world’s species are parasites, a life style that we humans detest, and most species are insects, another life form that most humans have learned to disrespect. Most conservationists, indeed most people who love nature, understand that the ecology of the world is complex, fragile, and altered at our peril. Recent history and indeed current events shows that the human species is capable of genocide of its own populations and annihilation of other species, albeit to date by relatively crude, inefficient and slow methods. Today, ‘gene drives could be a tool for modifying wild species to suit human needs, perhaps to bring about their extinction, perhaps to alter them to suit aesthetic preferences’ (National Academies of Sciences, Engineering, and Medicine 2016). The prospect of living in a world without pests, or even just without the most annoying and harmful insects, is seductively attractive, even to dedicated environmentalists and biologists. The public would be much more sympathetic to insects and indeed to nature in general if only the worst bugs were eliminated. The case can be made that driving the greatest enemies of humans to extinction would be beneficial not just for people but for biodiversity (Redford et al. 2019).

Nevertheless, the invention of revolutionary genetic-based extermination biotechnologies is frightening, even if there are desirable potentials, because we humans have demonstrated that we are prone to risky and destructive behaviours. In previous times, the most comprehensive scientific effort to eliminate the world’s pests centred on the insecticide DDT. The Swiss chemist Paul Hermann Müller was awarded the Nobel Prize in Medicine or Physiology in 1948 for developing the chemical as a pesticide. In 1945, Müller announced that DDT could ‘send malaria mosquitoes, typhus lice and other disease-carrying insects to join the dodo and the dinosaur in the limbo of extinct species, thereby ending these particular plagues for all time’ (Russell 2001). DDT, of course, became infamous for its disastrous environmental and health impacts, but it is important to appreciate from the DDT story how we humans are altogether much too eager to adopt technologies that seem capable of eliminating our major invertebrate enemies (Figure 62). This essay has stressed that most people are too prejudiced against invertebrate animals to appreciate that most are harmless, useful and rather admirable. Indeed, numerous ‘bugs’ that provide indispensable services would be crushed underfoot by many, ignorant of the importance of their preservation. Now that technologies are being created that could efficiently eliminate animals considered undesirable, it is critical that efforts be made to highlight the merits of all species, not just the narrow selection that the public currently admires. In particular, the war against the most reviled invertebrate pests needs to be tempered with appreciation of their ecological roles and contributions to the overall welfare of biodiversity.
Figure 62. Illustrations (public domain) from the 1940s showing misplaced enthusiasm to employ DDT for exterminating the world’s pests. (a) Second World War poster, U.S. Department of Agriculture, U.S. National Archives. (b) Detail from an advertisement for Pennsalt DDT products that appeared in Time Magazine, 30 June 1947. Credit: Science History Institute. Philadelphia.

Acknowledgements

Brenda Brookes skillfully assembled and enhanced the illustrations for publication. Bruce Gill provided constructive criticism of the manuscript. Creative Commons Licenses employed in this article: CC BY 2.0 (Attribution 2.0 Generic): http://creativecommons.org/licenses/by/2.0/; CC BY 2.5 (Attribution 2.5 Generic): https://creativecommons.org/licenses/by/2.5/; CC BY 3.0 (Attribution 3.0 Unported): http://creativecommons.org/licenses/by/3.0/; CC BY 3.0 AU (Attribution 3.0 Australia): https://creativecommons.org/licenses/by/3.0/au/legalcode; CC BY 4.0 (Attribution 4.0 International): https://creativecommons.org/licenses/by/4.0/deed.en; CC BY SA 2.0 (Attribution-ShareAlike 2.0 Generic): https://creativecommons.org/licenses/by-sa/2.0/; CC BY SA 2.5 (Attribution ShareAlike 2.5 Generic): https://creativecommons.org/licenses/by-sa/2.5/; CC BY SA 3.0 (Attribution-ShareAlike 3.0 Unported): https://creativecommons.org/licenses/by-sa/3.0/; CC BY SA 4.0 (Attribution ShareAlike 4.0 International license): https://creativecommons.org/licenses/by-sa/4.0/deed.en.

Disclosure statement

No potential conflict of interest was reported by the author.

Notes on contributor

Dr. Ernest Small is a principal scientist with Agriculture Canada, the country’s national department of agriculture, and has held adjunct professorships at several universities. He specialises on the evolution and classification of economically important plants, dealing particularly with food, forage, biodiversity, and medicinal species. Dr. Small has authored 15 books and over 400 journal publications. He has received several professional honours, including appointment to the Order of Canada, the nation’s highest recognition of achievements.

References

Albert, C., G. M. Luque, F. Courchamp, and J. E. Maldonado. 2018. “The Twenty Most Charismatic Species.” PloSOne 13: e0199149. doi:10.1371/journal.pone.0199149.

Al-Khleif, A., M. Roth, C. Menge, J. Heuser, G. Baljer, and W. Herbst. 2011. “Tenacity of Mammalian Viruses in the Gut of Leeches Fed with Porcine Blood.” Journal of Medical Microbiology 60: 787–792. doi:10.1099/jmm.0.027250-0.

Aloto, D., and E. Eticha. 2018. “Leeches: A Review on Their Pathogenic and Beneficial Effects.” Journal of Veterinary Science & Technology 19 (1): 511. doi:10.4172/2157-7579.1000511.

Arroz, A. M., R. Gabriel, I. R. Amorim, R. S. Marcos, and P. A. V. Borges. 2016. “Bugs and Society I: Raising Awareness about Endemic Biodiversity.” In Biodiversity and Education for Sustainable Development, edited by P. Castro, U. M. Azeiteiro, P. Bacelar-Nicolau, W. L. Filho, and A. M. Azul, 69–89. Switzerland: Springer International.

Arruda, K., and A. Pomés. 2013. “Every Cockroach Is Beautiful to Its Mother.” International Archives of Allergy and Immunology 161: 289–292. doi:10.1159/000345139.

Asebe, G., Y. Hailu, and A. K. Basu. 2016. “Overview of the Biology, Epidemiology and Control Methods against Hard Ticks: A Review.” Global Journal of Science Frontier Research: C Biological Science 16: 33–45. https://journalofscience.org/index.php/GJSFR/article/view/1775

Barker, S. C. 1994. “Phylogeny and Classification, Origins, and Evolution of Host Associations of Lice.” International Journal for Parasitology 24: 1285–1291. doi:10.1016/0020-7519(94)90195-3.

Basu, S. K., and W. Cetzal-Ix. 2018. “Call of the Wild: Conservation of Natural Insect Pollinators Should Be a Priority.” Biodiversity 19 (3-4): 240–243. doi:10.1080/14888386.2018.1523747.

Bates, C. 2016. “Would It Be Wrong to Eradicate Mosquitoes?” BBC News Magazine. http://www.bbc.com/news/magazine-35408835

Bell, W. J., L. M. Roth, and C. A. Nalepa. 2007. Cockroaches: Ecology, Behavior, and Natural History. Baltimore: John Hopkins University Press.

Bennett, J. R., R. Maloney, and H. P. Possingham. 2015. “Biodiversity Gains from Efficient Use of Private Sponsorship for Flagship Species Conservation.” Proceedings of the Royal Society B: Biological Sciences 282: 20142693. doi:10.1098/rspb.2014.2693.

Berenbaum, N. 2010. “This Bedbug’s Life.” https://www.nytimes.com/2010/08/08/opinion/08berenbaum.html
Functionnalization of Recombinant Spider Silk Using ‘Click’ Chemistry.” Advanced Materials 1604245. doi:10.1002/adma.201604245.

Harvey, M., N. Gasz, and S. Voss. 2016b. "Entomology-based Methods for Estimation of Postmortem Interval." Research and Reports in Forensic Medical Science 6: 1–9. doi:10.2147/RRFMS.

Hernandez, V. 2018. "Cockroach DNA Sequenced to Identify Genes that are Key to Its Survival." http://eqwnews.com/news/view/14246

Hewitson, W. C. 1856–1876. Illustrations of New Species of Exotic Butterflies: Selected Chiefly from the Collections of W. Wilson Saunders and William C. Hewitson. London: John Van Voorst.

Hodgson, E. W., J. L. Trina, and A. H. Roe. 2008. “Clothes Moths.” Utah State University Extension Paper 877. https://digitalcommons.usu.edu/extension_curall/877

Hogue, J. M. 2009. “Cultural Entomology.” In Encyclopedia of Insects, edited by V. H. Resh and R. T. Cardé, 239–245. 2nd ed. Cambridge, Mass: Academic Press.

Holm, S. 2019. “Deciding in the Dark: The Precautionary Principle and the Regulation of Synthetic Biology.” Ethics, Policy & Environment 22: 61–71. doi:10.1080/21550085.2019.1581419.

Hornok, S., K. Szőke, S. A. Boldogh, A. D. Sándor, J. Kontschán, V. T. Tu, A. Halajian, et al. 2017. "Phylogenetic Analyses of Bat-associated Bugs (hemiptera: Cimicidae: Cimicinae and Cacodinae) Indicate Two New Species Close to Cimex lectularius." Parasites & Vectors. doi:10.1186/s13071-017-2376-1.

Horvath, K., D. Angeletti, G. Nascetti, and C. Carere. 2013. "Invertebrate Welfare: An Overlooked Issue." Annali dell’Istituto Superiori Di Sanità 49: 9–17.

Hurricane Matthew. 2015. "Blog Discussion: How Can We Drive Cockroaches to Extinction?" Personality Café. http://personalitycafe.com/science-technology/542370-how-can-we-drive-cockroaches-extinction.html

Ibrahim, B. U., and D. A. Adebote. 2012. "Appraisal of the Economic Activities of Termites: A Review." Bayero Journal of Pure and Applied Sciences 5: 84–89. doi:10.4314/bajopas.v5i16.16

Ikonomopoulou, M., and G. King. 2013. “Natural Born Insect Killers: Spider-venom Peptides and Their Potential for Managing Arthropod Pests.” Outlooks on Pest Management 24: 16–19. doi:10.1564/v24_feb_05.

Inward, D., G. Beccaloni, and P. Eggleton. 2007. "Death of an Order: A Comprehensive Molecular Phylogenetic Study Confirms That Termites are Eusocial Cockroaches." Biology Letters 3 (3): 331–335. doi:10.1098/rsbl.2007.0102.

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2019. Global Assessment of Biodiversity and Ecosystem Services. Bonn: IPBES. In press.

Iqbal, W., M. F. Malik, M. K. Sarwar, I. Azam, N. Iram, and A. Rashda. 2014. “Role of Housefly (Musca domestica, Diptera; Muscidae) as a Disease Vector; a Review.” Journal of Entomology and Zoology Studies 2: 159–163.

Jackson, J. A., I. M. Friberg, L. Bolch, A. Lowe, C. Ralli, P. D. Harris, J. M. Behnke, and J. E. Bradley. 2009. “Immunomodulatory Parasites and Toll-like Receptor-mediated Tumour Necrosis Factor Alpha Responsiveness in Wild Mammals.” BMC Biology 7 (1): 16. doi:10.1186/1741-7007-7-16.

Jena, M. 2012. “Worms, Termites, Microbes Offer Food Security.” https://ourworld.unu.edu/en/worms-termites-microbes-offer-food-security

Jepson, P., and M. Barua. 2015. “A Theory of Flagship Species Action.” Conservation & Society 13: 95–104. doi:10.4103/0972-4923.161228.

Jones, L. 2015. “What Would Happen if All the Parasites Disappeared?” http://www.bbc.co.uk/earth/story/20150127-what-if-all-the-pests-vanished

Jouquet, P., E. Chaudhary, and A. R. V. Kumar. 2018. “Sustainable Use of Termite Activity in Agro-Ecosystems with Reference to Earthworms. A Review.” Agronomy for Sustainable Development 38: 1–11. doi:10.1007/s1170-017-0483-1.

Kampmann, M.-L., I. B. Schnell, R. H. Jensen, J. Axtner, A. F. Sander, A. J. Hansen, M. F. Bertelsen, A. D. Greenwood, M. T. P. Gilbert, and A. Wilting. 2017. “Leeches as a Source of Mammalian Viral DNA and RNA – A Study in Medicinal Leeches.” European Journal of Wildlife Research 63: 36. doi:10.1007/s10344-017-1093-6.

Kellert, S. R. 1993. “Values and Perceptions of Invertebrates.” Conservation Biology 7: 845–855. doi:10.1046/j.1523-1739.1993.740845.x.

Kellert, S. R. 1996. The Value of Life: Biological Diversity and Human Society. Washington, D.C: Island Press.

Kelly, M. 2015. “Tiny Termites Can Hold Back Deserts by Creating Oases of Plant Life.” https://www.princeton.edu/news/2015/02/05/tiny-termites-can-hold-back-deserts-creating-oases-plant-life

Kerkisie, K. 2008. “Parasites and the Hygiene Hypothesis” Infection Research: News and Perspectives. https://pdfs.semanticscholar.org/a190/371b0efe04fd605a9077d5f5faa200ed1996bf.pdf

Khamesipour, F., K. B. Lankaran, B. Honarvar, and T. E. Kwen. 2018. “A Systematic Review of Human Pathogens Carried by the Housely (Musca domestica L.).” BMC Public Health 18 (1): 1049. doi:10.1186/s12889-018-5934-3.

Kikel, S. K. 2018. “Ticks and Tick-Borne Infections: Complex Ecology, Agents, and Host Interactions.” Veterinary Sciences 5 (2): 60. doi:10.3390/vesci5020060.

King, G. F., and M. C. Hardy. 2013. “Spider-Venom Peptides: Structure, Pharmacology, and Potential for Control of Insect Pests.” Annual Review of Entomology 58: 475–496. doi:10.1146/annurev-ento-120811-153650.

Kirkness, E. F., B. J. Haas, W. Sun, H. R. Braig, M. A. Perotti, J. M. Clark, S. H. Lee, et al. 2010. “Genome Sequences of the Human Body Louse and Its Primary Endosymbiont Provide Insights into the Permanent Parasitic Lifestyle." Proceedings of the National Academy of Sciences of the United States 107: 12168–12173. doi:10.1073/pnas.1003379107.

Kramer, G. R., S. M. Peterson, K. O. Daly, H. M. Streby, and D. E. Andersen. 2019. “Left Out in the Rain: Comparing Productivity of Two Associated Species Exposes a Leak in the Umbrella Species Concept.” Biological Conservation 233: 276–288. doi:10.1016/j.biocon.2019.02.039.

Kuehn, B. M. 2013. “CDC Estimates 300,000 US Cases of Lyme Disease Annually.” Journal of the American Medical Association 310 (11): 1110. September 18. doi:10.1001/jama.2013.278331.
Kularatne, S. A. M., and N. Senanayake. 2014. “Venomous Snake Bites, Scorpions, and Spiders.” Chapter 66. In Handbook of Clinical Neurology Volume 120, edited by J. Biller and J. M. Ferro, 987–1001. Amsterdam: Elsevier.

Kuo, D.-H., and Y.-T. La. 2019. “On the Origin of Leeches by Evolution of Development.” Ecology, Evolution and Development 61: 43–57.

Kutscher, U., I. Pfeiffer, and E. Ebermann. 2007. “The European Land Leech: Biology and DNA-Based Taxonomy of a Rare Species that Is Threatened by Climate Warming.” Naturwissenschaften 94: 967–974. doi:10.1007/s00114-006-0183-1.

Kwak, M. 2018. “Australia’s Vanishing Fleas (insecta: Siphonaptera): A Case Study in Methods for the Assessment and Conservation of Threatened Flea Species.” Journal of Insect Conservation 22: 545–550. doi:10.1007/s10841-018-0883-7.

Kyrou, K., A. M. Hammond, R. Galizi, N. Kranjc, A. Burt, A. K. Beaghton, T. Nolan, et al. 2018. “A CRISPR-Cas9 Gene Drive Targeting Doublesex Causes Complete Population Suppression in Caged Anopheles Gambiae Mosquitoes.” Nature Biotechnology 36: 1062–1066. doi:10.1038/nbt.4046.

LaFrance, A. 2016. “Genetically Modified Mosquitoes: What Could Possibly Go Wrong?” The Atlantic. https://www.theatlantic.com/technology/archive/2016/04/genetically-modified-mosquitoes-zika/479793/.

Lai, K. M. 2017. “Are Cockroaches an Important Source of Indoor Endotoxins?” International Journal of Environmental Research and Public Health 14 (1): 91. doi:10.3390/ijerph141010091.

Lai, O., D. Ho, S. Glick, and J. Jagdeo. 2016. “Bed Bugs and Possible Transmission of Human Pathogens: A Systematic Review.” Archives of Dermatological Research 308: 531–538. doi:10.1007/s00403-016-1661-8.

Latchininsky, A. V. 2013. “Locusts and Remote Sensing: A Review.” Journal of Applied Remote Sensing 7 (1): 075099. doi:10.1117/1.JRS.7.075099.

Latchininsky, A. V., G. Sword, M. Sergeev, M. M. Cigliano, and M. Lecoq. 2011. “Locusts and Grasshoppers: Behavior, Ecology, and Biogeography.” Psyche: A Journal of Entomology 2011: 578327. doi:10.1155/2011/578327.

Leandro, C., P. Jay-Robert, and A. Vergnes. 2017. “Bias and Perspectives in Insect Conservation: A European Scale Analysis.” Biological Conservation 215: 213–224. doi:10.1016/j.biocon.2017.07.033.

Lecoq, M. 2010. “Integrated Pest Management for Locusts and Grasshoppers: Are Alternatives to Chemical Pesticides Credible?” Journal of Orthoptera Research 19: 131–132. doi:10.16655/034.019.0107.

LeWitich, P. T., M. Bolton, and T. Chapman. 2016. “Evolutionary Biology and Genetic Techniques for Insect Control.” Evolutionary Applications 9: 212–230. doi:10.1111/eva.12280.

Legagneux, P., N. Casajus, K. Cazelles, C. Chevallier, M. Chevrinais, L. Guéry, C. Jacquet, et al. 2018. “Our House Is Burning: Discrepancy in Climate Change Vs. Biodiversity Coverage in the Media as Compared to Scientific Literature.” Frontiers in Ecology and Evolution 5. doi:10.3389/fevo.2017.00175.

Leo, N. P., and S. C. Barker. 2005. “Unravelling the Evolution of the Head Lice and Body Lice of Humans.” Parasitology Research 98: 44–47. doi:10.1007/s00436-005-0013-y.

Li, S., S. Zhu, Q. Jia, D. Yuan, C. Ren, K. Li, S. Liu, et al. 2018. “The Genomic and Functional Landscapes of Developmental Plasticity in the American Cockroach.” Nature Communications 9: 1008. https://www.nature.com/articles/s41467-018-03281-1.

Liu, D., F. Wang, and W. Li. 2011. “Cloning and Expression of Spider Dragline Silk Protein Gene in Escherichia Coli and Eukaryotic Cells.” Genomics and Applied Biology 30: 16–20.

Lockwood, J. A. 2004. Locust: The Devastating Rise and Mysterious Disappearance of the Insect that Shaped the American Frontier. New York: Basic Books.

Lockwood, J. A. 2013. The Infested Mind: Why Humans Fear, Loathe, and Love Insects. Oxford: Oxford University Press.

Lomer, C. J., R. P. Bateman, D. L. Johnson, J. Langewald, and M. B. Thomas. 2001. “Biological Control of Locusts and Grasshoppers.” Annual Review of Entomology 46: 667–702. doi:10.1146/annurev.ento.46.1.667.

Macdonald, E. A., A. Hinks, D. J. Weiss, A. Dickman, D. Burnham, C. J. Sandom, Y. Malhia, and D. W. Macdonald. 2017. “Identifying Ambassador Species for Conservation Marketing.” Global Ecology and Conservation 12: 204–214. doi:10.1016/j.gecco.2017.11.006.

Magnarrelli, L. A. 2009. “Global Importance of Ticks and Associated Infectious Disease Agents.” Clinical Microbiology Newsletter 31: 33–37. doi:10.1016/j.clinmicnews.2009.02.001.

Malik, A., N. Singh, and S. Satya. 2007. “House Fly (Musca domestica): A Review of Control Strategies for a Challenging Pest.” Journal of Environmental Science and Health, Part B 42: 453–469. doi:10.1080/03601230701316481.

Maloney, D., F. A. Drummond, and R. Allford. 2003. “Spider Predation in Agroecosystems: Can Spiders Effectively Control Pest Populations?” Maine Agricultural and Forest Experiment Station, Technical Bulletin 190. Orono: University of Maine. https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?referer=https://www.google.com &httpsredir=1&article=1018&context=ae_s_techbulletin.

Mans, B. J., J. Featherston, M. Kvas, K.-A. Pillay, D. G. de Klerk, R. Pienaar, M. H. de Castro, et al. 2019. “Argasid and Ixodid Systematics: Implications for Soft Tick Evolution and Systematics, with a New Argasid Species List.” Ticks and Tick-borne Diseases 10: 219–240. doi:10.1111/tid.12901.

Marc, P., A. Canard, and F. Ysnel. 1999. “Spiders (Araneae) Useful for Pest Limitation and Bioindication.” Agriculture, Ecosystems & Environment 74: 229–237. doi:10.1016/S0167-8809(99)00038-9.

Marusik, Y. M., and S. Koponen. 2000. “Circumpolar Diversity of Spiders: Implications for Research, Conservation and Management.” Annales Zoologici Fennici 37: 265–269.

Matavel, A., G. Estrada, and F. De Marco Almeida. 2016. “Spider Venom and Drug Discovery: A Review.” In Spider Venoms, Toxicology, edited by P. Gopalakrishnakone, G. A. Corzo, E. Diego-Garcia, and M. E. de Lima, 273–292. Dordrecht: Springer.

Maynard, D. S., T. W. Crowther, J. R. King, R. J. Warren, and M. A. Bradford. 2015. “Temperate Forest Termites: Ecology, Biogeography, and Ecosystem Impacts.” Ecological Entomology 40: 199–210. doi:10.1111/een.12185.

McFarlane, G. R., C. B. A. Whitelaw, and S. G. Lillico. 2018. “CRISPR-Based Gene Drives for Pest Control.” Trends in Biotechnology 36: 130–133. doi:10.1016/j.tibtech.2017.10.001.
Biodiversity Data Journal 2018 (6): e30842. doi:10.3897/BDJ.6.e30842.

Shaw, G. 1813. The Naturalist's Miscellany, or Coloured Figures of Natural Objects. London: Elizabeth Dodder.

Shelomi, M. 2016a. “What Is the Purpose of Mosquitoes and Flies on Earth?” Quora (Contribution to Blog Post). https://www.quora.com/What-is-the-purpose-of-mosquitoes-and-flies-on-earth

Shelomi, M. 2016b. “Mosquitoes: Can We Get Rid of Them, and What Would Happen if We Did?” Quora (Blog Post). https://www.quora.com/profile/Matan-Shelomi/Posts/Mosquitoes-Can-we-get-rid-of-them-and-what-would-happen-if-we-did

Shrivastava, A., L. Shrestha, S. Prakash, and R. Mehta. 2019. “Transgenic Mosquitoes Fight against Malaria: A Review.” Journal of Universal College of Medical Sciences 7: 59–65. doi:10.3126/jucms.v7i1.24695.

Sig, A. K., M. Guney, A. Uskudar Guclu, and E. Ozmen. 2017. “Medicinal Leech Therapy – An Overall Perspective.” Integrative Medicine Research 6: 337–343. doi:10.1016/j.imr.2017.08.001.

Simaika, J. P., and M. J. Samways. 2018. “Insect Conservation Psychology.” Journal of Insect Conservation 22: 635–642. doi:10.1111/jic.12407.

Simon, S., M. Otto, and M. Engelhard. 2018. “Gene Drive Organisms’ to Combat Invasive Alien Species? – Not Ready for Release.” Natur und Landschaft 93: 462–464. (In German).

Sirwinchester. 2016. “Meet the World’s Deadliest Animal – The Mosquito.” Steemit (Blog). https://steemit.com/life/@sirwinchester/meet-the-world-s-deadliest-animal-the-mosquito

Skerl, K. L. 1999. “Spiders in Conservation Planning: A Survey of US Natural Heritage Programs.” Journal of Insect Conservation 3: 341–347. doi:10.1023/A:1009641620689.

Skef, B., and P. Trontelj. 2008. “Global Diversity of Leeches (Hirudinae) in Freshwater.” Hydrobiologia 595: 129–137. doi:10.1007/s10750-007-9010-8.

Small, E. 2011. “The New Noah’s Ark: Beautiful and Useful Species Only. Part I: Biodiversity Conservation Issues and Priorities.” Biodiversity 12 (4): 232–247. doi:10.1080/14888386.2011.642663.

Small, E. 2012. “The New Noah’s Ark: Beautiful and Useful Species Only. Part 2: The Chosen Species.” Biodiversity 13 (1): 37–53. doi:10.1080/14888386.2012.659443.

Small, E. 2016. “The Value of Cartoons for Biodiversity Conservation.” Biodiversity 17 (3): 106–114. doi:10.1080/14888386.2016.1203818.

Sneath, J., and J. W. Toole. 2010. “Head Lice: A Review of Topical Therapies and Rising Pediculicidal Resistance.” STL Pharmacist 5 (2). https://www.skintherapyletter.com/pharmacist-edition/head-lice-pediculicidal-resistance-pharm/

Sobotková, K., W. Parker, J. Levá, J. Růžková, J. Lukeš, and K. J. Pomajbíková. 2019. “Helminth Therapy – From the Parasite Perspective.” Trends in Parasitology 35: 501–515. doi:10.1016/j.pt.2019.04.009.

Sonenshine, D. E., and M. R. Roe, eds. 2014. Biology of Ticks. Vol. 2. 2nd ed. New York: Oxford University Press.

Soucaros, P. N., A. E. Beris, K. N. Malizos, C. T. Kabani, and S. Pakos. 1994. “The Use of Medicinal Leeches, Hirudo medicinalis, to Restore Venous Circulation in Trauma and Reconstructive Microsurgery.” International Angiology 13: 251–258.

South, R. 1907. The Moths of the British Isles. London: Frederick Warne.

Spitzer, M. 2005. “Spiders, Snakes and Humans – The Amyloid Nucleus and the Fear of Strangers.” Nervenheilkunde 24: 736–739. doi:10.1055/s-0038-1629971.

Stejskal, V., and P. Horák. 1999. “Webbing Clothes Moth, Tineola bisselliella (Hum.), Causing Serious Feeding Damage to Lactuca sativa and Other Plant Seeds.” Anzeiger für Schädlingskunde (Journal of Pest Science) 72: 87–88.

Stewart, C., and N. Coverstone. n.d. “Beneficial Insects and Spiders in Your Maine Backyard.” University of Maine Cooperative Extension Bulletin 7150. https://extension.umaine.edu/publications/wp-content/uploads/sites/82/2015/04/7150.pdf

Su, N. Y., and R. H. Scheffrahn. 2000. “Termites as Pests of Buildings.” In Termites: Evolution, Sociality, Symbioses, Ecology, edited by T. Abe, D. E. Bignell, and M. Higashi, 437–453. Dordrecht: Springer.

Suettsug, K. 2019. “Social Wasps, Crickets and Cockroaches Contribute to Pollination of the Holoparasitic Plant Mitrastramon yamamomotoi (Mitrastramonaceae) in Southern Japan.” Plant Biology 21: 176–182. doi:10.1111/plb.12972.

Sunderland, K. 1999. “Mechanisms Underlying the Effects of Spiders on Pest Populations.” Journal of Arachnology 27: 308–316.

Talbot, B., N. Keyghobadi, and B. Fenton. 2019. “Bed Bugs: The Move to Humans as Hosts.” Facets. https://www.facetsjournal.com/dof/full/11.139/facets-2018-0038

Tessler, M., S. R. Weiskopf, L. Berniker, R. Hersch, K. P. Mccarthy, D. W. Yu, and M. E. Siddall. 2018. “Bloodlines: Mammals, Leeches, and Conservation in Southern Asia.” Systematics and Biodiversity 16: 488–496. doi:10.1016/j.sbsfmt.2018.1435729.

Thakur, R. K., N. Hooda, and V. Jeeva. 2003. “Termites and Global Warming - A Review.” The Indian Forester 129: 923–930.

The Guardian. 2013. “Pests That Bug Us Have Their Own Ecological Importance.” https://www.theguardian.com/environment/2013/may/21/insects-cockroach-bed-bugs-environment

Thomas-Walters, L., and N. J. Raihan. 2017. “Supporting Conservation: The Roles of Flagship Species and Identifiable Vics.” Conservation Letters 10: 581–587. doi:10.1111/conl.12319.

Ting, W., W. Meng, W. Wenfang, L. Qianxuan, J. Liping, T. Huai, and M. Deng. 2019. “Spider Venom Peptides as Potential Drug Candidates Due to Their Anticancer and Antinociceptive Activities.” Journal of Venomous Animals and Toxins Including Tropical Diseases 25: e146318. Epub June 03. doi:10.1590/1678-9199-jvatitd-14-63-18.

Titex, N., K. Henle, J.-B. Mihoub, and L. Brotons. 2016. “Climate Change Disturbs Us from Other Threats to Biodiversity.” Frontiers in Ecology and the Environment 14: 291. https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.1002/fee.1303

Tilley, M. A., J. L. Snaddon, and E. C. Turner. 2017. “Scientific Research on Animal Biodiversity Is Systematically Biased Towards Vertebrates and
Temperate Regions.” *PloS One* 12 (12): e0189577. doi:10.1371/journal.pone.0189577.

Toon, A., and J. M. Hughes. 2008. “Are Lice Good Proxies for Host History? A Comparative Analysis of the Australian Magpie, Gymnorhina tibicen, and Two Species of Feather Louse.” *Heredity* 101: 127–135. doi:10.1038/hdy.2008.37.

Toups, M. A., A. Kitchen, J. E. Light, and D. L. Reed. 2011. “Origin of Clothing Lice Indicates Early Clothing Use by Anatomically Modern Humans in Africa.” *Molecular Biology and Evolution* 28: 29–32. doi:10.1093/molbev/msq234.

Tunnessen, N., and M. Hsieh. 2018. “Eating Worms to Treat Autoimmune Diseases?” *Frontiers for Young Minds* 7: 32. doi:10.3389/frym.2018.00032.

Uniyal, V. P. 2004. “Spiders as Conservation Monitoring Tools.” http://vpuniyal.com/images/spiders_as_conservation_monitoring_tools.pdf

Verma, V., S. Sharma, and R. Prasad. 2009. “Biological Alternatives for Termite Control: A Review.” *International Biodeterioration & Biodegradation* 63: 959–972. doi:10.1016/j.ibiod.2009.05.009.

Vlasáková, B., J. Pinc, F. Jůna, and Z. Kotyková Varadínová. 2019. “Pollination Efficiency of Cockroaches and Other Floral Visitors of Clusia Blattophila.” *Plant Biology* 21: 753–761. doi:10.1111/plb.12956.

Whitaker, I. S., D. Izadi, D. W. Oliver, G. Montaeth, and P. E. Butler. 2004. “*Hirudo medicinalis* and the Plastic Surgeon.” *British Journal of Plastic Surgery* 57: 348–353. doi:10.1016/j.bjps.2003.10.014.

Wikelius, S., J. Ardö, and T. Fransson. 2003. “Desert Locust Control in Ecologically Sensitive Areas: Need for Guidelines.” *Ambio: A Journal of the Human Environment* 3: 463–468. doi:10.1579/0044-7447-32.7.463.

Wilson, E. O. 1984. *Biophilia*. Cambridge: Harvard University Press.

Wilson, E. O. 1993. “Biophilia and the Conservation Ethic.” In *The Biophilia Hypothesis*, edited by S. R. Kellert and E. O. Wilson, 31–41. Washington, D.C.: Island Press.

Windsor, D. A. 1995. “Equal Rights for Parasites.” *Conservation Biology* 9: 1–2. doi:10.1046/j.1523-1739.1995.09010001.x.

World Health Organization. 2014. *The Guidance Framework for Testing Genetically Modified Mosquitoes.* Geneva: World Health Organization. http://apps.who.int/iris/bitstream/10665/127889/1/9789241507486_eng.pdf?ua=1

World Wildlife Fund. 2014. “Black-Footed Ferret Facts: The Masked Bandits of the Northern Great Plains.” https://www.worldwildlife.org/stories/black-footed-ferret-facts-the-masked-bandits-of-the-northern-great-plains

Yamaura, Y., M. Higa, M. Senzaki, and I. Koizumi. 2018. “Can Charismatic Megafauna Be Surrogate Species for Biodiversity Conservation? Mechanisms and a Test Using Citizen Data and a Hierarchical Community Model.” In *Biodiversity Conservation Using Umbrella Species*, edited by F. Nakamura, 151–179. Singapore: Springer.

Young, O. P., and G. B. Edwards. 1990. “Spiders in United States Field Crops and Their Potential Effect on Crop Pests.” *Journal of Arachnology* 18: 1–29.

Zaidi, S. M., S. S. Jameel, F. Zaman, S. Jilani, A. Sultana, and S. A. Khan. 2011. “A Systematic Overview of the Medicinal Importance of Sanguivorous Leeches.” *Alternative Medicine Review* 16: 59–65.

Zhang, L., M. Lecq, A. Latchininsky, and D. Hunter. 2019. “Locust and Grasshopper Management.” *Annual Review of Entomology* 64: 15–34. doi:10.1146/annurev-ento-011118-112500.

Ziegler, M. 2016. “The Promiscuous Human Flea.” https://contagions.wordpress.com/2016/09/27/the-promiscuous-human-flea/

Zimmerman, P. R., J. P. Greenberg, S. O. Wandiga, and P. J. Crutzen. 1982. “Termites: A Potentially Large Source of Atmospheric Methane, Carbon-Dioxide, and Molecular-Hydrogen.” *Science* 218: 563–565. doi:10.1126/science.218.4572.563.