Conservation of Arthropod Parasites: Restoring Crucial Ecological Linkages

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Abstract

Parasitic biodiversity is focussed as a key component of conservation targets based on their ecological roles in the present review. Arthropods adopt parasitism as one of the common strategies for survival. However, some parasites are threatened by not only direct factors such as environmental conditions but also by indirect ones such as the effect on their hosts/prey. Conservation of parasites would help to sustain evenness in arthropod communities. Diptera, Hymenoptera, and Siphonaptera are orders of insects, mites, and ticks implicated as vectors in transmission of diseases in human populations and agricultural ecosystem of tropics and subtropics. Recently, outbreak of Zika viral disease has been reported in over 12 countries. This comprehensive review will be of value to scientists, students, and policy makers for biodiversity management.

Keywords

Conservation • Ecology • Parasites • Vector • Zika virus

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3.1 Introduction

Arthropods are evolved from wormlike coelomic animals, much earlier to most of other animals. There are parasites that exploit the host and some serve as hosts for organisms. Arthropods are generally ectoparasitic on, or in the skin of vertebrate hosts. Many arthropod species are hematophagous (rely on the blood), but others can be histophagous (rely on tissues). Parasitic infestations are transmitted from one host to another either by direct contact or by free-living larvae (Marquardt et al. 2000).

Mites and ticks are arthropods belonging to subclass Acari and class Arachnida. Because of the small size, they largely go unnoticed. A huge number of mites live as parasites on plants or animals and some on molds. To date nearly 30,000 mite species have been identified. One family of mites, Pyroglyphidae or west mites, live primarily in the nests of birds and other animals. These mites are primarily, largely parasitic and consume the blood, skin, and keratin of hosts (Gómez et al. 2012).

Ticks parasitise mainly terrestrial vertebrates living on land. Parasite infections are transmitted by bacteria, virus, rickettsia, protozoa, and other pathogens. They feed mainly on the blood, and their mouthparts are armed with small backward-facing teeth to aid in attachment. Two major tick families are identified based on morphological features: the Ixodidae (hard ticks with a tough cuticle and a large anterodorsal scutum) with some 650 species that attack reptiles, birds, and mammals and the Argasidae (soft ticks) with 160 species that infest and mainly attack higher vertebrates.

Fleas are wingless insects, have flattened body with hind limbs swollen, so that they can jump. The larvae are not parasitic but feed on debris associated mainly with bedding, den, or nest material, whereas the adult stages are parasitic and feed on host blood. There are about 2500 species of flea; most are parasitic on mammals (especially rodents) and some on birds. Flies and mosquitoes are winged insects with two pairs of wings attached to the thorax and a well-developed head with sensory and feeding organs. Species of fleas vary in their feeding habits, both as adults (parasitic or free living) and larvae (parasitic or free living). There are over 120,000 species belonging to 140 families (Rendell and Verbeek 1996).

3.2 Why Study Parasites?

Parasites have a huge impact on the health and well-being of the human population, particularly in the developing world. Parasites exploit resources of host to feed and reproduce. This lowers host fitness to considerable extent. Parasites can negatively impact human and animal health, food production, economic trade, and biodiversity. They can be difficult to study and have been regarded as having little or no influence on ecosystem functioning. Not surprisingly, parasitic biodiversity has not been considered as an important group by biologists and conservationists (Gompper and Williams 1998; Dunn et al. 2009; Griffith 2012). The stated goal of the field of conservation biology is to maintain biodiversity, including the evolutionary processes that drive and sustain it (Meffe et al. 2006). Yet to ignore the conservation of parasites is to ignore the conservation status of the majority of life on Earth, as parasitism represents the most common consumer strategy on the planet (Poulin and Morand 2000; Dobson et al. 2008). It also means neglecting a fundamental biological relationship, as infection is fundamental to the ecological and evolutionary drivers of biological diversity and ecosystem organization (Marcogliese 2004). Recent research has shown that basic assumptions about parasites, their ubiquity, and relevance need to be reexamined. Parasitism may be the most widespread trophic strategy in the animal kingdom. Also, documented literature reveals that parasites are diverse, have key roles in ecological and evolutionary processes, and that infection/parasitism may paradoxically result in ecosystem services of direct human relevance. Of the 42 broadly recognized classes, 31 are predominantly parasitic and most others have multiple parasitic groups (Poulin and Morand 2000; de Meeûs and Renaud 2002). Nest-dwelling ectoparasites feeding on the blood of nestlings and adults constitute an important selective force affecting avian life history evolution (Moller 1997). These ectoparasites may reduce the reproductive success of hosts by reducing nestling growth (Merino and Potti 1995) or inducing nest desertion (Oppliger et al. 1994) and may even affect parental health (Tomás et al. 2007). For hole-nesters, fleas (Siphonaptera), flies (Diptera), and mites (Acarina) constitute the most important class of nest-dwelling ectoparasites (Merino and Potti 1995; Rendell and Verbeek 1996). Ectoparasitic faunas in bird nests vary depending on host species, even in conditions of sympatry (Bennett and Whitworth 1992; Bauchau 1998). These differences may depend on interspecific variation in host defenses based on parental behavior, nestling immunity, or nest properties. Animal parasites and vectors help veterinarians, fishery biologists, induce diseases of farmed animals (including cultured fish), wild caught animals used for food or at risk from disease, and forensic scientists. Parasites are ubiquitous in the lives of animalism in the wild and constitute a major element of floral and faunal elements (Price 1980).

3.2.1 Major Ecological and Evolutionary Effects of Parasites

Parasites as vectors of disease causing pathogens can affect species distribution and population (Nichols and Gómez 2011). By exploiting resources from hosts, parasites can change animals' energy needs that affect growth, reproduction, competition, and survival. Some parasites even directly alter their hosts' behavior and force them to do their bidding. Parasites also drive adaptation and evolution as they and their hosts engage in "evolutionary arms races." Current investigations of food webs indicate that ~75 % of the links in food webs involve a parasitic effect; these links are keys of host population and for reducing the effect of toxicant. This means that extinctions of parasite may have unpredictable effects that impact the population of a wide range of living organisms. The parasitic fauna of any host species reflects its interaction with the host's feeding niche, latitudinal range, and social system.

3.2.2 Coexistence and Evolution of Parasites and Humans

Using a Bayesian coalescent modeling approach, it is estimated that clothing lice, *Pediculus humanus humanus* (Fig. 3.1), have evolved from head louse, *Pediculus humanus capitis*, ancestors at least by 83,000 and may be 170,000 years ago (Toups et al. 2011). Because clothing lice descended from head louse ancestors once humans took to clothing. The emergence of clothing lice provides data on proximate dates of the period when man started using clothes. Sucking lice (Phthiraptera: Anoplura) are obligate, permanent ectoparasites of eutherian mammals, parasitizing 12 of the 29 recognized mammalian orders and 20 % of all mammalian species. These bloodsucking insects are morphologically adapted for life on mammals: they are dorsoventrally flattened, are wingless with tibiotarsal claws for clinging to host hair, and have piercing mouthparts. In the fore literature, more than 540 described species of Anoplura have been documented. All modern mammal orders are supposed to have diverged by 75 Ma, giving scope suitable habitat for the establishment and speciation in sucking lice.

Although there is concern among experts on timing of diversification events in the association between anoplurans and mammals, there is considerable disagreement between the host and parasite phylogenies. These contrasting views may be due to a complex history of host switching and extinction events that occurred throughout the evolutionary association between sucking lice and mammalian hosts. The second example is related to the Inca Empire of western South America. Livestock levels over time are being studied because ancient Peruvian cultures relied on domesticated animals (mainly llamas) for food, wool, fuel, fertilizer, and transport. Changes in livestock densities affect the amount of dung and, therefore, nutrients deposited. Variation in habitat enrichment influences the number and species of mites present. Mites, e.g., *Hydrozetes* sp. (Figs. 3.2 and 3.3), are being

Fig. 3.1 *Pediculus humanus humanus*

Fig. 3.2 *Microterys flavus* (http://boutique.crisop.fr/microterys-flavus-10)

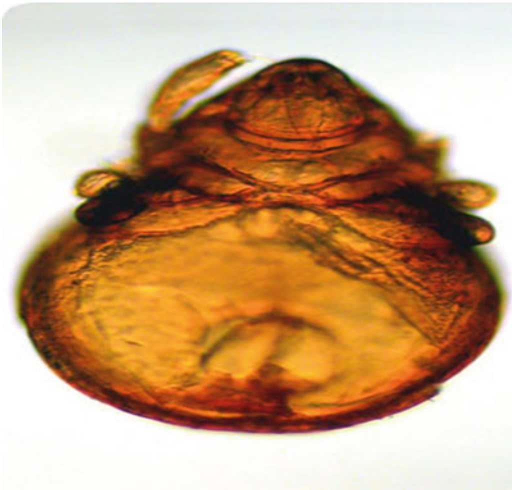


Fig. 3.3 *Hydrozetes* sp. (http://www.nhm.ac.uk/research-curation/life-sciences/terrestrial-invertebrates/research/mite-research/archaeological-indicators/index.html)

extracted from 1200 years of sediment samples from the in-filled lake basin of Marcacocha in Peru to assess mites as indicators of changing livestock densities and therefore agricultural activity, leading up to the end of the Inca Empire. The site is an area of pasture on an ancient trans-Andean trading route where llama caravans would have grazed and watered. Identifying the mites will shed light on their habitat and food preferences (http://www.nhm.ac.uk/research-curation/life-sciences/terrestrial invertebrates/research/mite-research/archaeological-indicators/index.html).

3.2.3 Taxonomic Revision

Parasites should not be excluded while making decisions on conservation (Gomez et al. 2012); rather they need to be included, because parasitism is perhaps the most prevalent life scape on planet Earth. Of all the animal phyla, 9 are entirely parasitic, 22 are predominantly parasitic, and the rest have parasitic groups scattered throughout them. There are an estimated 75,000–300,000 species that parasitize vertebrates, excepting the ones that choose spineless hosts. According to Gómez et al. (2012), numerically parasites may "outnumber free-living biodiversity by as much as 50 percent." Comparing the phylogenetics of the parasite, host, and vector is leading to better understanding of coevolution, co-speciation, and interactions between host-parasite relationships.

Conventional taxonomic descriptions, revisionary systematics, and faunal surveys are vital to the growth and development of collections and the preparation of keys and to contribute to parasite diversity. A revision in taxonomic procedure is in progress that will make taxonomy an even more reliable source of information for ecologists, cybertaxonomy (cyber-enabled taxonomy), which is able to produce results faster and better than ever before (Wheeler 2008, Wheeler and Valdecasa 2010). Quick gathering of biological data calls for development of suitable databases so that it becomes convenient for handling, retrieving, and analyzing the data. On vector biology, it is addressed by the development of VectorBase, a database that gives storage and analysis for genomic data of insect and other arthropod vectors of human diseases (Lawson et al. 2007). VectorBase contains information on genome for *Anopheles gambiae* and for other insect vectors. In addition, genomic sequences have initiated a community annotation system, a modern microarray expression data repository, controlled vocabularies for addressing anatomy, and insecticide resistance aspects (Topalis et al. 2008).

3.2.4 Parasites in Biological Control

A parasite is referred as a parasitoid when it fails to reproduce in its host but merely eats it from inside. The term "parasite" means insects that parasitize other insects. Many biological control workers, however, point to significant biological differences between such insects and other types of parasitic arthropods. "True" parasites are usually much smaller than their host, have a shorter life cycle than their host, and usually do not kill their host; examples include tapeworms and ticks. Recognizing this distinction, Reuter in 1913 coined the term "parasitoid" for insects that parasitize other insects. Some biological control workers prefer to use "parasite," whereas others use "parasitoid."

Many of the agricultural, horticultural, and forestry pests are attacked by one or more parasitoid species. It is estimated that, on a worldwide basis, there are about 68,000 species of parasitoids that are described. This forms about 10 % of all known insect species. Entomologists believe that about 10 % of all insects living on Earth are known to science and as many as 800,000 species of parasitoids actually live.

Most parasitoids belong to two major groups of insects: the orders Diptera (the true flies and their relatives), with about 15,000 known species of parasitoids, and within Diptera, the Tachinidae which is specially important for the biological control of agricultural, horticultural, and forestry pests. But the order Hymenoptera comprises the largest group of parasitoids and forms the most important group of natural enemies used in biological control programs. However, the parasitoids exist in several other groups as well, and an estimated 3000 species form the other major group of insects. The families of beetles that contain parasitoids are the carabids, one of the largest families of beetles. Many predators are important in biological control. About 500 species of ground beetles are parasitoids, primarily of soil-dwelling insects. These are ectoparasites, anchoring to the outside of their primary host. Several of these are in the genus *Lebia* that embraces parasites of Chrysomelidae. *Lebia grandis* parasitizes pupae of Colorado potato beetle. Many species of rove beetles (family Staphylinidae) are predators, and many of these are crucial for biological control; about 500 species are known to be parasitoids. The cedar beetles comprise a small family, with only about a half dozen species. Members of the genus *Sandalus* parasitize the nymphs of cicadas that are the soil borne, but are rare. The larvae of select blister beetles (family Meloidae) attack ground-nesting bees; some others attack the egg cases of grasshoppers. As egg cases carry several eggs, entomologists consider this group of blister beetles to be predators. Because each larva consumes only an egg case, others consider these to be egg-case parasitoids. Most of the parasitoids attack the pupae of flies, such as scavenging flies (houseflies, blowflies, flesh flies, etc.).

One species, *Aleochara bilineata*, is a common parasite of cabbage maggot. Family Ripiphoridae is a small family of about 400 species that parasitizes larvae of bees and wasps. Limited species of *rhipidius* are parasites of cockroaches. The wingless, larviform female of the parasite lays eggs on the ground in areas frequented by the hosts. The first instar attaches itself to a passing cockroach and enters the body, completing its larval life as an endoparasite. The order Strepsiptera is a small group of uncommon parasites closely related to the beetles. Bees, wasps, leafhoppers, and plant hoppers are the most common hosts, but a few species attack grasshoppers or bristletails. The order Neuroptera, which are predators, consists of the lacewings and ant lions. Adult mantidflies (family Mantispidae) are predators and have the front legs strongly modified for catching and holding the prey, similar to the modifications of legs found in praying mantids. The larvae are all parasitic within the egg sacs of spiders, which are ground dwelling.

3.2.5 In Agri-Horticultural Ecosystems

The egg parasitoids of the genus *Trichogramma* (Fig. 3.4) are the most frequently produced natural enemies in the world (Li 1994). Commercially produced species of *Trichogramma* parasitize the eggs of many lepidopteran pest species and have been used as biological control agents against several agricultural pests. The short generation time of *Trichogramma* wasps, and the fact that they can be reared on

Fig. 3.4 *Trichogramma* sp. (http://www.ecured.cu/index.php/Trichogramma_spp.)

factitious hosts, allows these wasps to be produced rapidly and affordably (Li 1994; Smith 1996). Despite the user-friendliness of *Trichogramma* species, there have been at least as many failures of biological control using *Trichogramma* as there have been successes (Smith 1996), and the quality of mass-reared wasps is one potential factor of variability in the success of biological control programs (Bigler 1989; Cerutti and Bigler 1995; Kuhlamann and Mills 1999; Losey and Calvin 1995; O'Neil et al. 1998). One parameter of natural enemy quality important to biological control programs is whether fitness of commercially produced wasps is sustained for long periods. Releasing the natural enemies to establish the population before pest densities have begun to increase has an advantage. The natural enemy reproduces on the target pest or an alternate host, and its population increases to levels sufficient to control the target pest later in the season. In China, inoculative releases of *Trichogramma* produce wasps which later in the season move into adjacent fields to suppress pests of cotton (Li 1994). Conservation as a biological control method includes crop management measures that encourage natural enemies and beneficials and increase their impact on pests. Interplanting ryegrass in seed corn production fields lowered soil temperatures which otherwise would be lethal to released *Trichogramma* (Orr et al. 1997). *Trichogramma* species commonly parasitize bollworms (corn earworm) on corn, sorghum, and other crop pests. These crops serve as an important source of adult wasps that disperse to cotton (Oatman 1966).

Parasitic wasps form important natural enemies of aphids – categorized under Aphelinidae and Braconidae. *Aphelinus flavipes* on cotton aphid is similar to *A. semiflavus. A. semiflavus* parasitizes several aphid species, including the green peach aphid *A. colemani.* This braconid wasp is cosmopolitan and occurs in many parts of the world. It reproduces well on cotton aphid, green peach aphid, and other species. This cosmopolitan species parasitizes numerous aphids in diverse cultivated ecosystems. In greenhouse, they parasitize larger aphids than does *A. colemani*, particularly potato aphid and foxglove aphid, *A. matricariae*.

Most of the parasites of leaf miners parasitize the larvae and pupae. This European braconid wasp, *Dacnusa sibirica*, is a solitary endoparasite of all instars of *Liriomyza bryoniae* and *L. trifolii*, and the chrysanthemum leaf miner. *Diglyphus* *isaea* parasitizes *L. trifolii*, *L. bryoniae*, and chrysanthemum leaf miner. *D. pulchripes* parasitizes the vegetable leaf miner. The eucoilid wasp, *Ganaspidium utilis* native to subtropical areas of North America, is a larval-pupal parasite of *L. trifolii*. The American braconid wasp, *Opius dimidiatus*, is one of the most abundant larval-pupal parasites of the vegetable leaf miner and *L. trifolii*. The braconid wasp *Opius dissitus* is a parasite of the vegetable leaf miner in Florida which also parasitizes *L.trifolii. Opius pallipes*, European braconid wasp, is a solitary endoparasite of all instars of *L. bryoniae* and chrysanthemum leaf miner larvae.

The family Encyrtidae includes parasitic wasps that are important natural enemies of soft scales. The cosmopolitan wasp, *Coccophagus lycimnia*, parasitizes over 47 species of soft and armored scales and has proven effective against brown soft scales in citrus and ornamental plants. *Metaphycus helvolus*, a small encyrtid wasp from South Africa, attacks young nymphal stages of several species of soft scales; *M. helvolus* readily attacks black and hemispherical scales, as well as brown soft scale; *Microterys flavus* (Fig. 3.2) is another internal parasite of brown soft scale. This parasite is also effective against other soft scales and commercially available for release in citrus orchards.

Encyrtus infelix and *Encyrtus lecaniorum* have been successfully utilized alone and in combination with *Metaphycus helvolus* for suppressing scales in French greenhouses. *E. lecaniorum* parasitized hemispherical and soft brown scales more effectively than *M. helvolus* or *C. lycimnia. E. lecaniorum* mimics ants that tend the scales, thereby preventing the other parasites from attacking the scales. The ectoparasitic wasp *Aphytis melinus* (Figs. 3.5, 3.6, 3.7, and 3.8) from India and Pakistan parasitizes select species of armored scales, including California red scale, ivy scale, San Jose scale, and oleander scale.

The Mediterranean wasp *Anagyrus pseudococci* (Fig. 3.9) looks like *Leptomastix dactylopii*, but it attacks half-grown to full-grown citrus mealybug nymphs. *Leptomastidea abnormis* attacks only young, second-instar citrus mealybugs and develops as a solitary endoparasitoid. The Brazilian wasp, *L. dactylopii*, is the most frequently used parasite for suppressing citrus mealybug. *Pauridia* (=*Hungariella*) *peregrine* is a solitary endoparasitoid of the long-tailed mealybug attacking the first

Fig. 3.5 *Aphelinus semiflavus* (http://ponent.atspace.org/fauna/ins/fam/aphelinidae/aphelinus_aph.htm)

Fig. 3.6 *Aphidius colemani* (http://www.arbico-organics.com/category/pest-solver-guide-aphids)

Fig. 3.7 *Aphidius ervi* (http://www.arbico-organics.com/category/pest-solver-guide-aphids)

and second instars. *H. peregrine* has been used successfully in cultivated ecosystems in subtropical areas and in greenhouses on ferns.

Select species of trichogrammatid and mymarid wasps parasitize eggs of thrips. Most of the parasitic wasps that have been found to attack thrips larvae are tropical or subtropical and belong to *Eulophidae. Ceranisus* (=*Thripoctenus*) spp. are eulophid wasps that develop inside thrips larvae. After female wasps lay single eggs in young thrips larvae, the thrips continue to appear and behave normally while the wasps develop inside them. *Ceranisus* (=*Thripoctenus*) spp. are eulophid wasps that develop inside thrips larvae. *C. menes* is a solitary endoparasitoid that attacks the first instar of western flower thrips. It occurs worldwide and has been found parasitizing western flower thrips on alfalfa and roses in California. *Thripobius semiluteus* is a parthenogenic wasp that was introduced in 1987 from Brazil and Australia as a possible control agent for greenhouse thrips in avocado orchards in southern California.

Fig. 3.8 *Aphytis melinus* (http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v047n01p16&fulltext=yes)

Fig. 3.9 *Anagyrus pseudococci* (http://bio-bee.ru/wp-content/uploads/2013/01/anagirus-400-266.jpg)

Encarsia formosa is an effective parasite under greenhouse conditions in semi-tropical areas of the New World. It has been used since the 1920s to suppress the greenhouse whitefly in greenhouses. *E. formosa* also parasitizes sweet potato white-fly in greenhouses, but this species is not a suitable host for this wasp, so pest suppression is not satisfactory. *Encarsia luteola* resembles *E. formosa* but is slightly smaller and lighter brown, and males are regularly produced. In the field it is usually present on upper leaves and parasitizes greenhouse whitefly. *Encarsia pergandiella*, an aphelinid wasp, native to North America, parasitizes greenhouse, sweet potato, and banded-wing whiteflies. *E. inaron* is a Mediterranean species parasitizing the pupae of greenhouse and sweet potato; *E. lutea* parasitizes sweet potato whitefly pupae; *E. meritoria* from California parasitizes banded-wing, greenhouse, and sweet potato whiteflies but prefers other species of chalcids, such as the Iris whitefly (*Aleyrodes spiraeoides*). The aphelinid wasp *Eretmocerus eremicus* (=*californicus*), indigenous to deserts in California and Arizona, parasitizes banded-wing silverleaf and sweet potato whiteflies. *Eretmocerus haldemani* is primarily a parasite of sweet potato and banded-wing whiteflies, although sometimes it will parasitize greenhouse whiteflies. *Eretmocerus mundus*, a Mediterranean parasite of sweet potato whitefly, oviposits on nymphal whitefly stage, although it likes second and third instars. *Encarsia formosa* is the most widely used parasite for suppressing whiteflies. It has been extensively utilized for several years in commercial vegetable greenhouses all over the world. The parasite can control whiteflies on vegetables like cucumber and tomatoes and ornamental plants, such as poinsettia. On vegetable crops that can tolerate a few whiteflies such as tomato, a single inoculative release of *Encarsia formosa* may satisfactorily suppress.

3.2.6 In Animal Husbandry

Most of the parasites belong to Hymenoptera, and they have been frequently integrated into pest management (IPM) systems to control houseflies and stable flies. Predatory beetles and competitor, viz., dung beetles, have been used for the management of horn flies (*Haematobia irritans*) and other insects of veterinary importance.

3.2.6.1 Transmission via Vectors

Parasites have both direct (the parasite is passed from one host to another through air, food, or water) and indirect life cycle (parasite develops or multiplies in a vector or in an intermediate host) (Marquardt et al. 2000). A vector is an invertebrate organism that transmits the parasitic agent from one vertebrate host to the next. It may be a mechanical vector (in which no development or multiplication takes place) or a biological vector in which either multiplication or development occurs. The host in which sexual development of the parasite (trematodes) takes place is the definitive host (e.g., vertebrates), and asexual development takes place in the intermediate host (e.g., snails). Transport or paratenic hosts are those in which a parasite does not develop or multiply but is carried to the next host usually through ingestion of the transport host.

Rapid and widespread urbanization brings an imbalance between development and quality of natural habitats. This has resulted in the increase of urban pest populations like cockroaches, ants, termites, rats, crows, etc. Vector-borne diseases like dengue, malaria, and filariasis are responsible for the prevalence of morbidity and mortality across tropical countries. In epidemiology studies, any agent that carries and transmits an infectious pathogen into another living organism is considered as a vector. Further it is postulated that parasites cause population declines in threatened mammals, have wide host ranges, and are transmitted via biting and bloodsucking arthropods, contaminated food, and water (Pedersen et al. 2007). They are generally ectoparasitic on the skin of vertebrate hosts. Many species are hematophagous (suck blood), while others are histophagous (tissue feeders) and bite or burrow in dermal tissues causing pain, infection and reactions that irritate the skin. Infestations are transmitted from one host to another by direct contact or free-living larvae or adults seek hosts for parasitizing.

Arthropods are involved in multiple parasitic relationships, either as parasites or as vectors for other arthropods or microorganisms. Arthropod vectors causing diseases include arachnid vectors such as soft ticks, hard ticks, and mites and insect vectors such as mosquitoes, flies (tsetse flies, sand flies, black flies, horseflies, biting midges), lice (head or body lice, crab lice), flea (human flea, rat flea, cat flea, jigger flea, bedbugs), and triatomine bugs (Arcari and Azzali 2000). Arthropods particularly mosquitoes, flies, and ticks act as vectors for many of the neglected tropical diseases affecting humans and domestic animals (Meyer 2012). Man continues to be a victim of arthropod borne diseases such as malaria, dengue, dengue hemorrhagic fever, Japanese encephalitis, and plague (Artsob 2000). Larvae or nymphs or adults may cross from one host to another to cause infections, while eggs or pupae may contaminate existing natural resources. Insects (fleas, flies, and lice) and arachnids (ticks and mites) depend on close contact between hosts. Many adults actively seek hosts to feed or oviposit. Winged insects (mosquitoes, flies) fly to new hosts to feed, while fleas jump onto passing hosts. Some adult flies (botflies) do not feed on hosts but oviposit eggs from which larvae emerge and feed on host tissues and fluids. Tick larvae actively seek hosts by climbing vegetation and questing for passing hosts. Some species complete life cycle on the same host (one-host ticks), while others detach after feeding and drop to the ground to molt before seeking new hosts and complete life cycle.

Transmission of diseases is the strategy used by protozoan parasites which inhabit the blood or internal tissues inside its host. This strategy implicates a hematophagous arthropod providing as an intermediary between successive vertebrate hosts. Many diseases caused by protozoa are transmitted by a volley of arthropod vectors. The vectors are not simply “flying syringes” but constitute a second host for the protozoan parasite. So, the pathogenicity life history of vector-transmitted diseases involves complex interactions and protozoan-vector interaction analogous to the complex human-protozoan interactions. The triatomine bugs defecate during feeding, and the excrement that contains the parasites inadvertently gets into the open wound by the host responding to pain and irritation from the bite.

Crustaceans that are parasitic serve as both hosts and vectors of viruses and parasites and other microbial pathogenic organisms. Important groups of parasitic crustaceans affecting commercial aquaculture species are external parasites: the Branchiura, Copepoda, and Isopoda. Crustacean parasites are numerous and have a worldwide distribution in marine and brackish water aquaculture systems. Copepods comprise the largest group of crustacean parasites on fish causing economical loss. Parasitic crustaceans are abundant and are globally distributed in fresh, brackish, and saline waters (Jithendran et al. 2008).

Vector transmission probably evolved multiple times. Vector transmission embraces complicated complex interactions between humans and vectors. This involves bioecology of human-arthropod interactions and bioecological cognizances so vector-transmitted parasites exhibit complicated life history involving interactions between humans, arthropods, and other organisms. An arthropod borne pathogen is transmitted mainly in two ways i.e., mechanical transmission and biological transmission. In mechanical transmission, no reproduction or development of pathogen takes place in the arthropod vector. But in the other type, the pathogen undergoes some type of biological development in the system of arthropod vector to complete life cycle (Gubler 2009). The bioecology of vector species and their associations with man serve as possible template for controlling the transmission of diseases to humans.

3.3 Concerns and Threats: Parasite Paradox

Parasites like hosts are not immune to the threats that normally affect wild species, and the present biodiversity crisis may well be primarily represented by the loss of affiliate species (Dunn et al. 2009). Emergence of pandemics and emerging disease pinpoint one of the consequences of global change but do not preclude that several parasites are threatened by it. It is proven that it creates risks for parasite perpetuation (Hudson et al. 2006; Lafferty 2012). For instance, land-use variation and contamination can both reduce the abundance and diversity of parasite species (Lafferty 1997; Huspeni and Lafferty 2004; Bradley and Altizer 2007). Climate change restricts parasite transmission (Afrane et al. 2012) resulting in phenological mismatches between parasites and hosts (Rohr et al. 2011). Parasites are threatened also by deliberate actions by humans to suppress or eliminate them. In certain situations, the extinction of parasites of public health or veterinary importance can be undoubtedly a gain, but suppression efforts affect populations beyond those initially targeted (Kristensen and Brown 1999). In other situations, daily veterinary practices can have the nontarget effect of eliminating intermediate hosts and interrupt enzootic transmission cycles in species other than those receiving the treatment (Spratt 1997; Wardhaugh et al. 2001). Parasites and taxa are threatened not only by direct environmental changes but also are adversely affected by the threats acting upon their hosts (Colwell et al. 2012). Parasites' dependense on host populations implies that they are endangered and co-extinct when hosts reduce. Several parasites need a threshold host population size for effective transmission. Few species of parasites will be endangered much before this decline which is irreversible (Altizer et al. 2007; Powell 2011). However, extinctions in dependent taxa are likely to represent the majority of extinction events in the current age of unprecedented biodiversity loss (Koh et al. 2004; Dunn et al. 2009); discrepancies remain between the number of documented and expected co-extinctions (Dunn et al. 2009). However, the threat of co-extinction must be carefully analyzed in many parasite conservation programs. Estimating the extent of the co-extinction threat for specific parasites will depend on the understanding of host and parasite behavior, natural history, phylogeny, and vital attributes such as host specificity and bioecology (Gómez et al. 2012).

Characterization of parasite species in wild animals is still in its infancy. Also, complicated man-made and environmental change makes wildlife disease problematic to forecast. Speeding-up changes in external factors, in addition to translocation of hosts and parasites, act synergistically to produce hard-to-predict disease outcomes in different ecosystems. These outputs are further complicated by the intimate connections between diseases in wild animals and diseases in man and domestic animals. Hence, it is important to unravel the interactions of parasites in wildlife, their response to environmental change, emerging diseases, and the role of humans and domestic animals to parasitic infections.

3.3.1 Ticks

Ticks (Ixodidae) can affect considerable economic loss in livestock production, and it becomes essential to control ticks, and it is virtually impossible to raise livestock economically in several parts of the world. The factors considered in the monetary losses in livestock production caused by ticks are unknown. However, results in research programs show the effects of tick control as it is related to mineral supplements, nutrition level, and cattle breed. Nevertheless data on control costs (inclusive of labor, equipment, and chemicals) and the benefits derived from these control programs are wanting. Ticks are the known vectors of agents that cause many economically important diseases in domestic livestock (Hoogstraal 1970; Neitz 1956). Some of the most important are anaplasmosis, east coast fever, theileriosis, babesiosis, equine encephalomyelitis virus, and Q fever virus (Berge and Lennette 1953; Stoker and Marmion 1955).

Ticks directly cause poor health and production losses to hosts by several species of parasites. Ticks transmit numerous kinds of viruses, bacteria, and protozoa among domestic animals. These microbes infect diseases that can seriously devitalize or fatal to domestic animals and humans. Ticks are particularly important to domestic animals in tropical and subtropical regions, where the higher temperatures enable several species to multiply. Also, the large populations of wild animals in warm countries provide a reservoir of ticks and infective microbes that spread to domestic animals. Farmers of livestock regulate several methods to control ticks. Veterinarians and animal health agencies work at private, national, and international levels to decrease the harm caused by ticks and diseases transmitted by them.

Range of Ticks Affecting Domestic Animals
Rhipicephalus **(***Boophilus***)** *annulatus* engorged female

Ticks are related to spiders in Arthropoda. Ticks are in the subclass Acari which comprises of several orders of mites and one tick order, the Ixodidae. There are also parasitic mites, but all ticks are parasitic feeders on the blood. Few mite species are mistaken for larval ticks at infestations, but their feeding habits are unique. All ticks have an incomplete or partial metamorphosis: after the egg hatches, a series of similar stages (=instars) develops from a six-legged larva to an eight-legged nymph and then a sexually developed, eight-legged adult. Ixodidae have the important genera *Amblyomma* (Fig. 3.10), *Dermacentor*, *Haemaphysalis*, *Hyalomma*, *Ixodes*, *Margaropus*, and *Rhipicephalus*. The important boophilid ticks, formerly of the genus *Boophilus*, are now classified under a subgenus within the genus *Rhipicephalus*. These genera are known as hard ticks because their outer surfaces contain hard sclerites. Within ten genera are about 100 species of significance to domestic animals and humans (Taylor 2007).

Fig. 3.10 Adult male bont tick, *Amblyomma variegatum* (Fabricius 1794)

3.3.2 Mites

The most important groups of arthropods transmitting etiological agents pathogenic to livestock are blood feeding and are inherently involved in transmission of diseases. Ticks, mosquitoes, tsetse flies, and biting midges, for instance, have leading roles in the transmission of pathogens causing severe livestock and poultry diseases. Of lesser importance are hematophagous arthropod groups that mechanically transmit pathogens. Horseflies, deer flies, stable flies, horn flies, and others have been implicated in disease transmission although not by continuous feeding.

There are arthropod groups in which several species are not bloodsucking. They are muscoid flies, grasshoppers, and beetles but, which by contact, transfer pathogens and serve as intermediate hosts of helminths. Meanwhile, instances can also be cited for a range of transmission modes and cycles within each of the major class of vectors.

The mite, *Psorergates bovis*, causes pruritus, but does little harm to cattle (Geevarghese et al. 1997). But *Psorergates ovis* feeding on sheep induces inflammatory and hypersensitive responses in the epidermis, resulting in intense pruritus and formation of scabs. Further spread to the skin and fleece of sheep happens when the sheep groom.

3.3.3 Mosquitoes

Mosquitoes are proven notorious as transmitters of severe human diseases. There is little to document the adverse effects on public health due to malaria, yellow fever, filariasis, and several mosquito-borne diseases of arboviral etiology. Rift Valley fever and the equine encephalitides are prime diseases of livestock spread by mosquitoes. Although over 2500 species of mosquitoes have been described worldwide

Table 3.1 List of diseases transmitted by arthropod parasites

Diseases	Causal organisms	Mode of transmission
Colorado tick fever	*Coltivirus*	Transmitted to humans by ticks
Fever	*Rickettsia rickettsii*	
Lyme disease	*Borrelia burgdorferi*	
Psoroptic skin disease	*Psoroptes ovis*	Transmitted to animals by mites
Psorergatic skin disease	*Psorergates bovis*	
Sarcoptic skin disease	*Sarcoptes*	
Mosquito-borne encephalitis	Mosquito-borne virus	Transmitted by mosquito
Plague	*Yersinia pestis*	Transmitted to human by infected fleas

in 18 genera and subgenera, species of the greatest significance as vectors of pathogenic agents are detected in the genera *Aedes*, *Culex*, *Anopheles*, and others.

The southern cattle tick, *Boophilus microplus*, is a vector of cattle babesiosis, bovine anaplasmosis, and benign bovine theileriosis. This tick is present in the warmer, humid regions of the West Indies, Mexico, Central America, South America, Africa, Australia, the Orient, and Micronesia. Earlier it has been found in Southern Florida and Southern Texas and is found in Puerto Rico and St. Croix, US Virgin Islands. A closely related species, *B. annulatus*, the cattle tick, was the most significant external parasite of cattle in the United States. It is a common vector of bovine babesiosis and has also been implicated in the spread of bovine anaplasmosis, bovine theileriosis, and spirochetosis of cattle, goats, sheep, and horses (Table 3.1).

3.3.4 Mosquito-Borne Encephalitis

Encephalitis is a disease caused by mosquito-borne viruses (arboviruses) adversely influencing the central nervous system. Infections vary from un apparent to mild, nonspecific illnesses (fever, headache, musculoskeletal pain, and malaise) to occasionally severe illness of the central nervous system resulting in permanent neurologic damage and death.

These viruses naturally infect a wide range of birds and mammals and are transmitted between animals by mosquito vectors. Occasionally, infected mosquitoes will attack man or cattle that are “dead ends” for the viruses, with little or no chance of subsequent transmission to other mosquitoes. Often viral infections result in severe illness or death of hosts like man or horses (EEE and WEE).

No commercial vaccine is available for humans, but vaccines for WEE and EEE are readily available for horses. The best protective practices are protection from mosquito bites, particularly during early evening hours, and repelling them away. Mosquito populations can be suppressed by eliminating breeding sites for vector species. Killing mosquitoes with area-wide applications of insecticides has been most effective in preventing epidemics.

Diseases like plague caused by bacteria *Yersinia pestis* are acute. Humans get infected by the bites of infected fleas but also directly from exposure to tissues or body fluids from diseased animals, especially when skinning animals. The symptoms of disease are sudden fever and shivering. Swollen and painful lymph nodes (buboes) developed in the armpits, groin, and other areas 2–6 days following contact. In addition to causing itchy bump, septicemic infection may develop involving other organs. Secondary infection of the lungs results in plague pneumonia that can be transmitted by a person to another by aerosol. The disease initially may be mild and short-lived but often advances to a severe form.

One sixth of the world's human population suffers from one or the other tropical diseases, and children are often the most harmed. There are presently 14 listed neglected tropical diseases (NTDs). Most can be prevented but the scale of the problem is huge. Further these diseases are now established on the global health agenda. They have a plethora of hosts, a multitude of developmental stages, that often bear little resemblance from one stage to another, and most forms remain hidden in other animal guts and tissues. Arthropods are responsible for hundreds of millions of cases of disease in man and animals every year. Over the past 30 years, there has been a global reemergence of infectious diseases in humans and animals and vector-borne diseases in particular, with an increased frequency of epidemic transmission and expanding distribution on Earth. The major concern is that important vector-borne diseases are found in the tropics and subtropics, in the areas where resources are most limited and surveillance is poor or absent. With highly increased human and animal mobility, globalization and trade has made these diseases not problems of the tropics alone but of the world. This underscores the need for physicians and veterinarians in non-endemic areas to be aware of vector-borne diseases and knowledge about them. New, mode-of-action chemistries are urgently required to update vector management practices in tropical countries where arthropod-borne diseases are endemic, especially where vector populations have acquired insecticide resistance.

3.4 Conservation Initiatives

The bioecology and control of parasite and vector interactions are vital to fully understand epidemiology before effective control strategies can be developed. Similarly, basic research on pathogen and blood-feeding insect vector biology along with drug discovery programs, clinical trials of vaccines, and field-based studies on vaccine efficacy are required.

Conservation of bloodsuckers and disease-causing agents is to explicitly weed out death and disease. Under natural conditions, this is a normal part of a functioning ecosystem, but for human world, it is not easily acceptable. Parasites should be recognized as "meaningful conservation targets no less relevant than their hosts." Only one parasite is listed in the IUCN Red List as endangered because of the rarity of its host, the world's smallest pygmy hog-sucking louse (*Haematopinus oliveri*) (Whiteman and Parker 2005). It is estimated that there are between 75,000 and

300,000 helminth species parasitizing the vertebrates. Of them 3–5 % are threatened in the coming 50–100 years. Pandemics and emerging disease illustrate one of the consequences of global climatic change. Similarly many parasite species are also threatened by extinction.

3.4.1 Co-extinction of Species

The concept of co-extinction (parasites, mutualists, and commensals becoming extinct alongside their hosts) has been around since the 1990s. In general, it is expected that inefficiently transmitted parasites are lost initially; later efficiently transmitted species with low host specificity will persist at low host densities. Host variety of a parasite will reduce as each potential host is lost or declines in host range and population. This indicates that parasitic species will decline at a rapid rate than their host species. Populations of Galapagos mockingbirds, *Nesomimus melanotis*, have dropped dramatically since they were first described by Charles Darwin in 1835 (http://www.nhm.ac.uk/research-curation/lifesciences/terrestrialinvertebrates/research/mite-research/mites-galapogos/index.html). As parasites are directly affected by the number of mockingbirds, genetic data obtained from research may help to conserve and reintroduce mockingbird populations. The trematode *Pleurogonius malaclemys* infects snails only when the endangered diamondback terrapin, the single host for the trematode (Byers et al. 2011), and when a diamondback terrapin population declines; it takes its parasites too.

3.4.2 Regulation of Host Populations

Parasites often serve as modulators of host population, which in generalist pathogens may result in strong frequency-dependent control over relative abundance across the host community. When the black-footed ferret (*Mustela nigripes*) was deloused during captive breeding after extinction in the wild, the ferret louse (*Neotrichodectes* sp.) may become extinct. All species are important, and adding back only the cute and charming ones undercuts the notion that reintroduction programs are about ecosystems, not just aesthetics. Determining the part played by parasites in regulating natural ecosystems still remains a major challenge for biologists. If the core job of conservation biologists is to sustain functional food webs and food chains, then it is crucial that parasites as an important and essential component of biodiversity are sustained.

Parasites are also biotic entities of natural selection altering a range of host characteristics, from phenotypic polymorphism and secondary sexual features to sexual reproduction (Wegner et al. 2003; Lively et al. 2004; Blanchet et al. 2009). These effects ultimately lead to biological diversification by changing host reproductive isolation and speciation (Summers et al. 2003). Common conservation strategies for hosts such as captive management, reintroduction, and translocation include wide-spectrum veterinary treatments to limit or prevent parasite transmission (Phillips and Scheck 1991; Moir et al. 2012). By maintaining disease-free host populations, the likelihood of conservation intervention success may be increased at the cost of parasite decline, particularly, for parasites of endangered, rare, or spatially restricted hosts (Gómez et al. 2012). For instance, the extinction of the louse *Colpocephalum californici* is suspected to be associated with the *ex-situ* veterinary treatment of California condors (Koh et al. 2004). However, such interventions can lead to unanticipated and negative impacts for hosts, including increased susceptibility of hosts to infection following reintroduction or translocation (Gompper and Williams 1998; Almberg et al. 2012). This indicates that maintenance of host-parasite relationships in managed wildlife populations can be beneficial and highlight vital play of the vertebrate parasitologists in conservation programs.

3.4.3 Modulators of Competitive Interactions

The differential effects of infection of generalist parasites can regulate competitive interactions. For instance, parapox virus-mediated competition can explain the ecological success of introduced gray squirrels (*Sciurus carolinensis*) in Europe (Tompkins et al. 2001). Infection can also affect reproductive behaviors and output, for example, causing abortion or sterility. In the most extreme case, parasitic castrators divert the host's metabolism for their own reproductive success, driving changes in host density and maturation rates (Lafferty and Kuris 2009).

3.4.4 Conservation vs Control

Parasitic agents which normally develop in hosts other than humans but can infect humans if given the opportunity are called *zoonotic agents*. Modern research has revealed that emerging diseases in humans have a zoonotic reservoir, that reservoirs are often wildlife species populations (Jones et al. 2008), and that anthropogenic influence is usually associated with human and wildlife disease emergence patterns (Daszak et al. 2000).

Associations among competitors, predators, and preys have historically been seen as the foundation of community structure. Parasites – long ignored in community ecology – are now recognized as playing an important role in affecting species interactions and consequently affecting ecosystem function. Parasitism can interact with other ecological drivers, resulting in both detrimental and beneficial effects on ecosystem services and biodiversity. Species interactions including parasites are also vital to understanding several biological invasions and emerging infectious diseases. This review combines community ecology and epidemiology to develop a wide-ranging monitor of how parasites and pathogens alter different aspects of communities, enabling the new emergence of ecologists to include parasites as a prime consideration in future programs.

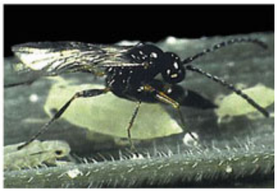
		
Fig.1 *Pediculus humanus humanus*	**Fig.2** ***Microterys flavus*** http://boutique.crisop.fr/microterys-flavus-10	**Fig.3** *Hydrozetes sp.* http://www.nhm.ac.uk/research-curation/life-sciences/terrestrial-invertebrates/research/mite-research/archaeological-indicators/index.html
 **Fig.4** *Trichogrammma* sp. (http://www.ecured.cu/index.php/Trichogramma_spp.)	 **Fig.5** *Aphelinus semiflavus* http://ponent.atspace.org/fauna/ins/fam/aphelinidae/aphelinus_aph.htm	 **Fig.6** *Aphidius colemani* http://www.arbico-organics.com/category/pest-solver-guide-aphids
 **Fig.7** *Aphidiu servi* http://www.arbico-organics.com/category/pest-solver-guide-aphids	 **Fig.8** *Aphytis melinus* http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v047n01p16&fulltext=yes	 **Fig.9** *Anagyrus pseudococci* http://bio-bee.ru/wp-content/uploads/2013/01/anagirus-400-266.jpg

Plate 3.1 List of select important parasitoids

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