

27 Biological conservation and parasitism

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1 Introductory remarks

1.1 Threats to biodiversity

Expansion of the human population has inexorably led to the destruction and degradation of ecosystem diversity with the consequence of a biological diversity crisis on the Earth. The example of the thylacine (*Thylacinus cynocephalus*) in Tasmania is among the best known cases of recent mammal extinctions. What is less recognized is the fact that in addition to habitat deterioration and hunting, a disease could have played a central role in this extinction (Guiler 1961). Another example is the white-tailed deer (*Odocoileus virginianus*). During the last century, the range of the white-tailed deer has expanded greatly in North America as a result of human forestry activities. During the colonisation of new territories, white-tailed deer was a carrier for meningeal worm (*Parelaphostrongylus tenuis*). Whereas meningeal worm was not virulent for white-tailed deer, moose (*Alces americana*) and woodland caribou (*Rangifer tarandus*) were highly susceptible to the nematode and succumbed to neurologic diseases (Anderson 1972). This demonstrates that habitat deterioration may promote range expansion of one host species with a parasite that may function like a biological weapon against its potential competitors. These two cases, among others, highlight the importance of taking into account diseases and parasites when studying the causes of the decline of threatened populations.

This chapter investigates how parasites are involved and interact with the main causes of population declines and also emphasizes the positive roles that parasites may play in the maintenance of biodiversity.

1.2 Do we need to conserve parasite species?

Pandas, tigers, right whales and gorillas are emblematic and charismatic species worldwide and a consensus exists for the need of their conservation. The same is true for economically important species such as salmonids and sturgeons. But do we really need the conservation of parasitic species? Not really! During our childhood, we all have favourite stuffed animals (representing one of these emblematic species) we take to sleep. However, do you ever see a child squeezing a stuffed worm, flea or tick? The lack of affect for cryptic species and the perception of parasites as disgusting creatures among the public certainly leads to a disinterest among governmental and conservation agencies to preserve them. Fortunately, in 1990, Donald A. Windsor expressed his concern for this matter in the famous slogan: "Equal Rights for Parasites!" (Windsor 1990). Five years later he pleaded once more for parasite conservation in an editorial that appeared in "Conservation Biology" (Windsor 1995). During the same time, the ominous term "co-extinction" was proposed to characterize the dual extinction of a host and its specialized parasite (Stork and Lyal 1993). Despite the passing of 15 years since these passionate declarations and the exponential increase of an interest in conservation biology, we can point out that parasitic species are far from being in a leading position among current conservation priorities. Very few parasites are listed on the IUCN Red List of Threatened Species (IUCN, 2003; Whiteman and Parker 2005). Some parasite extinctions have been even intentionally provoked as revealed by the will to remove parasites from hosts in captive breeding programs (Stork and Lyal 1993).

To convince resource managers that parasites are an important component of all ecosystems, the following arguments, which mainly rely on their potential utilitarian effects, are advocated by the parasites' defenders. First, parasites are living organisms and are *de facto* part of biodiversity. They shape community structure by reducing competitive abilities and vulnerability to predation of their hosts and have strong impact on ecosystem functioning (Hudson 2005). Moreover, parasites could maintain biodiversity by mediating competitive interactions between different members of an ecosystem. Because the rate of molecular evolution is usually faster in parasite DNA than that within the homologous loci of their hosts (Moran et al. 1995; Nieberding et al. 2004), the study of the evolution of parasite DNA sequences could provide valuable information on past population dynamics, evolutionary history and current demographic processes of endangered hosts (Whiteman and Parker 2005). Parasites could thus be used as a biological "magnifying glass" (Nieberding et al. 2004). Another utilitarian effect of parasites is their potential use as indicators of environ-

mental quality and ecosystem health (Marcogliese 2005). Indeed, parasites may be used as accumulation indicators of heavy metal contamination, particularly in aquatic ecosystems (Sures et al. 1999). In addition, parasite species and composition revealed perturbations in ecosystem structure and function (Marcogliese 2005). Furthermore, the use of parasite in human medicine is a new promising field of investigation, as illustrated by the use of helminths as therapeutic agents for inflammatory disease (Hunter and McKay 2004).

2 Parasite resistance and stress

2.2 Environmental stress and parasite susceptibility

Wild animals in their natural habitat have to cope not only with predictable environmental changes such as the cycles of seasons and their associated modifications in resource availability and temperature but also with unpredictable events such as catastrophes, spread of new diseases and human disturbances. Whereas animals react adaptively by behavioural and physiological modifications to predictable changes, unpredictable disturbances may have negative effects on population dynamics of living organisms. Increasingly rapid disappearing and fragmentation of habitats, which may be considered as unpredictable environmental changes, translates in a cascade of negative effects and can result in physiological stress on animals (Suorsa et al. 2003, 2004). The first physiological responses of an animal to stressful stimuli include cardiovascular effects and a hormonal response involving synthesis and secretion of glucocorticosteroids (Romero 2004). Consequently, a corticosteroid response might be a good indicator of a stress response (Hofer and East 1998). It is, therefore, not surprising that corticosteroid level is measured in many studies in ecology and conservation biology that have evaluated the effect of different environmental and human perturbations on the stress level of wild animals (Creel et al. 1997; Creel et al. 2002; Mostl and Palme 2002; Romero 2004; Palme et al. 2005). The consequences of a stress response on parasite resistance are complex and alter host immunocompetence in different ways (Apanius 1998). The immune system appears to be down regulated under stressful environmental conditions (von Holst 1998), particularly under severe chronic stress with prolonged periods of high cortisol concentrations (Mostl and Palme 2002). Stress stimuli may arise due to different factors in a perturbed environment. Habitat fragmentation may be related to chronic

food shortage (Zanette et al. 2000). Thus degradation of environmental conditions may decrease resource availability that in turn affects body condition and immune defences (Chandra and Newberne 1977; Klasing 1998; Christe et al. 2003). As body condition is usually positively correlated with immune defences (Møller et al. 1998), individuals with poor body condition will be especially vulnerable to attacks of parasites (Christe et al. 1998; Christe et al. 2000). Edge effect due to fragmentation may also be a source of stress because predators may have easy access to dense forest patches which were previously inaccessible. It has been experimentally demonstrated that exposure to predators reduced the ability of hosts to cope with parasitism mediated through effects on immune function (Navarro et al. 2004). Consequently parasitism may be favoured in fragmented habitat through the effect of predators. Thus, parasites, which can also be considered as an environmental stressor, may reinforce the effect of habitat degradation and participate in the reduction of a population.

In addition to habitat degradation and fragmentation, anthropogenic factors such as environmental pollution, hunting, tourism and leisure activities exert a negative pressure on wildlife and are thought to cause stress (Fowler 1999; Mullner et al. 2004). Clearly, more studies are needed to investigate the relationship between anthropogenic factors, level of stress and parasitism in endangered populations.

3 Parasitism in isolated and declining population

3.1 Review of theory on parasitism and extinction risks

Conservation biology deals with two major paradigms: population invasion and population decline. Both are related to each other (i.e. decline may be a result of an invasion) and both emphasize the potential roles of parasites and/or pathogens (Prenter et al. 2004).

Theoretical, experimental and empirical studies have established clearly that parasites play important roles in regulating population dynamics (Scott 1987; Scott and Dobson 1989; Albon et al. 2002; Rosa et al. in this volume) and structuring free-living communities (Minchella and Scott 1991; Morand and Arias Gonzalez 1997; Hudson and Greenman 1998; Tompkins et al. 2001). Parasites then have a large impact on biological conservation (Dobson and May 1988; McCallum and Dobson 1995; Sasal et al. 2000), as parasites and pathogens may compromise reintroduction or translocation programs (Viggers et al. 1993). They may have a higher impact on

threatened species generally characterized by a lower level of genetic variability, particularly on genes associated to immune system (Hedrick, 2003).

3.1.1 Threshold in host-parasite population dynamics

Small-sized host populations may be prone to extinction due to stochastic events. Several processes, including the Allee effect (Stephens and Sutherland 1999; see below), may increase the probability of extinction of small populations. These processes operate when host population size decreases to under a critical or threshold level, below which populations are almost doomed. Population viability analysis is one approach that has been developed for management purposes of small-sized endangered populations.

Threshold size has been also extensively studied in the case of host-parasite dynamics (Dobson 1989). The basic reproductive number, R_0 , is the major concept in host-parasite population dynamics. This quantity is defined as the number of new infections occurring after introduction of one parasite, or one infected host, into a naïve and susceptible host population. R_0 is positively linked to host density in the case of direct-transmitted parasites (see Rosa in this book). Parasites, or infection, can spread in the population when $R_0 > 1$ and as R_0 depends on host density, the condition of parasite invasion corresponds to a case when the density of host population exceeds a threshold density. Obviously, host-parasite dynamics are viewed in terms of parasite invasion or parasite invisibility. The task of disease management is then to decrease R_0 below one, i.e., below the threshold density.

The interplay between host and parasite thresholds has not been considered adequately. Deredec and Courchamp (2003) emphasized the importance of the relative position of the host and parasite thresholds: when the parasite threshold is higher than that of the host, the parasite is driven to extinction and the host population is relieved of its parasite; when the host population threshold is higher than that of the parasite, the host is driven to extinction while the parasite continues to exert strong pressure on the host until it reaches its own threshold. Hence, mathematical epidemiology and population dynamics are important tools for investigating thresholds and persistence of both hosts and parasites. They may help in determining the conditions to maintain a high level of parasite threshold in comparison to the host threshold.

3.2 Which diseases are important for conservation?

Microparasites are generally considered as an important threat in conservation biology (Daszak et al. 2000; Cleaveland et al. 2001). All conservation textbooks refer to the canine distemper virus, rinderpest and the avian malaria as examples of pathogen-driven extinction. Introduced diseases have been implicated in the local extinction of a number of species (McCallum and Dobson 1995; Vitousek et al. 1997) and the global species extinction of Hawaiian birds (VanRiper et al. 1986) and the thylacine (Guiler 1961) among others. Daszak et al (2000), in their review, mentioned 19 microparasites and no macroparasites as important threats for conservation and as zoonotic threats for human health through spill-over. The lack of reference to macroparasites may suggest that they are indeed less important, and that their survey is not of major interest, with the notable exception of ectoparasites (ticks, fleas) because of their roles as vectors of numerous virus, bacteria and protozoans.

Moreover, results based on comparative analyses in carnivores show that host species that live in low density within a restricted geographic area experience low parasitic pressure in terms of parasite species diversity, suggesting that parasites may not represent a particularly important risk for these host species (Torres et al. 2006). In contrast, widespread host species that live in high density are exposed to a wide range of parasite species that may affect drastically the population dynamics of these carnivores, suggesting that macroparasites may regulate them at least locally. These results lead to the paradox that parasite infection, and particularly that of macroparasites, is less crucial for small and isolated populations than for large populations. This paradox is apparent and resolved by considering the investment in immune defences, which is directly related to the prevalence and/or diversity of parasites as a mean to control infection (Martin et al. 2001). Evidence comes again from comparative studies, which suggest that hosts allocate their investment in immune function as a function of their probability of exposure to parasites (Møller and Legendre 2001; Møller et al. 2005). Large populations are composed of highly immunocompetent individuals and small populations of low immunocompetent ones. Hence, parasites and pathogens are threats to small and isolated populations because of poor performance of their immune system against pathogen introduction, but parasites (and parasite diversity) are probably necessary to maintain high levels of immune defence, which helps against new pathogens.

3.3 Allee effect

The Allee effect may be defined as “a positive relationship between any component of individual fitness and either numbers or density of conspecifics” (Stephens et al. 1999). The beneficial effects of conspecifics not only include antipredator vigilance, predator dilution, social thermoregulation, reduction of inbreeding but also social facilitation of reproduction through helpers (Stephens and Sutherland 1999; Courchamp et al. 2000). When population size reaches a low density, animal species that are subject to an Allee effect will suffer from a reduction in some aspects of their fitness that in turn will affect negatively growth rate of populations. Because of their potential role in extinctions of declining species, the Allee effects have thus become much studied in conservation biology (Stephens and Sutherland 1999; Lafferty and Gerber 2002). Interestingly, Allee effects and parasitism have several features in common that are of interest when studying population dynamics in conservation biology (Derecedo 2005). For example, theoretical models demonstrated the importance of host density in the probability for a parasite to become established in a host population (see above) and empirical studies have shown a positive relationship between host sociality or density and parasite prevalence and intensities (Anderson and May 1978; Brown and Brown 1986; Møller et al. 1993; Stanko et al. 2002; Altizer et al. 2003). Thus, animal species that aggregated as a behavioural response to the strong Allee effects, would be more prone to suffer the negative effects of parasites. Parasite species may also be subject to the Allee effects that influence the occurrence and the severity of epidemics as illustrated by patchy distributions of worms in hosts as a result of the necessity for female worms to find a mate in order to reproduce (Cornell et al. 2004).

It has been suggested that sexual selection, in particular female mate preferences, could lead to an Allee effect (Møller and Legendre 2001). If only males of poor quality are available for mating in a small population, females may refrain from reproduction or reproduce at a low rate. As a consequence of mating with a male of a non-preferred phenotype, females could decrease their parental investment resulting in poor reproductive success (Møller and Legendre 2001). Parasite-mediated sexual selection has been the focus of numerous studies since the influential hypothesis of Hamilton and Zuk (1982). A meta-analysis of the available studies related to this topic has revealed a negative relationship between parasite load, immunocompetence and the expression of male secondary sexual characters (Møller et al. 1999). Thus, parasites, by decreasing the expression of male secondary sexual characters, may contribute and reinforce the potential Allee effects created by sexual selection.

4. Invasive species and parasites

4.1 Parasite mediated competition

Mediation of competition by parasites is one mechanism of parasite interference (Anderson 1972; Hudson and Greenman 1998; Poulin 1999). Parasite-mediated competition is inferred when two different host species have different susceptibilities to the same non-specific parasite species. The presence of a given host species may decrease the fitness of the other host species simply by transmitting a pathogen to the more vulnerable host species (Hudson and Greenman 1998). The abundance of the more vulnerable host to the parasite is then depleted, potentially under the host threshold. Moreover, as the parasite infects two host species, the parasite threshold is obviously low. This “apparent” competition, mediated via a shared pathogen, differs from the classical competition for limited resources. Strong evidence of this competition was obtained not only from experiments but also from the field (Tompkins et al. 2000), e.g. red and grey squirrels in England (Tompkins et al. 2002b) and pheasant and grey partridge in England (Tompkins et al. 2002a). Parasite-mediated competition may operate for introduced host species, as they can be best competitors simply by introducing and transmitting a new parasite to the naïve native species. This can lead to a non-fit combination that can be more pathogenic (Hudson and Greenman 1998; Prenter et al. 2004). In this case, the invader uses parasites as biological weapons. Immune-naïve residents will be weakened or even killed by the new pathogens.

The most famous example of such a process comes from the history of the expansion of European humans through America where million of native people were killed by the influenza and other pathogens that accompanied conquistadors.

4.2 Parasite release hypothesis

Parasite mediated competition is not the only way by which parasites may interfere in competition processes. Recently, it was shown that many introduced species lost most of their parasites from their native habitats when introduced to new ones (Torchin et al. 2002; Torchin et al. 2003). This could be responsible for the demographic explosion of some introduced species, formulated as the “parasite release hypothesis”.

The parasite release hypothesis was proposed as an ecological mechanism to explain the success of introduced species. As the introduced species lose their parasites when invading new habitats, they have a competitive advantage over local species. Mitchell and Power (2003) and Torchin et al. (2003) found that parasitism is significantly reduced in organisms in their introduced range, supporting the “parasite release hypothesis”. One cause to explain that invaders may leave behind their parasites is that many parasites have complex life cycle stages with more than one host. If one of those hosts is absent in the new colonized area, the life-cycle of the parasite would be disrupted.

4.3 Immunity

In the invasion process, invasive host species harbouring a high diversity of parasites in their native habitat have advantages as they lose a large number of parasites and pathogens (see above). Invasive host species have another advantage if they have invested in strong immune defences in their natural range, which may then subsequently confer a better capacity to control parasites that they may acquire in the introduced habitat. Hosts having evolved strong immune defences are prime candidates for successful invasion (and also more resistant towards invaders). This hypothesis was proposed in the case of introduced plants and recently for the case of introduced animals (Lee and Klasing 2004; Møller and Cassey 2004). In contrast, hosts that are exposed to a low diversity of parasites may invest less in immune defences. Maintaining a strong immune system for threatened host species, or for individual hosts maintained in captivity in the view of reintroduction, is a new task for conservation biologists.

5 Conservation genetics and parasites

5.1 Genetic diversity and pathogen resistance

Habitat fragmentation and its degradation is probably one of the main factors leading to the disappearance of many species. Indeed, it often leads to a decrease in population sizes as well as to the appearance of barriers to gene flow between isolated populations. The small populations that result from this fragmentation often suffer from reduction of genetic diversity associated with genetic drift and inbreeding effects. This loss of genetic

variation can result in a rapid reduction of fitness (lower possibility to adapt to long term changes in environment, poor reproductive ability associated with a lower sperm quality, higher juvenile mortality, lower general survival, etc) (O'Brien 1994). Several recent studies (Cassinello et al. 2001; Keller and Waller 2002; Spielman et al. 2004) also showed that populations with a low genetic variability are generally more susceptible to infectious viruses, bacteria and other pathogens. The case of the cheetah (*Acinonyx jubatus*) is probably one of the best known concerning this phenomenon. The two major subspecies of cheetah (*A. jubatus jubatus* from southern Africa and *A. jubatus raineyi* from eastern Africa) display markedly reduced levels of genetic variability compared to other mammal species (O'Brien 1994). This would result in intensive inbreeding. When a breeding colony of this species was contaminated by feline infectious peritonitis (FIP) in Oregon state (USA), 100% of the captive animals showed morbidity symptoms and 60% of them died (O'Brien 1994). In contrast, in domestic cats, the mortality incidence of this virus is very rare (around 1%). According to O'Brien (1994), the high sensitivity of this cheetah colony to the FIP would be directly linked to the very low (almost monomorphic) level of variation of the Major Histocompatibility (MHC) genes characterising the cheetah.

A wide variety of gene classes (where the MHC is the most notable but see also the eosinophil-associated RNase (EARs) genes, the tumor necrosis factor gene promoter, the interleukine receptor or the γ -interferon receptors; Hill 1998; Zhang et al. 2000) are normally variable in natural populations and could contribute to disease resistance. MHC genes encode cell-surface glycoproteins, binding antigens derived from pathogens and parasites and constitute the most polymorphic genes in vertebrates (Parham 1999; Charbonnel et al. in this volume). They present antigens to T-lymphocytes which develop the appropriate immune responses. Two major groups of MHC genes are recognised: the MHC class I genes are specific to the immune defence against intracellular pathogens by binding peptides mainly derived from viral proteins or cancer infected cells. The MHC class II genes present with T-lymphocytes, peptides essentially derived from extra-cellular parasites (bacteria, nematodes, cestodes, etc.). The variability of MHC genes is correlated with the diversity of the T-lymphocyte receptors, which, in turn, determine the resistance of an organism to pathogens and parasites (Parham 1999).

Therefore, the cheetah, with its very low variability of MHC genes, is not well protected against the FIP and probably against many other pathogens and therefore is at a high risk of extinction. However, according to several recent studies, several processes would help to maintain high levels of MHC genes diversity. Indeed, these studies demonstrated that the anti-

gen binding sites (ABS) display more non-synonymous than synonymous substitutions compared to what would be observed under neutral theory (in this condition, the rate of synonymous substitution is predicted to be larger than the rate of non-synonymous substitution as the latter change the amino acid composition and would be likely deleterious) (Sommer 2005). This phenomenon cannot be explained by higher mutation rates in this region (Hughes and Yeager 1998) and the hypothesis accepted at present is that this particular nucleotide diversity in MHC genes would be the result of balancing selection. This would allow the maintenance of large numbers of alleles in populations and also the persistence of allelic diversity over long periods of time. Following this strategy, the binding of a large set of antigens would be possible.

Two main types of balancing selection have been proposed to explain high levels of genetic diversity in MHC genes of vertebrates:

- “Overdominance” strategy (Hedrick 1998; Richman 2000), where the heterozygotes are expected to have higher fitness than parental homozygotes as the latter will carry less divergent allelic sequences and, therefore, will have less chance to resist a large panel of antigens and/or multiple types of pathogens and parasites.

- “Frequency dependent selection” strategy (Hedrick 1998). This occurs when an allele or genotype is favoured at one frequency, but disadvantaged at another frequency. This hypothesis is based on the fact that host-parasite dynamics is considered as a co-evolutionary race. Pathogens adapt to infect the most common genotype, leaving rare genotypes least infected. If alleles are favoured when they are rare, but selected against when they are common, this will result in a balanced polymorphism (Sommer 2005)

Different studies confirmed the effect of balancing selection on the high MHC diversity. One of the best examples concerns the Nicolas Island fox (*Urocyon littoralis dickeyi*) (Aguilar et al. 2004). On the basis of different neutral markers (microsatellites, minisatellites and allozymes), this species is considered as one of the most monomorphic among sexually reproducing species. Regarding the low variability of these markers, this species would have many problems of fitness as well as low resistance to pathogens. However, it is characterised by a surprising high level of MHC diversity which makes it much more resistant to what could be expected. This observation is interpreted as being the result of intense periodic balancing selection at the MHC which may have allowed the persistence of variation within this species despite strong genetic drift.

5.2. Inbreeding, MHC and risk of extinction

Under some circumstances (for example, particular historical events such as bottlenecks or founder effects), strength of selection acting on MHC genes can be insufficient to maintain variation in small or fragmented populations over a long period of time (Sommer 2005). In these cases, the power of genetic drifts can be stronger than the power of selection. This can lead to a loss of genetic diversity not only on the neutral markers but also on the MHC genes. This would explain the very low genetic variability in highly threatened species such as the cheetah (*Acinonyx jubatus*) (see above), the Asian lion (*Pantera leo persica*) (O'Brien, 1994), the common hamster (*Cricetus cricetus*) in the Netherlands (Smulders et al. 2003), the Scandinavian beaver (*Castor fiber*) (Ellegren et al. 1993), the Northern elephant seal (*Mirounga angustirostris*) (Hoelzel et al. 1999) and the Scandinavian moose (*Alces alces*) (Ellegren et al. 1996). Under these circumstances, threatened species present a high risk of extinction as they can be very sensitive to new diseases and changes in environment.

However, other studies demonstrated that endangered species such as the Przewalski's horse (*Equus przewalski*) (Hedrick et al. 1999), the Arabian oryx (*Oryx leucoryx*) (Hedrick et al. 2000) and the Malagasy giant jumping rat (*Hypogeomys antimena*) (Sommer 2003) are characterised by a low number of MHC alleles but which are separated by a high level of nucleotide and amino acid divergence. Analysis at the ABS showed that non-synonymous substitutions were higher than synonymous ones, suggesting selection leading to an increase of amino acids changes in the ABS region and thus to higher divergences between MHC alleles (Sommer 2003). These studies indicated that other selection processes are able to maintain some MHC polymorphism (not on the number of alleles but rather on the genetic difference between the existing alleles) even in species surviving bottlenecks. This would be sufficient to prevent immediate pathogen-induced declines. However, such kind of adaptive processes to changing conditions is probably limited and does not predict the outcome effects of introduced pathogens, which differ from commonly encountered diseases. Probably, the maintenance or even renewal of variation in functional important regions of the MHC, either from mutation, recombination or immigration from other populations, would be an important genetic component to allow an appropriate immune response (Sommer 2005). However, too strong genetic bottlenecks, leading to important inbreeding depressions, do not permit such kind of processes to operate and this explains why some species like the cheetah or the Asian lion are so sensitive nowadays to diseases.

6. Management

6.1 Breeding program and risk of parasite transmission

As mentioned by McCallum and Dobson (1995), “diseases and parasites pose particularly severe problems in captive populations, in which animals are held at high density, may be stressed and may be exposed to cross-species transmission”. During the last 20 years, a great amount of zoos worldwide have participated in the management of endangered species. Many threatened species have captive populations that act as insurance against extinction in the wild and, indeed, captive breeding programs have saved some endangered species from extinction (e.g. Père David’s deer, European bison, etc) (Frankham et al. 2002). Because parasites may have negative effects on their host, veterinarians in zoos take great care to reduce or even to remove entirely parasite loads on captive animals. As the ultimate goal of breeding programs in zoos is to increase threatened populations or to reintroduce individuals into the wild, parasites play an important role. What could be the consequences of maintaining hosts during many generations in a parasite-free environment? The potential risk is to release into the wild individuals that have lost their defences against pathogens and diseases. Once in the wild, they will be in contact with a vast array of parasite species and may be unable to resist to their detrimental effects. Maintaining some parasites on individual hosts kept in captivity could be a way to solve part of this problem.

6.2 Beneficial effects of parasites and parasite conservation in captive breeding program

Macroparasites, because of chronic infections, have evolved several kinds of immune evasion strategies (Charbonnel et al. in this volume). Some strategies of immunomodulation displayed by many macroparasites may have some beneficial effects on their hosts by regulating Th1/Th2 cytokine responses (Weinstock et al. 2004). Th1 responses induce inflammatory cell activity to control intracellular infections while Th2 responses drive humoral immune responses to control extra-cellular parasites (see Weil et al. in this volume).

Mice with helminths have blunted Th1 responses while helminths promote Th2 responses associated with production of interleukin 4 (IL-4), which helps impede Th1 cell differentiation. Thus, induction of IL-4 could

underlie the alterations seen in host immunity (i.e. high inflammatory activities). Helminths also appear to protect the host from aberrant Th2 diseases such as asthma and food allergy (Weinstock et al. 2004), and there is now an immunological basis for protection by helminths. Human epidemiological data and several animal studies support the notion that helminths protect the host from immunological disease (Elliott et al. 2005), particularly those caused by the activation of the Th1 response by microparasites. For example, helminths protect mice and rats from experimental autoimmune encephalomyelitis, as well as other diseases of immunity. Thus, natural exposure to helminths may guard animals from developing severe immunological diseases, suggesting that helminths should be useful in conserving both endangered and captive species.

Gompper and Williams (1998) proposed a series of measures to maintain endangered parasite species originating from threatened hosts in captive breeding program. However, they pointed out that because most of the public disapprove of protecting parasite species, attempts to conserve unique species of parasites could result in a hostile public response against efforts to preserve hosts. Therefore they proposed a series of measures aimed to save parasite species without damaging attempts to conserve hosts. One of those measures was to find alternative hosts to maintain parasite populations for potential reintroduction once the host population was restored. However, the problem of parasite conservation concerns mainly highly host-specific parasites. To find alternative hosts on which specialist parasite populations would be viable may be a difficult task because experiments on cross-species infection have shown a strong decrease on both parasite survival and reproductive success on the foreign host, even if this new host species belongs to the same host genus (Giorgi et al. 2004).

7 Concluding remarks

The consequence of human population growth is closer contact between human and reservoir hosts of numerous diseases. The spread of disease to endangered wildlife species due to contact with humans and domestic animals, and vice versa, increases as humans and their domestic animals get in more contact with these species due to habitat fragmentation. Emergence of new diseases and particularly those from small mammals such as rodents or bats are of great public health concern (Leroy et al. 2005). Conservation medicine, a new theme within the field of conservation biology, has been viewed as the application of medicine to improve the conserva-

tion of wildlife and ecosystems (Aguirre et al. 2002). Conservation medicine, according to Ostfeld et al. (2002) is “devoted to understanding the interactions among human-induced and natural changes in (1) climate, habitat and land use; (2) pathogens, parasites, and pollutants; (3) biodiversity and health within animal communities; (4) health of humans” (Ostfeld et al. 2002). The 2005 “*Anus horribilis*” for bats worldwide illustrates the importance of this new field of investigations. While it was discovered in China that bats are the reservoir of SARS virus (Lau et al. 2005; Li et al. 2005), it was found in Africa that they are probably the reservoir for Ebola virus (Leroy et al. 2005).

We strongly hope that this chapter will convince ecologists and conservation biologists that pathogens and parasites, mostly investigated by veterinarians and physicians, should not be ignored or eradicated because of their crucial importance to wild and domestic animals and humans.

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