Putting Theory into Practice: Wildlife Health in Conservation

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Abstract: Infectious and noninfectious diseases are being recognized by conservation biologists as an increasing challenge to the conservation of wildlife. The amplified role of diseases as a factor limiting species’ survival can be traced to anthropogenic changes on a global scale that have direct and indirect influences on the health of wildlife species. These changes include human population growth, habitat fragmentation and degradation, the isolation of populations of species, and an increased proximity of humans (and their domestic animals) to wildlife. Further, some conservation projects have caused more harm than good by unwittingly introducing diseases to wildlife populations, whereas others have failed to meet their objectives because they did not take disease factors into consideration. Conservation biologists need to move quickly past the decades-old debate on the relative importance of wildlife health to conservation and begin using all the tools available to ensure the effectiveness of their efforts. We briefly review the literature on wildlife diseases, place wildlife health in the context of global changes affecting wild animal populations, and offer concrete suggestions for ways to integrate wildlife health sciences into conservation, such as including health assessment or monitoring programs and research on interspecies disease transmission in field biology projects, training wildlife professionals in the design and implementation of wildlife studies that incorporate health components, and encouraging interdisciplinary collaboration. Our goal is to raise awareness that conservation biologists working in disciplines ranging from field biology to policy making have an important role to play in facilitating a transition toward a new conservation paradigm that includes wildlife health. This paradigm shift will take an academic understanding of the importance of wildlife disease and turn it into practical actions that will help conserve wildlife more effectively.

De la Teoría a la Práctica: la Salud de la Vida Silvestre en la Conservación

Resumen: Los biólogos de la conservación reconocen que las enfermedades infectosas y no infectosas son un reto cada vez mayor para la conservación de vida silvestre. El papel de las enfermedades como un factor limitante de la sobrevivencia de especies se puede deber a cambios antropogénicos a escala global que tienen influencia directa e indirecta en la salud de especies de vida silvestre. Estos cambios incluyen el crecimiento de la población, la fragmentación y degradación del hábitat, el aislamiento de poblaciones y una mayor proximidad de humanos (y sus animales domésticos) a la vida silvestre. Adicionalmente, algunos proyectos de conservación han causado más daños que beneficios al introducir, inconscientemente, enfermedades en las poblaciones de vida silvestre, mientras que otros han fallado en alcanzar sus objetivos porque no tomaron en consideración a factores de enfermedades. Como biólogos de la conservación, necesitamos rápidamente superar el debate que se ha dado por décadas sobre la importancia relativa de la salud de la vida silvestre para la conservación y comenzar a utilizar todas las herramientas disponibles para asegurar la efectividad de nuestros esfuerzos. Brevemente examinamos la literatura sobre enfermedades de vida silvestre, colocamos la salud de la vida silvestre en un contexto de cambios globales que afectan poblaciones silvestres de animales y ofrecemos sugerencias concretas para integrar las ciencias de la salud de vida silvestre en la conservación, como incluir la evaluación de la salud o programas de monitoreo e investigar la transmisión de enfermedades entre especies en proyectos de campo, entrenar profesionales de la vida silvestre en

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el diseño e instrumentación de estudios de vida silvestre que incorporen componentes de salud y colaboración trans-disciplinaria. Nuestra meta es crear conciencia de que los biólogos de la conservación que trabajan en disciplinas que van de la biología de campo a definición de políticas juegan un papel importante en la transición hacia un nuevo paradigma de conservación que incluye la salud de la vida silvestre. Este cambio de paradigma tendrá el entendimiento de la academia acerca de la importancia de las enfermedades de la vida silvestre y transformarlo en acciones prácticas que ayudarán a conservar a la vida silvestre más eficientemente.

Introduction

The conservation of wildlife requires an understanding of biogeographical patterns, community structure, population dynamics, and individual behavior. A fifth factor that should be viewed as imperative for sound conservation efforts is an understanding of health issues that affect populations. If one reads recent editorials and reviews in scientific journals, it is easy to come away with the impression that disease and health issues have only just been discovered as important factors in the conservation of wildlife (Meffe 1999; Daszak et al. 2000). In fact, for many decades, disease has been recognized as a critical issue. What is new, however, is the increasing attention the subject is receiving from the wider conservation community. This is encouraging because the attention suggests that we are poised to move beyond an academic interest in the effect of diseases on wildlife.

Health and disease are broad terms, so it is useful to define them in the context of our discussion. The World Health Organization defines health as a state of complete physical, mental, and social well being and not merely the absence of disease or infirmity (Last 1983). While this state can serve as a laudable goal, it does not provide us with objective criteria for determining the health of wildlife. Wobeser (1981) defines disease in free-ranging wildlife populations as "any impairment that interferes with or modifies the performance of normal functions, including responses to environmental factors such as nutrition, toxins, and climate; infectious agents; inherent or congenital defects, or combinations of these factors." Those impairments that negatively affect the long-term persistence of populations and the ability of healthy populations to fulfill their ecological roles in an ecosystem are of primary concern to those of us involved in conservation.

Impairments to the health of wildlife are being exacerbated by the human population explosion, habitat fragmentation and degradation, isolation of wildlife populations, and an increased proximity of humans (and their domestic animals) to wildlife (Jones 1982; Scott 1988; Daszak et al. 2000). These phenomena are occurring on an unprecedented global scale, which in turn is creating novel opportunities for disease to have a negative effect on wildlife and on efforts to conserve it.

We (1) provide a historical perspective on what is sometimes referred to as "conservation medicine" by briefly reviewing how health and disease factors have been seen to affect the persistence of wildlife populations; (2) describe in more detail how global changes are expanding the role disease plays in population persistence; and (3) make practical recommendations for prioritizing activities that workers should focus on in trying to incorporate wildlife health concerns into conservation efforts.

Historical Perspective

In 1933 Aldo Leopold stated that the "role of disease in wildlife conservation has probably been radically underestimated" (Leopold 1933). Even though "conservation medicine" has only recently reached the mainstream conservation literature (Meffe 1999; Osofsky et al. 2000), research began in the decades following Leopold’s statement and established a large body of scientific knowledge on wildlife diseases and disease ecology. Diseases of wildlife were first seriously addressed by the scientific community as they related to either the health of domestic species (i.e., ruminants, pigs, chickens) with which wildlife had contact or to that of game species (i.e., deer, ducks) that were important economically (Friend 1976; Pastoret et al. 1988; Plowwright 1988b). Other diseases of domestic and wildlife species that were originally noted as a major concern were zoonoses (diseases transmissible from animals to humans) such as rabies, brucellosis, and tuberculosis (Friend 1976).

Beginning in the 1970s and 1980s, surveys that incorporated epidemiologic approaches were conducted on a variety of free-ranging wildlife populations. Additional interest and funding was sparked in the 1980s as a result of the passage of the U.S. Endangered Species Act (Spalding & Forrester 1993). From the 1970s through the 1990s, relevant publications included theoretical models describing parasite biology (Anderson & May 1979a; 1979b; Anderson & Gordon 1982; Anderson 1991), empirical examples of significant negative effects of diseases on free-ranging wildlife populations (Thorne & Williams 1988; Heide-Jorgensen et al. 1992), and conceptual statements on the role of wildlife health in con-
One issue that has received a significant amount of attention in its own right is massive die-offs associated with disease in free-ranging wildlife populations (Young 1994). Examples include diseases such as rinderpest in ungulate species (Plowright 1982) and botulism in waterfowl (Smith 1982), die-offs associated with oil spills (Garrot et al. 1993), and infectious disease epidemics such as canine distemper virus in lions (Roelke-Parker et al. 1996) and malaria in endemic Hawaiian birds (Warner 1968; Van Riper et al. 1986). For many years the primary role of wildlife veterinarians was the management (conservation) of populations experiencing disease epidemics associated with high mortality.

In the recent past, naturally occurring infectious agents and noninfectious etiologies (causes of disease) have been recognized as integral in shaping many aspects of wildlife behavior and ecology (Yuill 1987; May 1988). Increasingly, many conservation scientists, including veterinarians, have begun to put these phenomena into the context of the current biodiversity crisis and to examine more explicitly the role disease can play in the loss of species (Dobson & Hudson 1986; May 1988; Scott 1988; McCallum & Dobson 1995; Hansen & Johnson 1999; Daszak et al. 2000). A review of the literature reveals decades of relevant research, providing a foundation for efforts to integrate concerns about wildlife health and disease into practical conservation efforts. Workers have provided much of the data needed to understand how the current global changes such as increasing interactions among wildlife, livestock, and humans affect our efforts to conserve wildlife populations.

Global Trends Affecting Wildlife Health in Conservation

There are three broad processes affected by ongoing global changes which have profound implications for wildlife health and conservation: alterations in landscapes and habitats, shifts in wildlife populations, and the resulting changes in disease ecology. We recognize that to some extent the distinctions between these categories may seem arbitrary; they clearly overlap and may be at work simultaneously, which complicates and compounds their effects (Soulé & Kohn 1989). Nevertheless, in the interest of creating a simple conceptual framework for discussion of the issues, we have chosen to categorize them in this way.

Furthermore, changes taking place at the global scale have direct and indirect effects on the health of wildlife species. We include examples of global changes acting in indirect ways on wildlife health, making populations under stress more susceptible to disease outbreaks that otherwise would run their course without risking extinction of an entire species. Such disease outbreaks represent the way many conservation biologists traditionally have understood how disease processes act on wildlife populations. We also discuss certain global anthropogenic changes that have a direct effect on wildlife persistence, stressing that there are opportunities for familiar diseases to act on wildlife populations in new ways and situations allowing completely novel diseases to come into play. Disease events that fall into the latter group are not confined to an already failing population, but rather can be a major cause of decline in themselves.

Changes in Landscapes and Habitats

Environmental changes caused by human activity have amplified the role of diseases as regulating factors in species' survival. These changes include the conversion of wildlife habitat for human use, resulting in habitat loss and fragmentation, macro- and microclimate changes, and environmental contamination.

Fragmentation of ecosystems has a variety of implications related to disease and has generated particular interest from island biogeographers and wildlife disease researchers. Fragmentation of ecosystems can result in human-made "island ecosystems" that have been compared to geographical islands, functioning to isolate populations of species geographically and to confine them to smaller areas. Much has been written about island extinctions associated with human introduction of infectious and parasitic diseases (Van Riper et al. 1986; Dobson 1988; Quammen 1996).

Even though the biological diversity of islands is a small percentage of the world's total, of the recorded number of invertebrate and vertebrate extinctions that have occurred since the 1600s, 367 have been island species and only 124 continental species (Smith et al. 1993). Extinction may also be the fate of many wildlife species located within newly created "artificial islands." African wild dogs (Lycaon pictus) represent one well-known example of isolated populations now teetering on the brink of extinction, for which conservation efforts have been hampered severely by disease (Alexander & Appel 1994; Kat et al. 1996). Protected areas that are intentionally isolated by fencing, as was true in Kruger National Park, South Africa, or inadvertently isolated by human population growth and activities, such as the intense agriculture one finds in Virunga National Park, Rwanda, and south Florida, United States, are also examples of "island" ecosystems. In all these areas diseases have a significant effect on the survival of wildlife populations within their boundaries (Maehr et al. 1991; Keet et al. 1996; Mudakikwa et al. 1998; Sleeman 1998).

One result of land degradation and fragmentation is the increased opportunity for contact among humans, domestic animals, and wildlife. This increased proximity
may result in increased transmission of diseases between these groups, including zoonotic and anthropozoonotic diseases (Morell 1995; Wolfe et al. 1998; Gao et al. 1999; Wallis & Lee 1999). The intentional practice of “multi-species land use” and buffer zones in which domestic animals graze the same lands as wildlife may facilitate the transmission of disease between these two groups (Pastoret et al. 1988; Plowright 1988a; Foreyt 1990; Roelke-Parker et al. 1996; Karesh et al. 1998).

Other environmental changes related to human activity, such as climate change and pollution, have been implicated in infectious disease states in both human and animal populations, but the long-term implications of these findings for conservation have only begun to be explored. For instance, we know that global climate changes, such as warming trends and rainfall patterns, can influence the epidemiology of various infectious diseases (Harvell et al. 1999). This realization has also occurred among conservationists concerned with long-term species survival in reserves affected by these anthropogenic climatic changes (Peters & Darling 1985).

Air and water pollution are also linked to various non-infectious diseases. Large-scale pollution events such as oil spills are obviously detrimental to wildlife (Garrot et al. 1993), but long-term and low-level toxin exposure due to pollution are now also being recognized as detrimental (Colborn et al. 1996). Two areas of toxicologic research that have received a great deal of attention in recent years are the negative effects of estrogenic agents that disrupt normal endocrine function (Colborn et al. 1996; Yamamoto et al. 1996) and the negative effects of PCBs on immunocompetence (O’Hara & Rice 1996). For amphibians, a taxonomic group extremely sensitive to environmental changes, there are reports of deformities related to pesticide exposure (Ouellet et al. 1997). Light and noise must be considered pollutants. For example, the effect of light pollution on the survival of hatching sea turtles is well documented (Peters & Verhoven 1994). Certain “new” epidemics of infectious diseases such as fibropapillomatosis (Herbst 1994) and chytridiomycosis (Berger et al. 1998), and a number of marine mass mortality events (Heide-Jorgensen et al. 1992), are thought to be a direct or indirect result of environmental pollution.

Wildlife Population Dynamics

The manipulation of wildlife, whether an individual or a population, can alter the dynamics of disease within populations. Translocations, hunting, and live captures for commercial trade have direct and indirect effects on health. Alterations of host-pathogen interactions that result from these human activities affect not only the health of targeted animals but also that of conspecifics and sympatric species.

Animal translocation, as broadly defined by The World Conservation Union (1987), is the movement of living organisms from one area for release in another. Thus, translocation encompasses introduction, reintroduction, and restocking. Many examples exist in which animal translocations resulted in serious wildlife disease problems (Fischman et al. 1992; Jessup 1993; Meltzer 1993; Woodford & Rossiter 1993; Davidson et al. 1996). Such problems typically fall into the following three categories: diseases brought by a subclinical (nonsymptomatic) host to a new region (Office International des Epizooties 1987), disease vectors introduced to new geographic locations (Curasson 1943), and diseases encountered by translocated animals (naive to such diseases) after being moved to a new region (Pandey et al. 1992). Examples of species experiencing disease problems caused by the release of captive-bred animals among free-ranging populations include golden lion tamarins (Leontopithecus rosalia) in Brazil (May & Lyles 1987), white-tailed deer (Odocoileus virginianus) in North America (Davidson et al. 1996), and Arabian oryx (Oryx leucoryx) in Saudi Arabia (Kock & Woodford 1988; Bush et al. 1993). Similar threats to wild populations have been documented with the reintroduction of confiscated tortoises and orangutans that may have acquired an infectious disease while in captivity from either captive animals (Jacobson et al. 1995) or from humans (Warren et al. 1998), respectively.

Although dismissed as being insignificant and uncommonly used by many in the conservation sciences, translocations of animals have increased substantially in the past several decades (Griffith et al. 1993), with over a million live animals moved and released as of the early 1990s (Davidson & Nettles 1992). In practice, much of wildlife management still depends heavily on such strategies.

Illegal and legal hunting for sport and bush meat and capture of wild animals for the pet trade must be considered if we are to know the true scale and frequency of animal movements that fall outside the normal geographic or behavioral scope of a given species. Removing individuals from populations and transporting their live or dead bodies (including all the pathogens and parasites they carry) to new areas can have enormous potential for affecting the health of wild and domestic animal populations (described for infectious agents of canids in the southeastern United States [Davidson et al. 1992] and for rinderpest of ungulates in Africa [Plowright 1982]). In the case of trophy hunting, there is also an effect on the health of the source population in that the healthiest and potentially most disease-resistant individuals often are removed from populations already under pressure. In developing countries, endangered species are frequently confiscated and end up in the care of foreign national biologists or rehabilitators who lack the resources to screen for disease before release. Thus, many animals are returned to the wild only to expose their conspecifics.
to novel diseases picked up during rehabilitation (Karesh 1995). In our experience, this type of “underground translocation” is common.

Disease Ecology

Ongoing anthropogenic modifications of the environment, including changes that increase interspecies contact and confine individual populations, the translocation of susceptible hosts to regions with novel pathogens, and the introduction of novel pathogens to susceptible hosts in a new region, are responsible in many instances for a change in disease ecology (Wilson 2000). One example of a shift in disease ecology is the loss of endemic stability. An endemically stable disease is one in which the agent, vector (in vector-borne diseases), host, and environment coexist in a manner that results in the virtual absence of clinical disease (Norval et al. 1992). In many regions of the world, diseases of domestic animals that were once endemically stable, such as heartwater (Deem et al. 1996) and theileriosis (Moll et al. 1984), are now unstable due to anthropogenic changes. This change, to either an endemically unstable or an epidemic state, could happen in wildlife populations but is not as well documented for them due to a lack of information on those diseases historically endemically stable in wild-animal populations.

Several factors influence the spread and perpetuation of a contagious agent once it has been introduced into a host population: the density of susceptible hosts, the frequency of host contact, the infectiousness and pathogenicity of the disease, and the average time an infected host is infectious (Anderson & May 1979a, 1979b). These four factors are profoundly affected by global changes in landscapes and wildlife dynamics.

Suggestions for Integrating Animal Health into Conservation

Although the role of disease in species conservation has been appreciated for years, it has only been in the recent past that health and disease issues have come to the forefront of conservation biology as limiting factors in wildlife conservation (Meffe 1999; Daszak et al. 2000; Osofsky et al. 2000). Unfortunately, although many conservation biologists are interested in including questions and concerns about disease in their study design or sampling methods, there is a misconception that the only reason to work with veterinary wildlife professionals is to have them immobilize study animals. Although the veterinary profession has been instrumental in improving the safety and efficiency of animal handling procedures (Osofsky & Hirsch 2000), other pressing issues mandate collaboration between conservation biologists and wildlife health professionals. Thus, we present some practical steps to foster such collaboration. We base our suggestions not only on the literature but also on a decade of experience in integrating wildlife health concerns into field biology and conservation efforts. We recommend only those approaches of highest priority and/or those we have found most cost effective.

Veterinary Involvement in Conservation Projects

The use of veterinary skills in the form of either prevention or treatment is probably the most controversial issue surrounding the role of animal health in conservation efforts (Macfie 1992; Gascoyne et al. 1993; Inserro 1997). Many conservation biologists insist that “human intervention” in the form of veterinary services should not be provided in any way for wild animals because such action would interfere with evolutionary processes. But there are probably few species that have not been influenced by some form of “human intervention” (Redford & Richter 1999). Even the simple act of conducting field research in an “untouched” area affects change. Other people may object to veterinary involvement because of the potential risk of doing more harm than good. This concern can easily be addressed by involving experienced, qualified health professionals in decision making and procedures. We further recommend that the same standards be applied to the evaluation of risk of disease transmission or environmental contamination resulting from field research not related to animal health. Rather than debate whether intervention is good or bad, it would be more sensible to determine the most appropriate prevention and treatment options for wildlife populations on a case-by-case basis. Appropriate strategies for the prevention or treatment of wildlife diseases might range from public and staff health-education and vaccination programs to intensive disease management. Examples of intensive management include the black-footed ferret (Mustela nigripes; Thorne & Williams 1988) and African wild dog (Gascoyne et al. 1993) conservation programs and control of waterfowl disease epidemics (Pearson & Cassidy 1997). Aside from ethical considerations, which vary widely among different groups of humans, decisions about the level of veterinary involvement in a project should be based on (1) the status of the species or populations affected or at risk; (2) the nature of the cause of the health problem, which requires veterinary investigation; (3) the spatial distribution of the species; (4) the costs and practicality of necessary preventive and treatment measures; (5) specific disease issues of concern; and (6) implications of intervention or lack thereof on the health of other species, including humans and domestic animals.

We stress that preventing the introduction of new health problems, as opposed to intervening once a situation has already reached the crisis point, can and should be a bigger part of what we do as conservation biolo-
gists. When and whether preventive measures and crisis intervention are needed to limit wildlife health problems depend on so many variables in each locale that expertise in wildlife health should be aggressively cultivated for more effective future conservation programs.

Applied Veterinary Medicine and Research in Conservation

HEALTH ASSESSMENT AND MONITORING

Veterinarians perform health surveys or assessments and long-term health monitoring that provide critically needed baseline information on species of interest. In contrast to our knowledge of humans and domestic animals, few data sets exist to establish the “normal” or expected range of values for most of the world’s threatened or endangered wild species. These data sets should include blood parameters such as complete blood count, serum biochemistry profiles, vitamin and mineral levels, evidence of exposure to infectious agents such as antibodies or microbes, and residues of chemical contaminants.

Health assessment and monitoring programs integrated into field biology projects have been described (Karesh et al. 1997a; Karesh et al. 1997b; 1997c).

Baseline data on population health should be used in population viability analysis because the viability of a population is inseparable from its health (Karesh & Cook 1995). These data can be used in comparisons with the same population at a future date to determine the effects of various disturbances (i.e., ecotourism, weather extremes, habitat loss) and for comparison with different populations. Such comparisons are valuable in determining the appropriateness of various conservation management techniques for individual populations or species. Just as mammal, bird, or reptile surveys allow one to quantify population trends, documenting changes in prevalence or exposure to infectious and toxic agents provides objective data for management action. Changes noted in these parameters, before and after an event (all else being equal), would confirm that the event had an influence on the health of the population and thus could threaten long-term survival. Events that might be expected to influence the health status of free-ranging wildlife include disease transmission from domestic animals in the region; exposure to industrial, agricultural, and urban pollution; tourism; and disease transmission between wildlife species. Identification of infectious disease threats or the presence of toxic agents would inform decisions about zoning and the use of terrestrial and aquatic areas and could mobilize local and international support for conservation efforts.

HEALTH STUDIES OF ZOONOTIC, ANTHROPOZOONOTIC, AND INTERSPECIES TRANSMISSION OF DISEASES

Health assessment and monitoring programs should focus more on zoonotic diseases, which are transmitted from animals to humans; anthropozoonic diseases, which are transmitted from humans to animals, and other forms of interspecies disease transmission such as vertebrate-to-vertebrate and vector-borne diseases. The conservation of wildlife species is greatly complicated by these possible disease transmission routes, and they must be addressed to minimize potentially devastating results for wildlife, humans, and domestic animals.

There have been many reports of disease epidemics in both nonhuman (anthropozoonic) and human (zoonotic) primates (Kalema et al. 1998; Mudakikwa et al. 1998; Wolfe et al. 1998; Gao et al. 1999; Wallis & Lee 1999). These epidemics are suspected of being caused by the direct and indirect contact of one group with another. Activities such as behavioral research or tourism, although well intentioned, can serve to introduce new diseases to wild populations (Wallis & Lee 1999).

As humans encroach on lands inhabited by nonhuman primates, increase the use of nonhuman primates as a source of protein, and continue to collect nonhuman primates for trade as pets, the incidence of these epidemics surely will increase. An understanding of the epidemiology of these diseases through field studies is necessary to ensure that conservation projects guarantee the survival of nonhuman primate species without risking the health of humans.

Diseases transmitted among livestock, other domestic animals, and wildlife are also of great concern (Pastoret et al. 1988; Roelke-Parker et al. 1996; Deem 1998; Karesh et al. 1998). As grazing lands designated for livestock continue to expand into regions where wildlife exist, the opportunity for epidemics in both livestock and wildlife populations increases. Policies to limit the use of land for livestock are routinely unacceptable to governments and local peoples. It is therefore imperative that we collect data to gain insight on the epidemiology of these diseases in both livestock and wildlife hosts so that conservation projects can be developed to ensure the survival of wildlife species and the health of domestic livestock. The same concerns are associated with the possible transmission of disease between wild and other domestic animals (e.g., dogs and cats) as increased contact occurs between these two groups (Blouin et al. 1984; Kariuki 1988; Roelke-Parker et al. 1996). Researchers, protected-area managers and staff, and tour operators need to be aware that their presence, along with that of their domestic pets and food animals, increase the risk of introducing diseases to wildlife populations (Karesh et al. 1997b; Wallis & Lee 1999).

TRAINING

Worldwide, wildlife-agency workers, veterinarians, and conservation biologists must be trained to design and conduct wildlife studies that incorporate crucial health considerations. Training should cover how to conduct
research on wildlife safely, humanely, and in a manner consistent with conservation goals, and should provide practical information on the ecology of diseases. We must raise awareness among professionals in other disciplines and within local communities. Everyone, from biologists to policymakers to cattle ranchers, should be welcome to participate in organized workshops and other outreach programs that inform them about their relationships to and effects on the health of wildlife. As Osofsky (1997) says, "think link."

INTERDISCIPLINARY COLLABORATION

Interdisciplinary collaboration should be directed at studies that shed light on the effects of pathogens and toxic chemicals on the persistence of wildlife populations. These studies often involve the investigation of relationships among disturbed habitats and the health of wildlife, domesticated animals, and human beings. This requires collaboration between livestock and wildlife veterinarians, physicians, and other workers in basic and applied biomedical research, as well as epidemiologists, conservation biologists, and ecologists. Some conservation biologists object to such collaboration, fearing that information on the diseases of wildlife will be misconstrued by the human medical community and politicians, resulting in the persecution of wildlife as disease carriers. This objection is based on suspicion and will not help protect wildlife. Whether or not veterinarians and conservation biologists choose to contribute their opinions and professional expertise to the human medical community, research directed at public health will continue. It is therefore imperative that veterinarians and conservation biologists take every opportunity to provide input to ensure that research is conducted in a manner consistent with a conservation ethic and that findings are interpreted with conservation goals in mind.

DATA COLLECTION AND MANAGEMENT

The community of people working on aspects of wildlife health as related to conservation is growing and will continue to grow as awareness of the effects of disease increases. It is important that we create software and databases that can make wildlife health information easy to record, disseminate, share, and interpret. Although a variety of programs exist for experimenting with theoretical epidemiological models, only recently have a few efforts been directed at standardizing and tracking current information collected on wildlife die-offs or at mapping these data.

Along similar lines, biologists, ecologists, veterinarians, and medical researchers need to coordinate their efforts better to capitalize on all opportunities for gathering information. Procedures for animal handling and/or sample collection should not be designed exclusively to serve one's special research interest. Simple guidelines can be followed that will allow samples to be collected for gathering a variety of health-related information simultaneously. For example, death should not represent waste in the context of conservation-oriented studies. Necropsies could be conducted on every animal found dead, which could provide critically needed information and would require only training in proper sample handling and human safety precautions.

DIAGNOSTIC CAPABILITIES

Better diagnostic capabilities are needed to identify the wide range of pathogens that are presently and will increasingly be found in wildlife. Identification of exposure to infectious diseases is often limited by the availability of tests developed for domestic animals and humans. For example, sensitive and specific antemortem diagnostic tests for tuberculosis are not currently available for wildlife species. Finding antibodies to morbillivirus in southern elephant seals (Mirounga leonine) using available tests developed for canine and phocid morbilliviruses does not identify the virus that caused the immune response in the seals (Karesh et al. 1997d). Diagnostic capabilities need to be developed to identify disease agents in wildlife. Although genetic and toxicology tests have advanced, there is still a need to refine and improve these techniques.

POLICY

The importance of integrating health issues, as one component of conservation, into policy development cannot be overemphasized. For instance, we must recognize threats to the health of wildlife posed by conservation and development strategies involving ecotourism, improvements in livestock production, and wildlife harvesting programs. Tourists and the food needed to support them may transport infectious organisms (Karesh et al. 1997c). Unvaccinated domestic animals may be carriers of infectious diseases. In the case of wildlife harvesting, a frequently overlooked health threat is the tracker or lure animals (e.g., dogs and parrots) used by hunters, which may transmit diseases to free-ranging wildlife. These situations underscore the importance of considering health implications when establishing policies and initiating new programs. Finally, theoretically sustainable harvesting models based on recruitment and harvest rates must take into account the effects of health and disease on sexual maturation, reproductive success, and longevity. These effects may vary from year to year, depending on factors such as host and sympatric species densities, vector abundance, environmental conditions, and agent pathogenicity.

We have used four policy-related strategies to prevent wildlife disease problems: (1) to inform and educate workers in funding agencies of the important relation-
ships among the health of ecosystems, wildlife, domestic animals, and humans; (2) to offer input into planning conservation or development projects that involve the management or manipulation of wildlife or domestic animals; (3) to analyze data on wildlife health and disease risks and integrate it into the creation of buffer zones, multiple land-use zones, and corridors; and (4) to support stringent regulations and guidelines on wildlife rehabilitation, reintroduction, and translocation to prevent the introduction of novel pathogens to wild populations.

Conclusion

The effects of disease on wildlife populations have been recognized for years. It is also clear that Earth’s wild places have become smaller and more artificial in the past century, leading to a greater potential for infectious and noninfectious diseases to adversely affect conservation efforts. As a result, viable conservation initiatives can no longer be designed without addressing the health issues of wildlife. Considering that human intervention in wildlife populations occurs daily all over the world, in mostly negative ways (i.e., human expansion into previously uninhabited regions, poaching, and the collection and movement of animals internationally), it is no longer possible or ethical to justify a “hands-off” approach when confronted with wildlife disease issues in a conservation context. Instead, the expertise of all relevant disciplines, including that of health specialists, should be employed in developing better management for wildlife and ecosystems. We have presented specific suggestions for integrating wildlife health into conservation efforts, and we have emphasized that although veterinarians and other health professionals have an obvious role to play in protecting the health of wildlife, conservation workers in every discipline have the ability and responsibility to help address this issue. With minimal additional effort and cost, conservation researchers can maximize the data collected for monitoring wildlife health, can keep in mind potential disease issues in their studies, and can take a precautionary approach to preventing transmission of diseases in research, conservation, and development activities. We hope our suggestions will stimulate innovative collaborations in the field and in the policy arena and raise awareness of the need for a new paradigm that integrates considerations of wildlife health and disease into mainstream conservation.

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