

Significance of Ecological Studies of Wild Animal Reservoirs of Zoonoses

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The paucity of information on the ecology of wild animal reservoirs over most of the world is one of the factors that has led to hesitation and failure in controlling these diseases in many areas. Extensive application of ecological studies and methods would not only assist in zoonosis control but might well also lead to the discovery of new diseases, to the acquisition of fundamental knowledge capable of application in other fields of biology, and to the finding of new experimental animals for laboratory work.

Although such studies properly require the co-operation of a wide variety of specialists—epidemiologists, ecologists, parasitologists, botanists, geologists and climatologists are among those who may to advantage be called upon—in practice much can be accomplished by a few interested and well-equipped field workers backed by a good museum and laboratory services.

The validity of an ecological approach to the study of infectious disease is now generally recognized but its application to the animal reservoirs of human disease has been slow in most countries. With few exceptions, ecological methods comparable to those applied to problems of agriculture, fisheries and other fields of economic biology have not been employed in studying or controlling zoonoses in most areas of the world. This attitude is sometimes defended on the plea that most of the human infection in zoonoses is contracted from domestic animals and from wild animals living in or around human habitations ("domiciliated" animals; Hoare, 1955). While this is largely true in so far as immediate transfer of infection is concerned, the domestic animals themselves derive their infection from wild hosts in many cases. Furthermore, increase of human populations and other economic factors are increasingly making it necessary to colonize uninhabited areas of the world, thus exposing man and his domestic animals to the usually masked or sub-clinical infections existing among wild animals in nature. Hunters, trappers, foresters, explorers, soldiers, farmers, refugees and others who go into the wilderness are also exposed to similar dangers. What is more, they may bring back the infection

into settlements and pass it on to other human beings, domestic animals or local arthropod vectors.

The absence of accurate knowledge concerning the ecology of wild reservoir hosts has been the most important reason for failures or hesitation to deal effectively with such important diseases as rabies, plague, tularaemia, yellow fever, and many other arthropod-borne diseases. In some cases the elimination of what appeared to be the principal host was followed by another local species taking over this role (Meyer, 1947). In contrast to this, zoonoses like bovine tuberculosis and glanders, with no wild reservoirs, have been eradicated from large areas with relatively simple procedures. In a few instances, where the ecological method has been applied, the efforts have been rewarded with success in eradication or control of the disease, e.g., plague in southern Russia (Meyer, 1957) and cutaneous leishmaniasis in Turkmenia (Hoare, 1955).

It is reasonable to expect that the over-all geographical distribution of a zoonosis with wild reservoirs or vectors will be found to correspond to the particular zoo-geographical region in which it occurs, unless interfered with by man. This is, however, not always the case with recorded distributions. Recent findings of the widespread occurrence of arthropod-borne encephalitides in Europe (Bardos 1957, and others)—and possibly also of tularaemia (Neri, 1957)—which had hitherto been considered to be restricted to a few localities show that further

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work may bridge the gap between the distribution of the reservoir and vector on the one hand and of the zoonosis on the other, or provide an explanation for the divergence.

Another incidental advantage of ecological studies on wild animal reservoirs will be the possibility of finding more suitable experimental animals than are available at present. Most of the experimental animals in use in epidemiological work are domestic animals or pets that were available in Europe at the time of the growth of bacteriology. Hamsters, cotton rats and a few others have been added recently. Van der Hoeden (1954) found *Meriones crassus sacramenti*, a rodent common in Israel, to be particularly suitable for leptospiral investigations. The Egyptian gerbil (*Gerbillus pyramidum*) shows promise of being useful in work on brucellosis (Floyd & Hoogstraal, 1954). Several more experimental animals may be discovered which will make biotesting easier and more reliable.

There is little doubt, therefore, that accurate and fuller information about reservoirs and vectors in many areas of the world is needed before some of the major zoonoses (listed in the Annex) can be successfully controlled or eradicated. It may be mentioned that there is a common tendency to regard the domestic animal reservoirs as a somewhat uniform group in different parts of the world. But, looked at from the ecological point of view, they differ in different areas in certain important respects, such as population densities, movements and migrations, food, breeding and other seasonal cycles and their parasite burden. These and other environmental factors materially affect their reserves and donorship of human pathogens.

In this paper, the principal general characters of zoonoses with wild vertebrate hosts are briefly enumerated and extended ecological studies suggested. Some recent inquiries which warrant more extensive application of the ecological method to zoonoses are also cited.

SOME RECENT INQUIRIES

Most of the ecological studies so far carried out on zoonoses concern diseases with arthropod or snail vectors.

During the last two decades, extensive investigations have been carried out in the USSR on the ecology of zoonoses under the leadership of Academician E. N. Pavlovsky (see Pavlovsky et al., 1955), who has evolved what has been called the

“doctrine of natural nidity of disease”, the word “nidity” (*ochagavost*) being used to express the concept of focal localization. This concept means that wild enzootic foci of many diseases, particularly zoonoses, exist in nature independently of man and domestic animals. These foci present well-defined ecological peculiarities wherein the pathogens and natural hosts are associated, often through an intermediary vector. The most important environmental factors determining these associations are climate, soil, vegetation and other topographical features (hence the term “landscape epidemiology”). These peculiarities can serve as reliable indicators of the existence of certain diseases. For example, areas at the edge of a desert, inhabited by burrowing rodents such as *Rhombomys opimus*, may harbour cutaneous leishmaniasis, and areas at the junction of mountain forests and steppe grasslands may be expected to harbour tick-borne encephalitis and spotted fever. These natural foci (“silent zones of disease”; May, 1950) may remain undetected until susceptible human beings come in contact with them directly or indirectly and become infected. With accurate ecological knowledge, similar foci in other areas may be detected before human infection takes place. In West Pakistan, foci of fascioliasis (*F. gigantica*) have been found associated with easily detectable indicators, such as clay soil, fresh oxygenated water and characteristic aquatic vegetation (Sarwar, 1956).

In the USSR, natural nidity has been established for tick-borne spirochaetoses, tick-borne and Japanese B encephalitides, plague, tularaemia, tick-borne rickettsioses, leishmaniasis, listeriosis, haemorrhagic fevers (“nephroso-nephritis”), opisthorchosis, diphyllbothriasis, trichinellosis, bilharziasis, and possibly, also for psittacosis (ornithosis) and brucellosis. Natural nidi may be localized to small areas, such as rodent burrows or ponds, or may be diffuse and extensive, as in a big forest.

As has been pointed out by Audy (1958), this concept, in a simple form, had been recognized by many previous workers (e.g., by Parker for Rocky Mountain spotted fever, Meyer for plague and Swynnerton for African trypanosomiasis). But the credit for its generalization and large-scale application in field studies rightly belongs to Pavlovsky and his co-workers.

In USA, the ecological method has been applied to extensive studies on the arthropod-borne encephalitides (reviewed by Eklund, 1953; Hess & Holden, 1958). Several important points in the epidemiology of these diseases have been clarified. Birds serve as

natural hosts and mosquitos as vectors of these diseases. Man and horse are accidental and "dead-end" hosts in that they are not likely to pass the infection to other hosts or vectors. Mammals as well as birds have been suggested as possible reservoirs. Either mosquito vectors or birds appear to be possible overwintering reservoirs. The possibility of infection being reintroduced each season by migratory birds needs further investigation.

There are some basic similarities in the ecology of the American mosquito-borne encephalitides and the Murray Valley encephalitis of Australia (Burnet, 1953a) as well as West Nile virus infection of the Nile Valley (Taylor et al., 1956). The Australian as well as the Egyptian disease is transmitted by mosquitos and has birds as natural hosts. Man gets involved incidentally. Studies on other arthropod-borne viruses, especially yellow fever, have led to a clearer understanding of their epidemiology and also to the discovery of new viruses and zoonoses (Smithburn, 1952; Dick, 1953; Taylor et al., 1955; Work & Trapido, 1957; and others). Even so, a great deal more information on the ecology of reservoirs and vectors is needed before these diseases can be successfully tackled in the field.

Extensive studies on the ecology of sylvatic plague in the western United States have been carried out over many years (Meyer, 1947; Kartman et al., 1958). At first the large colonial rodents, such as ground squirrels, were considered to be important as reservoirs, but recently emphasis has shifted to the smaller species, *Microtus* and *Peromyscus*. The foci of infection are unrestricted and the disease is readily transferred from wild rodents to rats. Although human infection of sylvatic origin is infrequent, it is likely to increase with increasing suburbanization in the future.

In Malaya, Audy has studied for over a decade the "parasite-patterns" of different animal populations, with special reference to chiggers or harvest mites. The origin and development of these patterns has been studied in relation to the topographical localization of disease. It has been shown that a great deal can be learnt from the parasite-pattern alone about the habitat and habits of the host which have largely determined that pattern. In an important recent paper, Audy (1958) has discussed this work along with the important basic concepts and current hypotheses on the subject.

Apart from the foregoing ecological investigations of zoonoses may be mentioned the studies of May (1950, and later papers) on the geography of human

disease, which take into consideration not only environmental but also social and cultural factors. The forthcoming publication of a treatise on medical ecology by May has been announced (Audy, 1958). Rodenwaldt's *World Atlas of Epidemic Diseases* also describes the world distribution of various communicable diseases.

GENERAL CHARACTERISTICS OF ZONOSSES WITH WILD ANIMAL RESERVOIRS

1. Usually one or more vertebrate species in an area act as reservoirs of infection, the maintenance of which requires a particular density of population.

2. Very often a vector (mosquito, flea, louse, bug, acarine, snail or worm) is concerned in circulating infection in the animal population. Where the infective agent is capable of multiplying in the vector, the latter becomes an additional reservoir. Generally, the infections vectored by ticks and mites are also transmitted transovarially in these hosts.

3. The most characteristic feature of zoonoses in their wild hosts is the sub-clinical or mild and chronic syndrome they present. This represents a long-standing reciprocal evolution with mutual adjustments between the host and the parasite. It benefits the parasite by perpetuating infection and may be of help to the vertebrate host in warding off enemies such as man. Rabies may appear to be a prominent exception when it occurs in canines, but the existence of asymptomatic infection in desmodid and insectivorous bats is now established (see Enright, 1956). The mild and sub-clinical diseases usually escape detection and biotests as well as antibody surveys are generally necessary.

4. The necessary conditions of transmission exist in the infective process—e.g., the causative agent circulates in sufficient concentration in the blood to be taken up by the blood-sucking arthropod vector, or is present in body tissues, secretions and excretions to be picked up by other hosts or vectors. Sometimes, it is transmitted to the next generation *via* the placenta or is passed on to the offspring. Even minor alterations of conditions may cut the chain of infection. Accurate information on transmission and the transmitting agents is therefore of great importance. Some vectors are confined to a single host, while others attack two or more hosts, including man.

5. The elimination or disappearance of the principal host or vector or both from a focus may not

necessarily mean the disappearance of infection. Alternative hosts or vectors may take it up and maintain it. It is this ability of the infective agent to multiply in alternative hosts which makes it communicable to man, who is an accidental or secondary host.

6. After man has picked up infection from a wild focus the following courses may be followed:

(a) The infection may remain limited to the persons who picked it up from the natural focus and may disappear from the community when this connexion ceases.

(b) The infection may pass on from person to person by direct contact, as in psittacosis and rabies. This is, however, very rare.

(c) The vector in the sylvan focus may be imported along with the infection into a human settlement and circulate it in the susceptible population (oriental sore and Gambian trypanosomiasis). Alternatively, one of the urban vectors may start disseminating the infection (yellow fever).

(d) In some cases, the domestic animals or those living in houses (rats) may take up the infection and replace wild animals as reservoirs (plague, Q fever, Mediterranean kala-azar, Chagas' disease, etc.). Q fever in its natural foci is circulated among rodents by ticks but in domestic animal reservoirs contact infection assumes much greater importance (Stoker & Marmion, 1955; Kaplan & Bertagna, 1955).

7. In some zoonoses for which both wild and domestic or domiciliated animal reservoirs exist, the clinical features of the disease contracted from the two sources differ, apparently owing to modification of the virulence of the causal agent representing different degrees of adaptation. Sometimes the disease derived from different species of wild animal reservoirs also differs in its severity for man. A few examples of the foregoing modifications may be cited:

(a) Of the African trypanosomiasis, the more acute Rhodesian type occurs in thinly populated bush country abounding in wild ruminants and is transmitted by the game tsetse-fly (*Glossina morsitans*) from antelopes to man. This trypanosome appears to be so far ill-adapted to the human host. The Gambian trypanosomiasis, on the other hand, is less acute and has a greater tendency to invade the nervous system. It occurs in relatively well-populated localities with few wild animals and man-

to-man infection transmitted by the tsetse-fly (*G. palpalis*) appears to be the rule (Hoare, 1955).

(b) Two types of oriental sore have been observed in Central Asia. A "moist" type occurs in the people of rural areas on the fringe of deserts and is contracted from gerbils (*Rhombomys opimus*) through the agency of sand-flies. The other is a chronic "dry" type, characterized by late ulceration. It occurs in urban areas and represents man-to-man infection through sand-flies with better adaptation to the human subject. The two types are also immunologically distinct (Kojevnikov and others cited by Hoare, 1955).

(c) The classical type of rabies, prevalent in most countries, is caused by a virus adapted to canines (dogs, jackals, wolves and foxes). However, in South Africa, the disease has become so adapted to members of the mongoose family (Viverridae) that it remains restricted to areas inhabited by these animals, although it may be contracted from rodents and other mammals in the same area (Henning, 1956). The paralytic character of rabies derived from vampire bats (Desmodidae) in Central and South America is well known. Strains of the virus recently isolated from insectivorous bats have been found to be immunologically identical with the classical virus, but enough is not yet known about their other biological properties (Enright, 1956).

(d) Tick-borne encephalitis in the Far East and Siberia is attended with a higher mortality rate than this disease in Central Europe. Another clinical form of the disease described under the name "biphasic virus meningo-encephalitis" (Smorodintsev—unpublished data, 1958) is transmitted through drinking infected goat's milk in addition to the usual mode of transmission through ticks. The Rocky Mountain spotted fever of the Bitter Root Valley is distinctly more lethal than that occurring in the neighbouring State of Idaho. This difference has been attributed to the presence of a greater variety of small mammals in the former area which keeps its adaptability stronger than in Idaho, where only one or two small rodent species are available for holding the infection (Burnet, 1953b).

8. The original source of infection of the natural enzootic foci is to be looked for in the reciprocal evolution of the reservoir host in relation to its parasites and other animals in the environment. In certain diseases, such as plague, Q fever, rabies and certain parasitic infestations, the infection transported by man and domestic animals may get

established in a previously "clean" local fauna. Sometimes human agency brings about such changes in the fauna of a locality as favour the maintenance and spread of zoonoses. For example, the introduction of the Javan mongoose (*Herpestes javanicus*) into the Caribbean islands and of ferrets into Cuba, for the biological control of rats, was followed by a greatly increased incidence of rabies. Occasionally, man deliberately spreads infection among wild animals which pass it back to him. The use of bacterial rodenticides containing *Salmonella enteritidis* may be cited as an example (Jordan, 1925; Brown & Parker, 1957).

9. Vertebrate reservoirs of some diseases, especially birds, migrate over long distances, and may carry the causal organism from one area to another. In some cases, they may carry such "reservoir" parasites as ticks from one country to another.

THE ANIMAL GROUPS CONCERNED

The vertebrate animals concerned in the maintenance and spread of zoonoses are numerous. As many as 372 species of reservoir hosts have been listed for plague alone (Macchiavello, 1955) and a large number of species have been found to carry rabies, psittacosis (ornithosis), arthropod-borne encephalitides, etc. Usually, however, a few species play a predominant role in maintaining infection in a focus and the others get infected from them incidentally.

The largest number of reservoir species is found among mammals, particularly rodents, carnivores, monkeys, ungulates and bats. The birds are concerned mainly with virus infections of the nervous and respiratory infections. The reptiles and fishes are of minor importance; they act as intermediate hosts for some animal parasites.

Specialized literature on animal reservoirs is scanty. A few faunal lists of reservoirs of particular diseases have been published but information on their biology is widely scattered, except for certain groups such as rats. Information given in some medical, public health and veterinary text-books is generally inadequate, is often inaccurate, and shows disregard of the rules of nomenclature. Many of the treatises on zoonoses also are contented with using such general terms as "wild mammals", "birds", "monkeys", etc., no doubt for the sake of brevity.

It will help to create interest in animal reservoirs if available information on their biology is collected together and published. It will also lead to a better

coverage in text-books. The ecology of many of the animals concerned has been studied for reasons other than their implication in carrying human disease. This information is scattered in scientific literature and may not be easily available to public health workers, though it is of great interest to them. It should be included in the suggested publication, preferably on regional basis.

FACTORS TO BE STUDIED

In this paper, the factors which should receive attention in ecological studies of enzootic foci are stated only broadly. The usual starting-point is provided by the existence of a zoonosis in the human population. The animal reservoirs are looked for by the usual methods of epidemiological investigation. When an animal carrying the causal organism or the specific antibody has been found, ecological studies are started, though the decision as to which is the principal reservoir has to be deferred until other animal species in the area have been examined. After one such focus has been studied to a reasonable extent, the disease can be looked for in other areas with similar biotic and physical features.

The ecological study will generally include the following items:

1. Careful identification of the animal concerned and of all other animals in its immediate environment, including its parasites. For this purpose, the help of taxonomic experts in a museum or other such institution is generally necessary until a named reference collection for comparison has been built up locally. A very important part of this work is the proper preservation and preparation of the material required for identification.
2. Life-history studies with special reference to the relative susceptibility and capability of each stage to support and pass on infection. The rearing techniques developed will also be useful if the animal is found suitable for experimental work.
3. The statistics and dynamics of the population of the reservoir host and vector; these are of great importance.
4. The biotic, climatic and physical characteristics of the environment.
5. Animal interrelationships with special attention to enemies, predators and parasites. In this respect, the role of man and domestic animals is not to be overlooked.
6. Food, and host predilections in the case of parasitic animals.

7. Survey of the tissues of hosts and parasites for the presence and concentration of the causal organism and for morbid changes, if any.

8. Serological surveys of vertebrate animals for antibodies.

9. Ecological study of the vector, if any, and capability of the infective agent to multiply in its tissues. Sometimes minor changes of environment may throw the vector out of gear and break the chain of infection, thus indicating a simple method of control. At times, only particular races of the vector are capable of disseminating infection, and the same species may act as a vector in one locality but not in the other.

10. The conduct of ecological studies before undertaking expensive operations. The recent large-scale use of insecticides against arthropod vectors has underlined the necessity for this (Goodwin, 1958). In some cases, resistance to insecticides has been found to be due to changes in resting-habits, dispersal proclivity and other aspects of behaviour ("behavioural resistance") (Hess, 1952, 1953).

ORGANIZATION OF ECOLOGICAL SURVEYS

Team-work is nowhere so essential as in ecological surveys. In investigating enzootic foci in complex environments such as forests, river banks, swamps, ponds, deserts, fields, and outskirts of villages, it

is necessary to secure the co-operation of epidemiologists, microbiologists, taxonomists, ecologists and parasitologists. A botanist may look at the vegetation and the help of a geologist and a climatologist may be needed on occasion.

In actual practice, a very elaborate and expensive organization is not generally necessary. A few trained and, what is more important, interested field workers with proper equipment and the backing of a museum and efficient laboratory service can accomplish a lot. The large amount of work done by the United States Naval Medical Research Unit No. 3 in Egypt and neighbouring countries may be cited as an example (Hoogstraal, 1958).

Many countries have a number of naturalists who take interest and pleasure in the study of wildlife. During the last two hundred years, they have made important contributions to several fields in biology. Many of them may be induced to take up the study of vertebrates and vectors of importance in public health. They could be organized to form a club or society of public health ecologists and assisted with loans of literature and equipment.

Apart from the compilation of information on the biology and ecology of animal reservoirs already suggested, illustrated field guides to collection and preliminary field identification of various groups of animals stimulate and facilitate the study of wildlife. Their production in areas where they are not available needs to be encouraged.

Annex

LIST OF PRINCIPAL ZONOSSES WITH WILD ANIMAL RESERVOIRS

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| 1. Arthropod-borne encephalitides and related virus infections | 17. Plague |
| 2. Rabies | 18. Tularaemia |
| 3. Yellow fever | 19. Pseudotuberculosis |
| 4. Lymphocytic chorio-meningitis | 20. Rat-bite fever |
| 5. Encephalomyocarditis | 21. Toxoplasmosis |
| 6. Rift Valley fever | 22. Leishmaniases—Kala-azar, espundia and oriental sore |
| 7. Wasselsbron fever | 23. Trypanosomiasis—African and South American |
| 8. Psittacosis (ornithosis) | 24. Far Eastern schistosomiasis |
| 9. Murine typhus | 25. <i>Fasciolopsis</i> infestation |
| 10. Tick-borne typhus fevers | 26. Hydatid disease |
| 11. Tsutsugamushi fever | 27. <i>Hymenolepis</i> infestation |
| 12. Q fever | 28. <i>Strongyloides</i> infestation |
| 13. Rickettsialpox | 29. Trichinosis |
| 14. Leptospiroses | 30. Ectoparasites (ticks, mites, fleas, flies and bugs) |
| 15. Relapsing fever | 31. Myiasis |
| 16. Salmonellosis | |

RÉSUMÉ

L'écologie des réservoirs de zoonoses que constituent les animaux sauvages est mal connue dans de nombreuses régions du monde. Les investigations faites au cours des vingt dernières années ont fait ressortir que ce manque de renseignements a souvent provoqué des hésitations et des échecs dans les campagnes de lutte ou d'éradication. Dans quelques cas, en revanche, les études et les méthodes écologiques ont fourni la base de campagnes fructueuses d'éradication. Pour certaines maladies, on a pu reconnaître l'existence de foyers enzootiques dans la nature en examinant les caractéristiques du terrain, la végétation, la topographie et d'autres particularités du milieu (ce que Pavlovsky a appelé « l'épidémiologie de l'habitat »).

Il est donc évident qu'il faut largement étendre la méthode écologique pour étudier et combattre les zoonoses entretenues par des réservoirs d'animaux sauvages, notamment quand il s'agit de maladies transmises par des vecteurs et surtout dans les régions où cette méthode n'a pas encore été appliquée.

Indépendamment de leur intérêt pour les campagnes de lutte et d'éradication, les recherches écologiques peuvent aboutir à la mise en évidence de nouvelles zoonoses et à l'acquisition de connaissances fondamentales susceptibles d'être utilisées dans d'autres domaines de la biologie. On peut aussi espérer que ces travaux permettront de découvrir de nouveaux animaux d'expérience utilisables en laboratoire pour l'étude des maladies.

Les principales caractéristiques générales des zoonoses entretenues par des réservoirs d'animaux sauvages sont énumérées, afin de montrer l'importance des points qu'il s'agit d'étudier; l'article est complété par une liste des principales maladies dont il s'agit.

Les études écologiques de foyers enzootiques devront porter sur la taxonomie de tous les vertébrés et de leurs parasites, sur les populations animales en cause et sur leur cycle biologique, ainsi que sur les inter-relations entre les animaux et leur nourriture. Lorsqu'il y a intervention de vecteurs, ceux-ci devront faire l'objet d'investigations analogues.

Les tissus et les excréments des vecteurs et des animaux

qui composent les réservoirs devront être examinés afin de permettre la mise en évidence des organismes pathogènes et d'autres signes d'infection (modifications morbides, anticorps, etc.).

Un pareil travail exigera la collaboration d'épidémiologistes, de microbiologistes, d'écologistes, de parasitologues, de botanistes et, parfois, de géologues et de spécialistes de la climatologie. Dans la pratique, on peut attendre beaucoup d'une équipe composée d'un petit nombre de travailleurs compétents et bien outillés, qui disposeraient d'un bon musée et d'un service de laboratoire adéquat. Toute organisation de la santé publique devrait posséder des équipes de cet ordre.

Il conviendrait, par la distribution de matériel et de documentation, d'inciter les naturalistes à étudier, si possible, les réservoirs d'animaux sauvages et les vecteurs et l'on pourrait favoriser la formation d'associations et de groupements d'écologistes de la santé publique.

Les renseignements disponibles sur la biologie et l'écologie des animaux dont se composent les réservoirs de zoonoses devraient être rassemblés, de préférence sur une base régionale, et portés à la connaissance des travailleurs intéressés de la région. Il serait bon d'encourager la rédaction de guides pratiques donnant des instructions sur la manière de recueillir les animaux, de les conserver et de procéder à leur identification préliminaire, notamment pour les régions qui manquent de documentation appropriée.

Il s'est produit des cas où l'introduction de nouveaux hôtes animaux, dans le dessein d'obtenir la disparition de prédateurs et d'insectes nuisibles par des moyens biologiques, a eu pour résultat d'accroître la fréquence de certaines zoonoses (par exemple la rage dans la zone des Caraïbes). Il serait indispensable d'entreprendre des études écologiques minutieuses avant d'introduire de nouveaux animaux dans quelque région que ce soit. Il faudrait aussi interdire l'utilisation de produits destructeurs de bactéries, tels que les appâts raticides à base de *Salmonella*, car ce procédé constitue une menace d'infection pour l'homme.

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