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Agricultural development and arthropod-borne diseases: a review

Desenvolvimento agrícola e doenças veiculadas por artrópodes: Revisão

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SERVICE, M.W. Agricultural development and arthropod-borne diseases: a review. *Rev. Saude públ.*, S. Paulo, **25**:165-78, 1991. A review is presented of the interrelationships between arthropod vectors, the diseases they transmit and agricultural development. Particular attention is given to the effects of deforestation, livestock development and irrigation on the abundance of vectors and changing patterns of diseases such as malaria, trypanosomiases, leishmaniasis, Chagas' and some arboviral infections. The question as whether keeping livestock diverts biting away from people and reduces diseases such as malaria — that is zooprophylaxis, or whether the presence of cattle actually increases biting populations is discussed.

Keywords: Agriculture. Insect vectors. Communicable diseases, epidemiology. Ecology, vectors.

Introduction

The effects of agriculture on arthropod-borne diseases are complex. For example, deforestation followed by farming can create conditions favorable for some arthropod vectors while at the same time cause the displacement of others. In many areas of the world the benefits of irrigation for producing more food are being actively promoted, but irrigation can lead to a proliferation of breeding by certain vectors, especially mosquitoes in flooded ricefields. The introduction or intensification of livestock farming can effect the size of vector populations, their behavior, and disease epidemiology. Some of these interactions and linkages between agriculture and vectors are described in this paper. Although references are made to triatomid bugs, sandflies, tsetse flies and ticks, I make no excuse for concentrating on mosquitoes, because these are the vectors most commonly associated with agricultural development schemes, and also I know most about them.

Agricultural Requirements

Human population growth is usually very high in developing countries and often exceeds increases in food production, thus exacerbating the problem of world hunger. Urbanization is increasing alarmingly, with South America having the highest proportion (72.4%) of people living in cities (Service[87], 1989). By the year 2,000 it is estimated that more than half of the world's population will be concentrated in cities, and that there will be some 276 cities with more than 1 million people. Food has to be found to feed these people, most of whom will have little or no facilities for growing their own food. There is therefore a need to increase agricultural production, but development projects must be sustainable — as distinct from short-term programs that tend to deteriorate when agricultural experts leave. Sophisticated livestock production systems have sometimes been introduced into developing countries, but often with little success, mainly because few producers have the necessary resources and expertise to maintain such units commercially.

Irrigation is needed not only to grow food for human consumption but also for livestock feed. In 1985 irrigated crops formed 35.6% of the world's crop production, whereas it is estimated that in the year 2,000 about 43% of crops will be irrigated, and moreover that in 93 developing countries almost 20% of arable land will be under irrigation.

Poor grazing management, including overstocking, can lead to deterioration of pastures and consequently to decreased animal production, and has been well documented in Africa especially in association with animal trypanosomiasis. Bucher and Toledo[8] (1990) have also described how overgrazing can influence the epidemiology of Chagas' disease in South America.

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In developing countries, where people and livestock may live in close contact and where the risks of zoonoses may be continuous, such as in Asian areas endemic for Japanese encephalitis and where pigs are often kept near, or even under, houses, hygiene is crucial. Although considerable attention has been paid to the impact of vector-borne diseases on both livestock and humans, there has been relatively little consideration of the impact that livestock can have on the transmission of vector-borne infections to humans.

Changes in Land Use

Deforestation

African trypanosomiases are diseases that effect man and certain species of his livestock and are intractably related to agricultural development and land usage. The dynamic interrelationships between farming and trypanosomiasis are complex and the subject is too vast to be adequately discussed here, except for a very few basic and simple generalisations. The subject is well treated by Mulligan[57] (1970) and Jordan[39] (1986).

The major impact on land use is from animal trypanosomiasis, which precludes large areas of Africa being farmed economically for cattle. As a consequence cattle are often restricted to dry areas where tsetse flies cannot survive, but this gives rise to overstocking which causes land degradation and produces inferior quality cattle. On the other hand farming activities can sometimes reduce or eliminate tsetse, especially species in the *Glossina morsitans* group, which contains important vectors of animal trypanosomiasis. For example, when farmers clear forest or scrubland to plant crops a more open habitat is created which is unsuitable for tsetse flies. For example, low growing crops such as cassava, yams, groundnuts, pineapples, sisal, cotton and cereals do not provide sufficient shade for tsetse flies. Perhaps even more importantly the accompanying reduction of wild animals upon which the tsetses feed also causes a decline in tsetse populations. Such intensification of agriculture should in theory be reflected in a decrease in animal trypanosomiasis, but presently it is virtually impossible to quantify any such changes. Plantations of taller crops such as cocoa, coffee, oil palms and mangoes, however, can provide habitats favorable to tsetse colonization.

Deforestation can also have an impact on malaria. The Himalayan submontane area (Terai) India, was originally forested and the main malaria vectors were the stream-breeding *Anopheles minimus* and *An. fluviatilis*. DDT-house-spraying resulted in interrupting malaria transmission, allowing the inhospitable Terai to be cleared of forest and developed into a prosperous agricultural area. As a consequence *An. minimus*, which was common in the foothills disappeared, while *An. fluviatilis* was replaced by *An. culicifacies*, which is now the main malaria vector in the area (Sharma et al.[89], 1984).

In Malaysia, clearing dense forests has in certain areas led to larger populations of *An. maculatus* and increased malaria transmission (Abbas[1], 1972). Elsewhere in Malaysia and parts of India deforestation has caused the replacement of *An. dirus* with *An. minimus* (Yang[108], 1983, for review). In Thailand, cutting down forests for tapioca farming has by eliminating shade reduced breeding places for the shade-loving vector *An. minimus*, and also reduced the annual parasite index for malaria. These ecological changes, have in some other situations increased populations of *An. minimus*, which can breed in small streams around settlement areas and give rise to increased malaria transmission amongst the settlers. However, if deforestation is followed by planting rubber trees, then there is a gradual reversal to a shaded environment. In Thailand and Malaysia *An. minimus* is known to breed in established rubber plantations (Upatham[99], 1985; Sornmani[94], 1987), and also in fruit orchards (Rosenberg et al.[73], 1986). It is therefore possible that in Malaysian situations malaria transmission might resume if rubber trees are planted following deforestation.

At a water resource development scheme of the Quae Yai Dam Development Project in Kanchanaburi province, Thailand, surveys during 1972 to 1977 showed that *An. dirus* and *An. maculatus* were the principal malaria vectors in a village at the edge of the forest near the dam, *An. minimus* was rare. In contrast, in a nearby village where the forest had been cleared to resettle villagers formerly living at the dam site, *An. minimus* was the predominant species, while *An. dirus* was virtually absent (Sornmani[92, 93], 1972, 1974; Bunnag et al.[10], 1979). In densely forested areas of India where there were few people *An. fluviatilis* was formerly zoophagic, but destruction of the forest for agriculture has caused this mosquito to switch to feeding on people (Issaris et al.[36], 1953).

In West Africa shifting agriculture employing slash and burn techniques has resulted in tropical rain forests, formerly used as hunting and gathering places, to be replaced by more open cultivated areas, and this has been credited with decreasing *An. funestus* populations at the expense of sun-loving species of the *An. gambiae* complex (Wiesenfeld[104], 1969). The latter is, unfortunately a much more efficient malaria vector. Similarly cuting down forests to grow rubber has apparently resulted in greatly increased breeding of the *An. gambiae* complex in parts of West Africa and increased malaria incidence (Livingstone[44], 1958). Coluzzi et al.[15] (1979) believed that in some areas of eastern Nigeria deforestation near towns created islands of derived savanna which became colonized mainly by *An. arabiensis*, whereas, *An. gambiae* still predominated in nearby forested areas.

Tyssul Jones[98] (1951) believed that in Sri Lanka deforestation to grow tea created larval habitats for *An. culicifacies* and conditions for malaria epidemics. Large areas of scrub vegetation have been cleared for the Mahaweli Development Programme, and this has again favored breeding by *An. culicifacies* and generally increased malaria prevalence rates in the 1980s (Ault[3], 1989).

In the 1930s to 1940s forested areas in Trinidad were cleared for cocoa plantations. To protect the young trees from excessive sun, shade trees were planted which soon became colonized by epiphytic bromeliads, which in turn were colonized by *An. bellator* an important malaria vector. As a consequence there were malaria outbreaks in the cocoa estates (Downs and Pittendrigh[22], 1946).

In Latin America destruction of forests for farmlands has created ever increasing open land interspersed with patches of forest. Such environmental changes have led to the sylvatic leishmaniasis vector, *Lutzomyia longipalpis*, becoming peridomestic, and also enhanced the fox populations which are excellent reservoir hosts of visceral leishmaniasis (*Leishmania chagasi*). These habitat modifications, combined with immigration of people with infected dogs, have resulted in recent increases in leishmaniasis in the Amazon region (Lainson[43], 1989). In 1970 vast areas of forest in Pará State, Brazil were cleared for plantations of pines and gmelinas needed for paper making. Some 12 years later (Ready et al.[69], 1983) found that *Lutzomyia flaviscutellata* and the spiny rat (*Proechimys guyannensis*), which is a reservoir host of cutaneous leishmaniasis (*L. amazonensis*), were well adapted to the new conditions and some of the rats were infected with leishmanial parasites. In both instances farming and resettlement had encouraged the establishment of foci of leishmaniasis.

In many parts of Latin America leishmaniasis has become a serious problem in mountainous coffee-growing regions. The large shade trees planted amongst the coffee afford resting sites, and possibly breeding sites, for the phlebotomine vectors (Warburg et al.[103], 1990). Moreover, it is also possible that sugar provided by ripe coffee fruit may facilitate the development of *Leishmania* parasites in the vectors (Scorza et al.[78], 1985).

Forattini[27] (1989) has also explained how when in South America land is cleared of trees and cultivated this encourages sylvatic triatomine bugs to develop domicillary habits and allows Chagas' disease to become endemic in such areas. Often, however, farmed land is afterwards abandoned, giving rise to large areas of derived savannas. These changes may be accompanied by reduced endemicity of Chagas' disease.

Colonization and frontier zones

During 1974 there were 269,000 registered cases of malaria in the Latin American region, representing an annual parasite incidence of 1.34 per 1,000 people, whereas by the end of 1989, 1,099,436 malaria cases had been microscopically identified, corresponding to a rate of 2.72 per 1,000 population. Brazil accounted for 52.42% of the reported cases in the region (PAHO[64], 1990).

In the Amazon the number of malaria cases increased from a reported 37,600 in 1970 to 286,990 in 1983, and the Amazon States are currently responsible for 97% of malaria cases in Brazil, with the highest rates in 1989 being in Rondônia (45%), Pará (21%) and Mato Grosso (11%) (PAHO[64], 1990). Agricultural practices and also gold and gem mining activities, involving human migration, colonization and settlements on the forest fringe are one of the major causes of the increased malaria being reported in many Latin American countries (Marques[46], 1987; Sawyer[76], 1988). Such areas are often characterised by unstable malaria, and the vectors are often exophilic. For instance, *An. darlingi* has been generally considered an endophilic vector in Brazil, but it is now transmitting malaria mainly out of doors. Moreover, other *Anopheles* species not formerly considered as vectors are now being incriminated as such (Deane et al.[21], 1988).

In the Amazon region, especially in the States of Acre and Rondônia, tenant farmers during their first years begin by clearing and cultivating lands that are inaccessible during the rainy season. They live in very poorly built houses, or even in sheds with partial walls or no walls at all, and are consequently very exposed to anopheline bites. Malaria in this type of situation has been termed "frontier malaria". For these poor peasant farmers malaria is a serious problem, because when they are sick they have no family to take their place in the fields, and harvests can be lost through illness (Sawyer[75], 1987).

The municipality of S. Felix do Xingu in southern Pará State remained more or less isolated until a road built in 1981 connected it to the rest of Brazil. Private development and sale of land for agricultural development encouraged migrant farm workers to come from southern Brazil, and when gold was discovered there was an influx of landless migrant miners, mainly form the northeast (Fernandez and Sawyer[24], 1988). These changes in land use were followed by outbreaks of malaria in southern Pará, which in 1983 accounted for 73% of the malaria in Pará State.

Another example of the link between malaria and agriculture in the Americas is the increased malaria transmission in Peru, especially near San Martín and Junín caused by rice cultivation. A problem here is that immigrant workers contract malaria working on the farms and then return with the infection to the highland areas where it is spread to their families (PAHO[64], 1990). Similarly in Venezuela high malaria transmission on the border with Colombia is partly due to immigrant workers coming from Colombia to work on the farms, while in Belize malaria is linked to the seasonal migration of workers from El Salvador, Guatemala, and Honduras to pick bananas and citrus fruits. In Costa Rica agricultural stagnation in the highland areas has forced people to work on farms in the more malarious lowland areas.

Irrigation

In 1986 it was estimated that about 270 million ha of land was under irrigation, of which 65-70% was in developing countries, and more than half of this was in Asia. Irrigation allows, i) the cultivation of crops in arid or semi-arid areas, ii) the extension of the growing season, iii) increased numbers of crops that can be harvested in a year, and iv) increased crop yields.

Although many crops are irrigated the most extensively irrigated is undoubtedly rice, which is grown on about 146 million ha, and of which 77 million ha is under irrigation. More than 95% of rice is grown in the developing countries. The Food and Agriculture Organization has estimated that there needs to be a 3% annual increase in rice production to feed an ever expanding human population (Swamunathan[96], 1984). There have recently been several publications on irrigation and vector-borne diseases (Service[81, 83, 84, 85, 86], 1984, 1989; FAO[26], 1987; IRRI[35], 1988; Oomen et al.[60,61], 1988, 1990; Lacey and Lacey[42], 1990) and many have focused on rice and mosquitoes. Because of this surfeit of information, relatively little space will be devoted to irrigation in this review, especially as this will allow more detailed examination of the effect of livestock on arthropod-borne diseases, a topic that has not been so extensively covered by others.

Unfortunately flooded ricefields can generate phenomenonal numbers of mosquitoes, several of which can transmit diseases (see Lacey and Lacey[42], 1990 for review), the most important ones being malaria and Japanese encephalitis. In addition ricefield mosquitoes can transmit lymphatic filariasis — mainly due to *Wuchereria bancrofti* — and various, mainly zoonotic, arboviruses. [Schistosomiasis is a major disease associated with rice cultivation but is not dealt with here as it is not a true vector-borne disease]. In addition to providing abundant mosquito larval habitats, increased human and nonhuman hosts, associated with resettlement schemes and the introduction of livestock, may be supplying extra blood-meal sources so allowing increased numbers of mosquitoes. Moreover, extensive flooded areas may raise humidities in otherwise often dry areas, and in turn increase survival rates of adults and thus their vectorial capacity may be higher. For example, in Egypt the longevity of the malaria vector, *An. pharoensis*, increases during irrigation from July to September when humidities are elevated; when ricefields dry out, however, its survival rate decreases as does its efficiency as a vector (Rathor[67], 1987).

The main irrigation project in the Cuckorova plain near Adana town, Turkey came into operation in the 1970s and was followed by substantial influx of migrants, many of whom came from eastern Turkey where malaria was still endemic. Poor irrigation management and inadequate drainage caused an explosive increase of *An. sacharovi* and malaria transmission, culminating in 115,512 reported malaria cases in and around Adana in 1977. It was estimated that without control measures the number of cases would likely have risen to more than 250,000 by 1978 (Onori and Grab[59], 1980).

The are, however, a few exception to the rule that rice cultivation results in increased malaria transmission. For example, during the 1940s farmers in the Philippines in an area north of Manila filled up small streams during terracing for rice cultivation, and in so doing destroyed the breeding places of the vector *An. flavirostris*. As a result there was a decline in malaria transmission (Ejercito[23], 1951). In rice growing areas of the Kuo Valley, Burkina Faso *An. gambiae* populations remain high throughout the year and there are two main malaria transmission peaks coinciding with rice harvests, while in nearby non-irrigated savanna areas, *An. gambiae* populations decline sharply at the end of the rainy season, but are followed by an increase in *An. funestus*. In this latter area there is a single peak of malaria transmission towards the end of the rains. Paradoxically, although mean annual biting rates of *An. gambiae* in the rice-growing areas are about 10 times higher than in surrounding savanna villages, the infectivity rate is almost 10 times lower (Robert et al.[70], 1985). The cytogenetic form "Mopti" predominates (97%) in the rice areas, while the "Savanna" form is commoner outside the rice-growing areas, as is *An. arabiensis*. It seems possible that differences in the feeding patterns and survival rates of these two cytotypes may account for differences in their sporozoite rates (Robert et al.[70, 71, 72], 1985, 1986, 1989). It appears that the lower sporozoite rate in the "Mopti" form cannot be attributed to it being less susceptible to malaria infection (Robert et al.[72], 1989). I have suggested (Service[85], 1989) that another explanation might be that because of the greater mosquito biting densities in the irrigation villages people used bed nets more frequently and took antimalarial drugs, behavior that could reduce sporozoite rates. In marked contrast the extension of rice cultivation in the Rusizi Valley of Burundi has alarmingly increased malaria endemicity, where vectorial capacity was reported 150 times greater than in a nearby cotton-growing area (Coosemans[17], 1985; Coosemans and Barutwanayo[18], 1989; Coosemans et al.[19], 1989).

An ecological succession of mosquitoes often occurs in ricefields, with the pioneer colonizers being sun-loving species, such as the *An. gambiae* complex (Africa), *An. albimanus* (Mesoamérica), and *Culex tritaeniorhynchus, An. fluviatilis* and *An. culicifacies* (Oriental region); but when the rice grows taller it shades the water and shade-loving species, such as *An. funestus* and *Cx. antennatus* (Africa), *An. umbrosus* (India), *An. hyrcanus* group (Asia), *An. leucosphyrus* (Malaysia), and *An. punctimacula* (South America) usually become more abundant. These changes in species composition can affect the intensity of disease transmission. High Yielding Varieties (HYV) of rice, however, produce less shade than older varieties, and therefore may alter mosquito species colonizing ricefields, or their succession. Lacey and Lacey[42] (1990) present more examples of mosquitoes breeding in fields having short or tall rice plants.

Anopheles superpictus formerly bred in isolated pools in the foothills of the Kunduz Valley in northern Afghanistan where it was the most important malaria vector. In the early 1960s irrigation was introduced to the valley for rice and other crops, and was accompanied by increased numbers of people and cattle. This resulted in sewage pollution of *An. superpictus* larval habitats and the vectors gradual elimination. At the same time irrigated ricefields and overflows from irrigation ditches constituted new mosquito habitats which were colonized by *An. pulcherrimus* and *An. hyrcanus*, with the result that *vivax* malaria in some villages increased four-fold to reach 20 percent (Buck et al.[9], 1972).

Compared to Asia and Africa there is less documentation of linkages between rice cultivation and disease in Latin America, although in parts of Mexico and Venezuela rice appears to be associated with seasonal increases in malaria incidence (Zozaya[109], 1943; Berti and Montesinos[4], 1946). More recently Lacey and Lacey[42] (1990) pointed out that the Jari irrigation project in the central Amazon basin (McIntyre[47], 1980) where inundated rice is grow, is providing extensive new breeding places for *An. darlingi* and creating conditions conducive to malaria epidemics.

Farm mechanization

The increase in rice production that has occurred in the developing countries is being achieved largely through mechanization. Undoubtedly mechanization will have to increase to meet the projected world demand for rice in the year 2,000. In the developing countries mechanization seems to be proceeding fastest in Asia, particularly in Japan, China, Taiwan, Korea, Thailand, Sri Lanka and Malaysia. The changes caused by mechanization include, i) more crops per year, ii) increase in farm hectarage, iii) changes in land usage, iv) cultivation of marginal lands, v) increased usage of fertilisers and pesticides, and vi) reduction in livestock (Service[82], 1987). In the USA, Chambers et al.[13] (1981) reported that flooded tracks caused by harvesting machinery created additional mosquito sites.

With rice cultivation, mechanization is likely to be associated with increased areas under flooding and consequently larger mosquito populations, unless there are other changes that counteract this. For example, the introduction of so-called "dry" rice varieties, as practiced in some parts of China (Pao-Ling Luh[65], 1984), which results in fields becoming flooded for shorter periods. Preparing fields with oxen and other draught animals can take 7-10 weeks for lowland rice, whereas mechanization can shorten the preparation time and cut deeper (10-20 cm) into the soil. In Texas, Owens et al.[62] (1970) found that ploughing prior to flooding could, at least in small plots and playa lakes (hard clay depressions), reduce the numbers of certain *Aedes* and *Culex* mosquitoes. While in the Tennessee Valley region excellent control (73-100%) of floodwater mosquitoes, especially *Aedes vexans*, was obtained by ploughing followed by discing, which caused eggs to become buried so that resultant larvae were trapped under a layer of soil (Cooney et al.[16], 1981).

Generally, the introduction of mechanized farming will be a relatively slow process, accompanied by gradual environmental changes, and it is difficult to predict the impact it will have on vector-borne diseases.

Vector and Livestock Interactions

Most hematophagous arthropods which are pests of man or vectors of human disease will to a lesser or greater extent feed on animals, including domestic livestock. For example, several species within the African *Simulium damnosum* complex, which contains important vectors of human onchocerciasis, readily bite birds and cattle as well as man. *Anopheles culicifacies*, the most important malaria vector in the Indian subcontinent, and the Asian malaria vectors *An. sinensis* and *An. annularis* frequently feed on cattle in preference to man. The zoophagic habits of *An. sinensis* may be partially responsible for minimising its role as a malaria vector in some areas. Even *An. gambiae*, a very anthropophagic African malaria vector, will feed on cattle, especially when they are more numerous than people. The catholic feeding habits of *Culex tarsalis* on a wide range of hosts including cattle, dogs and cats, in addition to birds and man, may contribute to the low endemicity of western equine encephalomyelitis (W.E.E.) and St. Louis Encephalitis (S.L.E.) observed in some situations in the USA (Hess and Hayes[33], 1970).

Although integration of livestock in agricultural development schemes can increase protein production, it can also have adverse effects on the ecology of vectors and epidemiology of the diseases they transmit. The World Health Organization[106] (1979) provides a useful review of zoonotic diseases, but only some are pertinent to the interactions of livestock and vectors.

Predicting the possible outcome that might arise from the integration of livestock is complicated. In a rather simplified approach the presence of livestock (alternative hosts) can lead to the following scenarios:

1) Reduced biting on people and a reduced risk of transmission for non-zoonotic parasites - which has led to the idea of zooprophylaxis.

2) Increased population size of the arthropod pest or vector resulting from the provision of extra blood resources and/or additional larval habitats, leading to increased biting on people.

3) Increased risk of disease transmission because the alternative hosts are reservoirs of infection, or the maintenance hosts of parasites that the vectors are transmitting to man.

Firstly, however, it is appropriate to examine the reverse situation, that is what happens when there is a decrease in cattle, or other animals.

Reduction in livestock

When livestock have been reduced there has sometimes been increased mosquito biting on man. Probably the most convincing example of ecological change leading to the detriment of human health comes from Guyana (Giglioli[30], 1963). Before the 1960s malaria was transmitted in coastal areas of Guyana almost exclusively by *An. darlingi*, a highly anthropophagic and endophilic freshwater breeding mosquito. An eradication campaign based on residual house-spraying with DDT virtually eliminated *An. darlingi*, and as a consequence malaria was eradicated from coastal areas, including the Demerara river estuary. *Anopheles aquasalis* was also common, but because it fed on livestock it had not been a vector. Also because it was exophilic its population was not reduced by house-spraying. During the malarious free period the human population increased and most available pastures and fallow lands were converted to rice cultivation. More importantly cattle, which formerly occupied much of the now irrigated land, were displaced or eliminated, while mechanization replaced horses, donkeys and mules on the roads, and tractors replaced oxen for ploughing. Because of the deficit of livestock the originally zoophagic *An. aquasalis* switched to feeding on man. At the same time the return of malaria-infected itinerant workers from the gold fields and diamond mines in the interior, as well as other migrants, reintroduced the malaria parasites. As a consequence malaria returned to the Demerara river estuary 16 years after it had been eradicated, but this time spread by *An. aquasalis*. In retrospect it appears that the former abundance of livestock had been diverting the potential malaria vector, *An. aquasalis*, from man to cattle.

There are other but less well documented examples where reduction in livestock have been associated with malaria outbreaks. For example, a poor rice crop in Indonesia in 1977 forced farmers in one area to sell their water buffaloes, which reduced the ratio of cattle : man from 1:25 to 1:50. The principal malaria vector was the very zoophagic *An. aconitus*, and reported malaria cases increased 5.1-fold from 1976 through to 1978. This upsurge of malaria suggested that buffaloes had previously afforded the community some degree of malaria protection (Muir[56], 1981). In Malaysia the importance of *An. maculatus* as a malaria vector may be inversely correlated with the abundance of cattle in the area. Loong et al.[45] (1990) believed that the depletion of wild animals from many areas of Malaysia through hunting, and the development of the land for marginal farming, in which wild animals are driven away, has favored the spread of malaria, because *An. maculatus* has been forced to switch to feeding on people. Somewhat similarly in the frontier settlements in Brazil the expulsion of wild animals concentrates mosquito biting on humans, especially as the introduction of livestock into such areas can be a relatively slow progress (PAHO[63], 1988).

Malaria outbreaks in the USSR and to a lesser extent in other, mainly eastern, European countries during 1920-30 may in part have been due to the scarcity of farm animals caused by economic disruption, which forced the local anophelines to feed on people.

Drought can result in the mortality, slaughter or migration of cattle, but when the rains eventually come it may produce explosive increases in anopheline mosquitoes, which in the almost total absence of cattle bite people. Such a situation occurred in 1967 and 1971 in South Africa and caused malaria outbreaks (Hansford[32], 1972).

There is very little information on the effect mechanization has on vector populations and on disease epidemiology (Service[82], 1987). However, in many communities mechanization reduces the numbers of oxen and water buffaloes. In Pakistan for example, each tractor has displaced on average 2.0-2.5 bullocks, but not milking cattle. Similarly in Bangladesh, Jabbar et al.[37] (1983) reported that although 98% of the land is still cultivated by bullock-drawn ploughs, the relatively few tillers that have been introduced have replaced 2.0-2.5 bullocks per tiller. No one knows what effect these agricultural changes have had on mosquito populations, but in these areas the main malaria vector is the zoophagic *An. culicifacies*. Consequently mechanization may have increased the numbers biting people, and possibly even increased malaria transmission, but I have to stress this is just speculation.

Reduced biting on people and zooprophylaxis

The World Health Organization[107] (1982) defined zooprophylaxis as involving "the use of wild or domestic animals, which are not the reservoir hosts of a given disease, to divert the blood-seeking mosquito vectors from the human hosts of that disease". The concept of zooprophylaxis is not new. As early as 1903 Bonservizi (see Kay[40], 1990) suggested that in northern Italy, domestic animals indirectly protected humans from mosquito bites. In fact zooprophylaxis has long been practiced in various parts of the world to protect people from malaria, but its value has remained questionable. Cattle are the most suitable hosts for zooprophylaxis, because not only do several important vectors readily feed on them, but they are usually "dead-end" hosts. Brumpt[6] (1944-45) has reviewed examples of zooprophylaxis.

Bruce-Chwatt[5] (1982) believed that increased numbers of farm animals and a progressive deviation of *Anopheles* to biting cattle might have been partly responsible for the gradual decline of malaria in northern Europe, and much of the USA. Following the work of Raevskii, Platonov and Tarabukhin, Zavoiskaya and others in the USSR (see *Med. Parasitol.* (1942) volume 11) health administrators advised that whenever possible livestock sheds should be arranged in a continuous line along the perifery of human settlements, and that houses should be built 250-300 m away from them.

Cattle-baited traps in Trinidad were reported by Shannon[88] (1944) to give protection against *An. aquasalis*. In one village having a ratio of oxen and horses : man of 1:19 the spleen rate was 12.4, whereas in a neighbouring village with a ratio of animals: man of 1:140, the spleen rate was 31.3%. In the same area Senior-White[80] (1952) concluded that 88.4% of biting by *An. aquasalis* was on cattle and horses, and that there was a lower malaria incidence in villages where there was a tradition of livestock management than in villages that kept few cattle or horses. Gabaldon[28] (1949) believed that in rural areas of Latin America horses and cattle could under certain circumstances give zooprophylactic protection against biting by *An. bellator, An. cruzii, An. darlingi* and *An. pseudopunctipennis*. Horses, however, may become infected with certain arboviruses that infect man (e.g. the equine encephalitis viruses), consequently if they are used as a barrier to biting, then they should whenever possible be immunized against certain endemic diseases.

In Papua, New Guinea, Charlwood et al.[14] (1985) found that in the village of Maraga there was a large animal population, mainly pigs, which slept under peoples' houses, and the human blood index of the *An. punctulatus* group was only 9%. A unique host, a buffalo, was introduced and it was found that a diversion of 40-45% of mosquitoes feeding on people occurred up to 10 m, decreasing up to 60 m at which point there was no diversion caused by the buffalo. Charlwood et al.[14] (1985) believed that it might be possible to reduce mosquito-people contact by keeping domestic animals in villages.

However, in later studies in Maraga village, Burkot et al.[11] (1989) showed that when pigs were penned 30-40 m outside the village, and not as previously allowed to roam through the village, there was increased biting by *An. farauti* on other hosts, including people. It was concluded that changes in pig husbandry practices significantly changed the feeding patterns of this species. Working in Sri Lanka (Rawlings and Curtis[68], 1982) believed that because the same individuals of *An. culicifacies* were shown to bite both man and cattle this gave support to the concept that increasing the numbers of cattle near houses would divert mosquitoes to cattle, which are their preferred hosts. They also pointed out that marginal farming practices leading to the decimation of wild animals may increase risks of malaria if domestic animals are not introduced. However, in Sabah, Hii and Vun[34] (1987) found that there appear to be two sympatric but genetically distinct populations of the malaria vector, *An. balabacensis*, one preferring to bite people the other buffaloes, so in this type of situation they doubted whether cattle could divert feeding from people.

Walton[101, 102] (1958, 1962) believed that in East Africa keeping chickens and other domestic fowl in and around village houses could reduce transmission of tick-borne relapsing fever (*Borrelia duttoni*), because vectors within the *Ornithodoros moubata* complex would to some extent be diverted do feeding on the birds.

It has been suggested that if cattle were regularly sprayed with insecticides such as permethrin or deltamethrin the efficacy of zooprophylaxis might be enhanced. In eastern China cattle have been sprayed with permethrin in rice irrigation areas where there were high densities of *An. sinensis* (Self[79], 1987). Kuntz et al.[41] (1982) suggested that insecticide-treated cattle could be used against *Psorophora columbiae* in ricefields in the southern USA, while Schemanchuk and Taylor[77] (1984) discuss the protection offered by several pyrethroid insecticides against simuliid blackflies. However, bioassay tests indicate that mortality decreases rapidly after a week (McLaughlin et al.[49], 1989), and this has been substantiated by field observations on the effect of permethrin-sprayed cattle on *Ps. columbiae* (Nasci et al.[58], 1990). Rain also reduces the duration of effectiveness of permethrin on cattle, consequently spraying cattle will not be of much use in many tropical countries. It may also prove too costly or be impractical.

Sometimes animal shelters are sprayed with residual insecticides, while in some countries, such as Thailand, farmers protect their animals at night with mosquito nets. Both practices, however, may divert mosquitoes to feeding on people.

In summary, if a vector population is near the carrying capacity, or if a species is predominantly zoophagic, then introducing a high density of livestock may result in reduced biting on people as well as a decrease in disease endemicity. However, Sota and Mogi[95] (1989) showed, by mathematical modelling, that the introduction of animals can increase vector population size, and under certain conditions can lead to increased biting on man and higher malaria transmission. Similarly, Saul[74] (1990) has shown, again by modelling, that there may be increased malaria transmission when alternative hosts are introduced.

Although there are a few instances where animals have reduced, or appeared to have reduced, vectors biting people, it has to be stressed that there are virtually no good examples where their presence has been shown to have reduced disease transmission. One reason is that relevant epidemiological studies have not yet been undertaken to evaluate such a situation.

It must be appreciated that farmers will not adopt zooprophylactic measures unless they perceive the rearing of livestock as compatible with local agricultural practices. Keeping livestock must also give them a good economic return, unless they receive some other form of incentives.

Increased vector populations and biting

Kuntz et al.[41] (1982) showed that cattle, and to some extent horses, when kept on ricefields served as primary sources for blood-meals for *Ps. columbiae*. This study and those of Meek and Olson[51] (1976) indicate that cattle are a very important component in the ecology of *Ps. columbiae* in Texas ricefields. In California, Al-Azawi and Chew[2] (1959) found that in irrigated areas without cattle adult densities of *Ps. columbiae* were 0.8/m^2, whereas when there were cattle (unspecified number) densities increased to 9.8/m^2. Furthermore, Meek and Olson[52] (1977) found that eggs were about five times more abundant in fields with, than without, cattle; similar associations were reported by

Chambers et al.[13] (1981) and Williams et al[105] (1983). Even more convincingly McLaughlin and Vidrine[48] (1987) used regression techniques to show that there was an estimated 2-fold increase in larval density with an increase of 10 cattle per mile^2. Focks and McLaughlin[25] (1988) conclude that, host numbers, in this instance cattle, are the main determinant in the abundance of *Ps. columbiae* in ricefields in Texas.

In addition, rearing large numbers of livestock may increase mosquito breeding sites, such as cattle hoofprints (Meek and Olson[52], 1977) and borrow pits dug as cattle watering holes. For example, in Asia bathing pools for buffaloes provide mosquito larval habitats, especially in the dry season (Hansen et al.[31], 1990). Rajagopalan et al.[66] (1990) reported that in urban areas in India unregulated keeping of domestic animals aggravated breeding problems by providing feces-polluted standing water, which is attractive to ovipositing females of the filariasis vector, *Culex quinquefasciatus*. Also wandering pigs and cows may destroy banks of unlined drains and create more shallow larval habitats.

In Japan the numbers of farmers keeping cattle, pigs, horses, sheep and goats slowly increased from 1945 to the mid-1950s when the numbers decreased, although the actual population of animals steadily rose through the 1980s because farmers kept more animals (Mogi[54], 1987). This increase in numbers of animals necessitated larger animal sheds which tended to be built further away from houses and ricefields, and this has helped reduce biting on people by *Culex tritaeniorhynchus*.

In Central and South America triatomine vectors of Chagas' disease feed on a wide variety of domestic and peridomestic animals such as dogs, cats, armadillos, opossums and rodents, some of which are important reservoir hosts. The proportion feeding on livestock such as pigs, goats, cattle and horses, is generally low (< 1 – 10%), and moreover these hosts are seldom if ever, infected with trypanosomes (Minter[53], 1975). In contrast, triatomine bugs feed much more frequently on birds (7 – 74%) including domestic fowl, and it is not uncommon to find large numbers of bugs resting in chicken sheds. Because birds are insusceptible to infection, it can be argued that they will dilute vector infection rates, but on the other hand it can be equally argued that they build-up local bug populations leading to increased feeding on humans. Relocating chicken sheds away from houses might reduce the size of the household bug population.

There is often a cycle of habitat destruction, poverty and increased risk of Chagas' disease (Bucher and Toledo[8], 1990). For example, overgrazing by cattle results in a deterioration of grasslands, and this can lead to a gradual replacement with goats, which in turn exacerbates degradation. Moreover, keeping large numbers of goats in corrals placed very near houses builds up population of bugs (e.g. *Triatoma infestans*). Soler et al.[91] (1977) estimated that there could be some 20,000 triatomines in a single corral. These bugs readily invade nearby poorly constructed houses, with the consequence that there is increased risk of disease transmission (Bucher and Schofield[7], 1981). Bucher and Toledo[8] (1990) argue that the solution to Chagas' transmission in rural areas is improved livestock management that is compatible with the environment. They give two examples where good livestock management in the Salta area of Argentina has restored the original productivity of the ecosystem. In fact these two projects are among the very few in South America where sustainable productivity have reached operational levels (Solbrig[90], 1988). In both cases ecosystem restoration is based on enclosing areas to allow natural vegetation to recover, leading in some cases to afforestation, while cattle grazing is under a controlled and managed regime. Both are long-term management systems.

Increased disease transmission

Japanese encephalitis - In 1978 the Sri Lanka government initiated the Accelerated Mahaweli Irrigation Scheme for growing, mainly, rice on about 127,000 ha of land. Over seven years some 150,000 families were resettled and in one area farmers were advised to keep pigs to supplement their income. Not surprisingly this resulted in outbreaks of Japanese encephalitis (J.E.), 407 cases in 1985-86, followed by an additional 150 cases in 1987-88 and 1988-89. Now aware of the dangers of mixing pig-keeping with rice cultivation in Asia a vaccination program is Government policy.

Pig farming in Asia has to be reconciled with the potential spread of J.E. It is, however, the *relative* abundance of pigs to man, and their accessibility as hosts compared to man that is epidemiologically important. For example, in the early 1950s when J.E. morbidity in Japan was highest the pig: man ratio was 10^{-2} or less, whereas now it is about 10^{-1} (Mogi[55], 1990). This increase in the pig : man ratio has been accompanied by a reduction in the numbers of pig farms but an exponential increase in the numbers of pigs per farm. Also farmers are now generally living further away from piggeries, and people are more protected from mosquito bites by better housing, screened windows and bed nets. Also, because of air conditioning and television people are staying indoors more in the evenings. These social and economic changes together with reduced numbers of vectors breeding in ricefields because they are sprayed with insecticides to reduce rice pests, and vaccination of the human population has led to a reduction in the incidence of J.E.

In addition to feeding on humans and pigs *Cx. tritaeniorhynchus* will readily attack cattle, and so on the one hand cows can lead to an increase in the vector population by supplying a blood source for reproduction, but at the same time decrease the transmission efficiency of J.E. in the mosquito-pig cycle (Carey et al. [12], 1968). Wada[100] (1988) pointed out, that it can be difficul to decide whether or not cows are beneficial in rice-producing areas.

Rift Valley fever — This is a zoonotic disease characterised by high mortality in lambs and calves as well as abortion in sheep and cattle. The virus has been isolated from 20 mosquito species, but transmission is mainly by *Aedes lineatopennis, Ae. caballus* and *Culex theileri*, but also occasionally more directly through man handling infected material. The 1950-1951 epidemic in South Africa caused some 100,000 deaths of cattle and sheep, and an estimated 20,000 human cases (Theiler and Downs[97], 1973); there was another large epizootic in 1974-1976 involving both livestock and several human cases (Gear et al.[29], 1977).

Culex pipiens was considered the probable vector in a widespread epizootic in Egypt during 1977-1978 which involved about 18,000 human cases and 598 deaths (Johnson et al.[38], 1978; Hansen et al.[31], 1990), although the actual numbers infected may have reached 200,000 (Meegan[50], 1979). These explosive outbreaks in Egypt were unusual in occurring in areas outside its previous geographic range of subsaharan Africa, and also by the unprecedented clinical severity. There are indications that ecological changes have facilitated endemic conditions becoming epizootic in parts of Africa, and that outbreaks in Egypt and other parts of Africa have been associated with irrigation developments and wetland areas. Cattle are considered the most important amplifying hosts of R.V.F. in many parts of subsaharan Africa (Davies[20], 1975), but in some areas, including Egypt, sheep may also be important amplifying hosts, much depending on farm practices.

Kyasanur forest disease — Cattle have played a crucial role in the spread of Kyasanur Forest Disease (K.F.D.) in India. Larval and nymphal ticks attach to monkeys and rodents, causing epizootics in the former which act as virus amplifying hosts. Adult ticks are not found on rodents and other small animals and rarely on monkeys, but attach to large mammals such as deer and bison. In 1957 K.F.D. began to emerge as a human disease in Karnataka (Mysore) state, where an expanding human population resulted in more cattle, which during the wet season were grazed at the edge of, or in, forests. The cattle then became heavily infested with ticks, such as *Haemaphysalis spinigera*, and brought ticks in close association with villagers. Cattle undoubtedly play an important role in tick reproduction and in maintaining high population densities. In fact cattle rearing can be considered the most important man-made factor favoring high vector density at the very places frequented by people. More recently large numbers of goats have been introduced in K.F.D. areas, and it is possible they may also become involved in the ecology of the disease.

Conclusions

A number of international organizations and government agencies are concerned about the adverse effects that irrigation projects, especially for rice, can have on the health of the people living on or near such projects. The International Irrigation Management Institute (IIMI), with its headquarters in Sri Lanka, is encouraging the best water management systems to secure maximum agricultural production, and is fully aware of associated health hazards. The Panel of Experts on Environmental Management for Vector Control (PEEM) of the World Health Organization is also actively promoting the best strategies for vector control that are compatible with agriculture. The Blue Nile Health Project in the Sudan provides a good example of an integrated approach to the protection and control of diseases associated with irrigation, in this instance the emphasis is on schistosomiasis. However, all too often development has become a religion and there is often a tendency to ignore or minimise any undesirable side-effects that might arise. Insufficient attention is usually paid to environmental consequences, including health aspects, because generally other priorities, such as maximising agricultural production and economics, dominate the scene.

Clearly from an agricultural point of view it is desirable to integrate livestock into development projects to increase the local availability of protein. There should, however, be care that the introduction or intensification of livestock does not result in increased transmission of vector-borne diseases to humans, or livestock. Admittedly, predicting the possible changes is complicated, such as knowing whether cattle will lead to zooprophylaxis against a disease such as malaria, or promote an increase in mosquito populations.

It has been said many times before, but is worth repeating, that is there needs to be greater intersectorial and interdisciplinary collaboration before initiating development schemes, which should address the human and environmental risks that might arise.

SERVICE, M.W. Desenvolvimento agrícola e doenças veiculadas por artrópodes: revisão. *Rev. Saúde públ.*, S. Paulo, **25**: 165-78, 1991. Apresenta-se revisão do inter-relacionamento entre artrópodes vetores, as doenças por eles transmitidas e o desenvolvimento agrícola. Dá-se atenção especial aos efeitos decorrentes do desmatamento, do desenvolvimento pecuário e da irrigação artificial, sobre a abundância de vetores e mudanças de quadros epidemiológicos de doenças, como a malária, tripanossomíases, leishmanioses, doença de Chagas e algumas arboviroses. Discute-se a questão de se a presença de gado pode desviar, da população humana, as picadas dos vetores e assim, como zooprofilaxia, propiciar a redução de doenças como a malária, ou se, pelo contrário, a presença do gado, na atualidade se constitui em fator propiciador do incremento da população hematófaga.

Descritores: Agricultura. Insetos vetores. Doenças transmissíveis, epidemiologia. Ecologia de vetores.

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