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CONSEQUENCES OF RURAL DEVELOPMENT ON VECTORS AND THEIR CONTROL

by

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Degradation caused by man to this own environment is the theme which as been chosen by WHO for World Health Day, 7 April 1990 with the slogan «Our planet - Our Health; Think globally - Act Locally». In the framework of this action we intended to review the problems of vector-borne diseases related to rural development.

Man has always altered the environment to suit his needs. These changes resulted in the rising up of diseases, some of them being new. The recent doubling of the world population during the last 25 years, and it will double again before 2050, considerably accelerates the anthropisation of the globe, a spiral where man is beyond his own technology. More than 90 % of increase of human population takes place in developing countries. It is therefore evident that the priorities for these countries are to increase the food production by new land colonization and intensive cultivation schemes. The resulting ecological changes in rural areas alter the disease patterns.

Vectors of diseases, viz. arthropods, molluscs and rodents, are particulary affected by these environmental changes. Some species become scarce or disappear, others fit in the new manmade environment and find favourable conditions to proliferate. Epidemiology of the diseases changes with the modification of the vector ecological conditions, either by introducing new diseases and vectors, intensifying exposure to existing pathogens and parasites, or on the contrary by eliminating diseases and vectors.

1. Land Occupation

Extension of land use and migration brings about vector hazards, which are enhanced by low socio-economic conditions. In South America, domestic transmission of *Trypanosoma cruzi*, agent of the Chagas disease, by bugs was probably initiated in pre-Colombian times by agricultural practices which disturbed sylvatic transmission cycles in both savanna and forest ecosystems (68). Only a few species become well adapted to domestic environment. In houses, the domestic bugs like *Triatoma infestans* live in cracks and crevices. This suitable environment combined with abundance of hosts allows the bugs to build up high population densities, while in sylvatic species population densities are regulated by host density, climatic changes and predators (69).

Passive dissemination by man, associated with migrant workers and rural settlements, is largely responsible for the wide spread of *T. infestans* (94). In Brazil this species displaced the first wave of domestic species like *Panstrongylus megistus.* (69).

The health, social and economic impact of Chagas disease is very high, particulary in poor rural areas. Control of domestic vectors is feasible, while control of peridomestic or sylvatic species is difficult (19). The elimination of *T. infestans* with insecticides liberate a domestic niche which again could be occupied by species with wide-ranging sylvatic ecotopes, such as *P. megistus*, *T. sordida* and *T. braziliensis* (19, 69). In Venezuela palm trees are an important source for *Rhodnius prolixus* house invasion. Palms adjacent to the houses are used as roofing material. The bugs also migrate freely between palms and nearby houses (23).

Visceral leishmaniasis is often closely associated with the presence of vectors, well adapted to peridomestic and domestic habitats. Examples are *Lutzomyia longipalpis* in South America and *Phlebotomus perniciosus* in the Mediterranean basin, where dogs are the main reservoir of the parasite. Suitable shelters and breeding places of the vectors may be created by new human settlements (3). In Tunisia, a new focus of the disease has been observed in semi-arid areas, where sedentarisation and agricultural projects are developing (Attia pers. comm.). *P.perniciosus* has became very abundant in this region (Rioux *in* 3).

Although visceral leishmaniasis was well controlled in China, new foci, probably zoonotic, have emerged in the newly reclaimed desert areas of the North-West Xinjiang Region (91).

On the other hand the rapidly-expanding populations in East Africa led to a diminution of savanna fly-belts infested by *morsitans* tsetse flies (39) vectors of *Trypanosoma rhodesiense*. But actually *Glossina fuscipes* is the main vector of this sleeping sickness in Uganda. Previously this vector occupied the vegetation fringing the major rivers and swamps but has now gained peridomestic access, where the abundant growth of an ornamental bush (*Lantana*) offers a cover to the files (52, De Munck pers. com.).

2. **Deforestation**

Today the development of new land is mainly done at the expense of tropical forests.

Forest penetration

The cutting down of primary forests is associated with different human activities: wood exploitation, road construction, mining, new settlement for agricultural purposes, military manoeuvres. The penetration into the forest brings man in contact with zoonotic diseases such as yellow fever, leishmaniasis, etc.

In the neotropical regions various zoonotic leishmaniases are endemic over vast areas. Humans are accidental hosts. The population at risk firmly increases by spontaneous or organised immigration, generally without adapted health structure. *Leishmania (L)* of the complex *mexicana* are transmitted by terrestrial sandflies, particularly attracted to rodents, primary reservoir of the diseases (73).

Recently, there is some evidence that rodent leishmaniasis caused by *L. (L) amazonensis* may survive in artificial environments (61). The enzootic cycle *L. (L) amazonensis* has become well established in plantation of non-indigenous trees grown for wood pulp, particularly in pine plantation, where the vector *Lutzomyia flaviscutellata* and spiny rats successfully colonize the new biotope. Although *Lu. flaviscutellata* is not very antropophilic, an increase in the amount of non-climax forest could explain the increase of cases in the region near Belém (61).

In cultivated Yungas region of Bolivia, high numbers of *Lu. nuneztovari anglesi* enter houses wedged in the coffee plantations. This sandfly is the only anthropophilic sandfly found in houses which suggests that this species is probably involved in transmission of the tegumentary leishmaniasis (*L. (V) braziliensis*) in the area (45, 46). But in the forest area, man is only infected when entering fully shaded places; the vectors of the *Psychodopygus* genus avoid open places out of the forest coverage and in the nearby plantations and villages the transmission ceases (46).

With *L. (V) panamensis* and *L. (V) guyanensis* an arboreal cycle with the two-toed sloth as primary reservoir is involved. *Lutzomyia umbratilis* vector of *L. (V) guyanensis* in French Guyana is a dominant species in the canopy. Females descend from the canopy where they occasionally attack secondary hosts or man (4, 44). In the Manaus region many housing developments are situated on plateaux, with the houses at the level of the canopy, which may enhance the man-biting activity of *Lutzomyia umbratilis* (4).

The wide variety of epidemiological patterns of leishamaniasis requires for each situation a tailored control approach (18). Repellents can be used for individual protection (field workers), and relocation housing projects away from the forests edge have proved to be successful (2).

Man can also introduce pathogens in the forest, which will be further transmitted by local vectors. In Central America *Simulium ochraceum* is an efficient vector of onchocerciasis in the forest highlands, where it is the workers in coffee plantations who are most affected by the disease (74). The parasite was introduced during the time of slave-trading.

The edge effect

Cutting forests creates ecotones where concentration of some vectors can occur (edge effect). The wooded part (resting sites, reproduction sites) provides favourable microclimatic conditions for the vectors, while the cleared parts (feeding sites) allows an abundance of human hosts and domestic animals.

Glossina palpalis is rare in African tropical rain forests except where man has partially destroyed the natural environment. In the Ivory Coast, transmission of sleeping sickness occurs mainly at the boundaries between plantations and forest. The duration of man-fly contact increase the risk of contracting the disease, and thus the time spent in the plantation is a critical factor. Coffee plantations request more labour than cocoa plantations and are consequently more dangerous. Moreover, in the Vavoua trypanosomiasis focus, it was found that the immigrated Mossi group was considerably more affected by the disease than the local population. Here, human behaviour was the key factor. The Mossi tend to live in small encampments scattered within the plantation areas, while local people are located in hamlets. For different reasons, like water provision, the Mossi spend more time in high infested fly areas than local people (32).

Peridomestic transmission is more frequent in Cental Africa. The *Glossina* are concentrated at the edges of villages, where agricultural and domestic activities, breeding of domestic pigs in the periphery of the villages are propitious to fly population. Familial infections are common in these foci (22), where in Ivory Coast risk depends more on specific practices of each group (32).

The Loaloa filarial disease is confined to the African equatorial forest belt. The main vectors of this neglected disease are the tabanids *Chrysops silacea* and *Ch. dimidiata* which are particulary aggressive in the ecotones (55). Attracted by human activities, mainly wood exploitation, they leave the canopy to bite man at ground level. Some commercial plantations may increase the endemicity, like hevea plantation characterized by a low canopy and the absence of a dense undergrowth, which facilitates the location of man (27, 20, 64). On the other hand, the more open palmtree plantations, without canopy, are not favourable to the vector (20).

Clearance effect

Forest clearance favours heliophilic species such as *Anopheles gambiae*, the main vector of malaria in tropical Africa. This vector cannot develop in the undergrowth and so malaria endemicity is very low in Pygmies, who live in harmony with the forest-ecosystem without altering their environment. But a progressive degradation of the natural ecosystem, by implantation of villages, roads and agricultural fields, multiply the potential breeding sites, thus increasing the vector density (47).

In the same way, indiscriminate clearing of jungle and consequent exposure of streams to sun by planters in India and Malaya led to the multiplication of *Anopheles fluviatilis, An. minimus* and *An. maculatus* which contribute to new epidemic outbreaks (86). *An. maculatus* is more attracted to cattle than to man. Its importance as vector diminished with the introduction of domestic animals in these new settlements (9).

Forest clearance and new settlements are at par with formation of new breeding sites. This situation occurs in the Amazon Region of Brazil where the number of reported cases of malaria has increased tenfold since 1970. The immigrant population is the most affected by this outbreak. The vector, *Anopheles darlingi*, breeds in semi-shaded waters with floating debris, at the edge of the forest. Settlements, farming, construction and mining activities contribute to this type of breeding sites. Moreover, there is a striking association between the proximity of human settlements to the forest and the abundance of *An. darlingi* (15, 16).

On the contrary forest clearance removes the malaria vector *An. dirus* in South-East Asia. The shade afforded by the forest is essential to the survival of the aquatic stages and dense bushes are required for the survival of adults (86).

To show how difficult it is to predict the effect of man's intervention on the environment can be illustrated by the disappearance on the onchocerciasis foci of Kinsuka on the Zaïre river. The simuliid breeding places had become unproductive by deforestation and the invasion of the river by waterhyacinth, both reponsible for a insufficient quantity of available food for the larvae. Indeed it has been demonstrated the waterhyacinth, imported from Latin America, consumes most of the nutritive elements (31).

Forest degradation in Côte d'Ivoire goes at par with the appearance and successive proliferation of *Bulinus forskalii*, *B. globosus* followed by *B. truncatus* (70). In 1957 intestinal schistosomiasis appeared nearby Yaounde in Cameroun after *Biomphalaria camerounensis* became abundant in large ponds that had been established for pisciculture (55).

3. **Water resource projects**

Water resource projects are essential for the economic growth and development of a region or country, but the associated ecological changes they provide, are not without risk for human health. A proper knowledge of past experiences combined with a solid local database can be helpful to avoid or to minimize adverse effects in the future.

Water impoundments and dams

Disease outbreaks following the construction of large dams and man-made lakes has extensively been described. The Lake Volta in Ghana, Lake Nasser in Egypt, Lake Kariba in Zambia, Lake Kainji in Nigeria are often cited as typical examples (35, 92).

Without doubt, the greatest public health hazard arising from the establishment of artificial lakes is schistosomiasis. In Africa great improundments favour the rapid multiplication of bulins and/or *Biomphalaria* species. However, in the case of Lake Brokopondo in Suriname, the acidity of the water is unsuited for the colonization of *Biomphalaria glabrata*, which is almost absent in the Guyanese forest region (43); similar observations have been reported in other areas of the Amazonian region.

Dams provide important breeding sources for malaria vectors, such as the *Anopheles gambiae* complex, *An. funestus* in Africa, *An. sacharovi* in Turkey (51). In Suriname, *An. darlingi* was expected to proliferate but *An. nunez-tovari* was more successful although without malaria increase (43, 58).

Lakes overgrown with rooted or floating vegetation (*Pistia*, *Salvina*) become colonized by snails and *Mansonia* mosquitoes, which in Asia are important vectors of brugian filariasis.

Not only lakes could be involved in proliferation of vectors. Changes of the waterlevel downstream of a dam may affect breeding places. In the hydroelectric project on the Mahaweli River in Sri Lanka, most of the water is diverted for hydropower and irrigation, and only excess water is allowed downstream. During the dry season this is insufficient to flush out the rock pools in the river bed, breeding sites of *An. culicifacies*. A vector proliferation was followed by a malaria outbreak (90). In addition migratory movements of non-immune populations or infected populations and inadequate relocations procedures are indeed aggravating factors.

In Burkina Faso and Mali *Simulium damnosum*, vector of river blindness, colonizes the overflows of small dams. Resulting epidemics of onchocerciasis could be severe but very localized (42, 60). On the other hand, the submersion of rivers, like in Ghana with the Lake Volta, suppress rapids, which are breeding sites of this vector (60).

However, small dams are more abundant in developing countries and in terms of total influence they probably are of greater importance to human health. Indeed a single large dam has a shorter shoreline than a group of small dams, and we know that shorelines are potential breeding sites for vectors (37). Moreover, often no health care measures are foreseen in these small projects and lack of maintenance and seepage control favours the extension of vector habits.

Construction of small dams can extend the geographical spread of vectors and related diseases. Small impoundments have permitted the invasion of *Biomphalaria pfeifferi* in the Sahelian area of Bandiagara in Mali, where it had never been observed before (70).

The transmission of *Wucheria bancrofti* is only possible where pullulation of vectors occurs, like *Anopheles gambiae* in Africa, *An. barbirostris* in Indonesia. In this respect small impoundments largely contribute to create or maintain well localized foci in rural areas (7, 28).

Irrigation schemes

A great variety of crops can be irrigated such as cotton, sugar, vegetables, cereals, citrus and dates. However, rice is by far the most important irrigated crop with about 35 % of the 220 million ha of irrigated crops worldwide in 1985. Rice is the staple diet of about 60 % of the world population and the demand is continuously increasing (28, 72).

Rice production with surface flooding and soil saturation provides an ideal environment for many vector mosquito larvae and for snails, intermediate hosts of schistomosiasis, to propagate. The major vector-borne diseases associated with irrigated or rainfall ricefields, are Japanese encephalitis, malaria and schistosomiasis.

Mosquito reproduction in ricefields is related to the development of the rice plants, water depth, soil but also to agricultural pratices, like watering regimes, double-cropping and use of insecticides. Heliophilic species, like *An. gambiae*, *An. arabiensis* in Africa, *An. culicifacies* in India, *An. sinensis* in China, *An. aconitus* in Indonesia, *An. albimanus* in Central America, breed at peak densities during the early stages of rice growing. More shade-loving species, like *An. funestus* in East Africa, are more abundant when the rice plants become taller. Larval populations of *Culex tritaeniorychus*, the main vector of Japanese encephalitis, increase significantly after transplanting (28). However it is common that more mosquito larvae are found in seepage pools and fallow fields rather than in the fields of growing rice.

In irrigated areas the entire species composition of mosquitoes may change: species associated with swamps tend to disappear, and only a few species or favoured genotypes are successful in colonizing the irrigated area. In the Ahero irrigation scheme in Kenya, the relative density of *An. gambiae* represented 65 % of the biting mosquitoes, but less than 1 % in the nearby non-irriagated area where *Mansonia* species were predominant (76).

In West Africa, high frequencies of specific genotype Mopti of *An. gambiae* occur in widely separated rice-growing areas (11). In Burkina Faso, the chromosomal form of *An. gambiae* is largely prevailing in ricefields but the Savanna form is more frequent in the surrounding area where breeding places are temporary and limited to the rainy season. In Burkina Faso, rice fields are unfavourable for the larvae of *An. funestus* and *An. nili* (63). On the other hand in a rice-growing area of Burundi *An. gambiae* represents only 4 % of the indoor resting *An. gambiae sensu lato. An. arabiensis* of the *gambiae* complex is here predominant throughout the year and characterised by a low degree of inversion polymorphism (14).

In the coastal of Guyana, *An. darlingi* was well controlled, but the expanding rice culture displaced livestock and mechanization displaced horses and donkeys, with the result that the zoophilic *An. aquasalis* hurled itself on man (26).

Increased vector density, due to rice culture, can be associated with increased malaria transmission particulary when the basic reproduction rate is low, but where malaria is stable and transmission greatly in excess of that needed to maintain the parasite, few changes will be observed.

In Burkina Faso, even a decrease of malaria endemicity was observed in the irrigated area of the Kou Valley, in spite of a tenfold increase of vector density compared to the holoendemic surrouding savanna (62). On the contrary in Rusizi Valley of Burundi, an area of unstable malaria transmission, vectorial capacity was 150 times higher in the ricefield area than in the nearby cotton-growing area (12). But in both ricefield areas, periods with maximum vector densities were associated with absence of transmission, due to low survival rates of the vector. Transmission increased when the mosquito population decreased, but this was associated with an increase of their survival rate. The use of bednets and the shift of biting behaviour to domestic animals, more abundant in ricefield areas, may also account for low sporozoite infection rates of anophelines (62).

In China, *Anopheles sinensis* and *An. anthropophagus* are the main vectors of *Plasmodium vivax*. Despite the high instability of the disease, and continuous control efforts, frequent malaria epidemics still occur, resulting from extensive irrigation and increased rice-producting areas (17). However, outbreaks of malaria epidemics also result from periodic floods.

We can conclude that high vector densities associated with ricefields does not necessarily mean high transmission of malaria. On the other hand, Najera (57) underlined that tropical ricefields are often free from dangerous anophelines e.g. it has been observed that the plains of Assam are almost free of the local vector *An. minimus*. Malayan ricefields are relatively free of malaria, in spite of the presence of *An. aconitus*, which is zoophilic in this area and consequently plays a minor role in the transmission. But the presence of *An. maculatus* outside the ricefields complicates the malaria epidemiological picture (38).

Insecticidal spraying against rice pests can lead to an upsurge of productivity of mosquito vectors through the destruction of predators like *An. arabiensis* in Kenya (71) or *Culex tritaeniorhynchus* in Japan (53).

Bulinid and planorbid snails, intermediate hosts of *S. haematobium* and *S. mansoni*, are adapted to wide range of environmental conditions and in aestivation periods bulinid snails can survive out of water for weeks or even months. Because of the high water temperature in ricefields, snails are not common in ricefields. Snails found in ricefields are carried along by the current but no reproduction occurs in this place. They successfully colonize the draining canals and seepage ditches (80).

In Africa and in the Eastern Mediterranean region, schistosomiasis endemicity has considerably increased in human populations living near man-made waterbodies and irrigation schemes (82). In the Rusizi valley, in Burundi, immigration and irrigation has led to a 30 fold increase of *Schistosomiasis mansoni* in the last 3 decades (29). This disastrous effect was also observed in the Mwea-Tebere project in Kenya, which convinced the National Irrigation board of Kenya and the Ministry of Health to collaborate together (82).

In contrast to Africa where schistosomiasis is widespread, *S. japonicum* in Asia is confined to relatively small endemic foci (35, 82). The amphibious intermediate hosts, *Oncomelania* spp., are much less affected by dry conditions than the aquatic planorbid and bulinid snails, and irregular population changes may be independent of seasonal factors. They particularly flourish in poorly tended ricefields or idle parts, with emergent vegetation. But generally snails found in the ricefields appear to have spread from irrigation canals (80, 82).

Africa and Latin America have an enormous potential to further develop wetlands for rice cultivation. Control measures against vectors will require careful consideration right from project-planning stages. In Asia most potential areas are now exploited and more emphasis is now being placed on upgrading the management of existing systems (24).

Water supply

It is generally understood that adequate water- and sanitation facilities to a certain extent contribute to the improvement of community health. Domestic water supply reduces domestic water contact and exposure to infection of schistosoma and dracunculiasis. In remote rural areas of Africa and the Indian subcontinent still 140 million persons are estimated to be at risk of the infection with guineaworm (*Dracunculus medinensis*) by drinking water containing cyclopoid copepods infected with the third-stage larvae of the parasite (33). Although dracunculiasis is not a lethal disease, lesions caused by the emerging worms are painful and have a significant impact on education and agricultural productivity (5, 88). Population movements associated with war, famine or resettlement provide ideal conditions for further dissemination of the disease through impoverished populations which rarely have access to protected water supplies (79). A campaign to eradicate dracunculiasis has been underway from the beginning of the International Drinking Water Supply and Sanitation Decade (1981- 1990). Active surveillance for dracunculiasis combined with a program of provision of safe sources of drinking water supply, such as pipe wells or draw wells, the use of synthetic-fibre filters of 100 μm pore size (75), health education and vector control using temephos, already reduced the number of cases found through active detection by 35 % between 1983 and 1985. Most active countries are India, Pakistan and Côte d'Ivoire where it is on verge of being eliminated (33, 89). However, in some regions people still prefer a more tasty surface water from the river.

4. **Integrated vector management**

The integrated vector control takes its essence in applied ecology. It is a concept rather than a sum of techniques and methods. «The philosophy of integrated vector control should not be to ban insecticides but to minimize their use in order to reduce environmental contamination and postpone the spread of resistance» (92). Similar precautions must be taken for other methods too. For instance, biological control may lead to unexpected side effects by introducing exotic pathogens, or predators. The use of natural enemies will be preferred. In the same way, «draining marshes may destroy important aquatic habitats, whereas careful management might allow such habitats to be retained but their attractiveness to mosquitoes reduced» (92).

Chemical control

Chemical control has become less popular, because of the impact of insecticides on the environment, the lack of specificity, prohibitive costs of pesticides and development of resistance. However, insecticide treatment should be considered as a supplement to basic sanitation (84).

Minimal insecticide application schemes, suited to the local epidemiological situation, can be very successful and cheaper. In the ricefield areas of the Rusizi Valley in Burundi, indoor spraying with malathion is performed once a year, at the end of the rainy season, which was the highest transmission period before the control operations started. The malaria prevalence decreased from 70 % to less then 5 %, in spite of a continuous high vector density during the rainy season. Other methods eg. improvement of curative services, impregnated bednets, environmental engineering combined with a stimulation of the awareness in the community for maintenance problems and self-protection, will be evaluated by a progressive, but careful, decrease of spraying rounds (13).

In the Antananarivo region of Madagascar, *An. gambiae s.l.* was well controlled and *An. funestus* had been eliminated in 1952 after intensive insecticidal spraying of house during the malaria eradication compaign. Resurgence of malaria and recolonization by the vectors was easy to predict after the interruption of vector control activities in 1958. Malaria outbreaks are again regular since the beginning of the 80s (21).

In the Swaziland, malaria was reduced to near eradication by DDT house-spraying. The disease flared up after 1980 when the spraying activities were neglected. The main reason for this was the lack of trained personnel after the transfer of control activities to the primary health care services. It resulted in an epidemic outbreak in 1986. (Mouchet, report WHO).

However, where the stability of malaria is high, like in the Sudan Savanna of Africa, domiciliary spraying of insecticides has a very limited impact on the endemicity (54).

Insecticides applications have been very effective in controlling the Chagas disease in Brazil, where domestic bug populations were drastically reduced in the treated areas. The attack phase was followed by a vigilance phase mainly based on community participation and volunteers, in order to coordinate any denunciation of infested premises, confirm identification of the bugs and organize spraying of the infested dwellings. But in a few areas, sylvatic and peridomestical species reinvaded houses when the residual insecticide activity ended (19). However their vectorial capacity in the domestic cycle remains to be investigated.

The Onchocerciasis Control Programme (OCP) in West Africa, has a considerable socio-economic impact by decreasing riverblindness. Abandoned villages and fertile land have been reclaimed. The control activities are mainly based on wide scale larviciding activities. Reinvasion by *Simulium* in the controlled area and insecticide resistance are the main problems. The use of a new and effective drug against onchocerciasis, ivermectine, will be combined with the vector control (87).

Today the only molluscicide on the market is niclosamide, but its high cost and its toxic effects on fish are limiting factors to its use. Areawide mollusciciding as in China or in Egypt controlled the snails successfully. Focal control reduced transmission of schistosomiasis in many areas (Saint Lucia, Ghana, Yemen). To improve cost-effectiveness, more adequate strategies and delivery systems (slow-release formulation) are necessary. Plant molluscicides could be used in self-help projects, but more field research is required (81). Actually new effective drugs are suitable for large-scale chemotherapy and only focal mollusciciding can now be recommended to prevent or to limit reinfections (77).

It is now well known that massive use of insecticides against crop pest is mostly responsible for the induction of resistance development in many vectors by indirect exposure. Agricultural pesticides are often subsidized which could lead to excessive use disregarding optimum application, thus jeopardizing chemical control of vectors (56, 85). In Central America agricultural spray on irrigated cotton fields induced a wide range of insecticide resistance in *An. albimanus* (25). However, in Gezira valley, in Sudan malathion resistance in *An. arabiensis* was effectively induced by indoor spraying (30).

Countries, like Sri-Lanka, have restricted the use of malathion and fenitrothion in the public health sector in an attempt to minimize the development of resistance in malaria vectors, that could indirectly be caused by their use in agriculture (86).

Biological control

So far biological control has not scored many goals in the control of vector-borne diseases. The best results were obtained with *Bacillus thurigiensis* H14, for the control in the OCP programme of *Simulium damnosum* s.l., resistant to temephos (87). But, *Bacillus* sp. are in fact microbial insecticides rather than biocontrol agents. In ricefields their effective action is short.

Larvivorous fishes have been widely used. Reports mention their effectiveness in reducing mosquito larval population, although there has been little attempt to evaluate to what degree they reduce vector-borne diseases.

In the Grande Comore island, the larval habit of *An. gambiae s.l.* is always peridomestic and strictly connected with cisterns. Larvivorous fish were introduced to permanent water collections but no important decrease of malaria incidence was observed (Ouledi, pers. comm.). On the other hand, in Somalia where cement-lined water reservoirs are also the most favourable breeding site of *An. arabiensis*, introduction of larvivorous fish and drug administration led to a sharp and sustained decline in *An. arabiensis* density combined with a dramatic decline in the slide positivity rate (in 93).

In Colombia, a trial was performed with *Romanomermis culicivorax*, a nematode and obligate parasite of mosquito larvae. The *An. albimanus* population decreased and a coincidental reduction of malaria prevalence was observed. The seeding density was about 3000 eggs of the nematode/m2. The nematode ceased to recycle after two years for unknown reasons (65).

In Puerto-Rico, the snail *Marisa cornuarietis*, a competitor of *Biomphalaria glabrata*, has been evaluated, but the *Marisa* were feeding on rice seedlings and its use could not be recommended (82).

Once again it is important to emphasize possible nefast effects of pesticides on existing natural enemies.

Bednets, traps and lethal targets

Insecticides can be employed in ways different from conventional spraying techniques. An alternative method is to attract vectors to a lethal target.

The mass use of impregnated bednets with pyrethroïds in the Guangdong Province, China, has decreased the incidence of malaria by 98 % (48). In Burkina Faso a similar trial reduced malaria transmission by 82 %. While the parasite index remained about the same, the mean parasitic load and the number of clinical malaria cases decreased significantly (10). This method can easily be integrated in primary health care, but it should be recommended that planning, coordination and delivery of the insecticide must be carried out by specialized agencies (66).

Traps, such as the biconical trap, and insecticide-impregnated screens have been shown to be effective in reducing tsetse populations (40). In the forest area of Côte d'Ivoire, nearly 16 000 blue screens sited in the plantations reduced by 98 % the apparent of tsetse flies after 5 months (41). The efficacy ot these targets, based on visual attraction can be enhanced by chemical attractants (octenol and acetone) as has been demonstrated for *Glossina morsitans* and for *G. pallidipes* (78), but poor results were observed with these compounds in the case of the *palpalis* group (Laveissière, pers. comm.).

Environmental management

In the above described methods need to be applied by vertical structures, or at least with a strong expertise and supervision of peripheral structures, it is unthinkable to develop an environmental management programme for vector control without a high of intersectorial cooperation, which is a complex task and could be difficult to achieve.

Socio-economic, cultural, environmental and epidemiological factors will determine in the choice of vector management strategies. Strategies developed in temperate zones, where the period favouring vector reproduction is shorter, will not necessarily be the same in sub-tropical or tropical regions, where successful control will be more difficult to achieve. This seems evident, but often environmental management programmes in temperate industrial countries are mentioned as examples of what could be achieved in tropical developing countries.

Environmental modification

Appropriate physical transformations of land, water and vegetation will prevent, eliminate or reduce vector habitats. Large-scale engineering works could be involved. They imply high initial capital outlay, but maintenance costs are low. Other methods, like chemical control or chemotherapy have large recurrent costs. Environmental modification programmes for vector control should be incorporated especially in new development projects and as a part of rehabilitation of existing projects (6). However, numerous smallholder rice farmers, faced with high production costs, are unable to apply such engineering methods (6).

In Kerala, on the East Coast of India villagers removed aquatic vegetation from pools and fish has been introduced for breeding. *Mansonia* mosquitoes decreased and Brugian filariasis disappeared. Aquatic vegetation was used as fertilizer for coconut palms but now a nitrogen-fixating leguminous plant, is used and the production of coconut has been increased. This constitutes the direct benefit for the villagers and vector control is only considered as a by-product. This community participation required an important input by the vector control division of Pondicherry to motivate the villagers. (Rajagopalan & Panicker pers. comm.).

Environmental manipulation

Planned recurrent activities, like vegetation removal, regulation of the water level, stream flushing could produce temporary unfavourable conditions for breeding of vectors in their habitats (83). The methods must be acceptable to farmers and cost- effective. Introduction of new agricultural practices, like crop rotation or periodic drainage have to be considered.

Alternate wetting and drying of ricefields can decrease the larval population of mosquitoes and the ability of snails to survive, without a drop in rice yield. But this method is only possible for some particular varieties of rice and soil types. However the main limiting factors are the requirement of a complete system of irrigation and drainage, which is often lacking, and constant supervision by well trained irrigators. The wet-dry cycle of course depends on the biology of local vectors. The use of this method can thus not be generalized. In China intermittent irrigation was successful in reducing mosquito densities of *An. sinensis* and *Culex tritaeniorhynchus* by 53-70 %(59). However, a submersion period below 15 days is difficult to avoid for agricultural reasons. This is too long to interrupt the development of *An. gambiae.*

Crop rotation effectively controls the amphibious snails *Oncomelania* in the Philippines and in Japan (82).

Experimental studies showed that complete coverage of water surface by azolla, a free-floating, aquatic fern used as organic fertilizer, was found to be detrimental to adult emergence of *Anopheles sinensis* and to inhibit oviposition of *Culex* species. (49, 50). Actually the use of azolla as fertilizer is decreasing in Asia, where it has not come up to the farmers' expectations. Research activities involving molecular biology techniques are currently undertaken to improve the activity of azolla.

Improving housing structures

While in the short term insecticide applications will reduce Chagas disease, in the long term, it is likely that control of the disease will mainly be achieved by improvements in rural housing. Replacement of traditional houses by modern ones is generally too expensive and often difficult to comply with cultural and climatic requirements (68). A very satisfactory programme has been adopted in Venezuela, where local techniques and materials are used to make houses unsuitable for triatomine bugs. A socio-psychological intervention, in order to increase the self-confidence of the community and the individuals, has been introduced as part of the programme (8).

The construction of new villages at a distance of 1.5-2 km from breeding grounds of mosquitoes would reduce mosquito-man contact and also discourage people, not working in the ricefields, from contact with schistosome infected waters. In this case the problem of an adequate water supply for domestic use remains (51).

Water supply and sanitation

Reduction of domestic and recreational contact with cercariae-contamined water can be obtained by setting up drinking fountains and wells, washing boards, foot-baths, foot-bridges. But occupational contact will continue to occur. Bore-hole latrines may reduce contamination, but are unlikely to control urinary schistosomiasis. Such improvements are applicable only to nucleated settlements, with financial participation of the community. A health education programme and awareness-building in the community for its maintenance is of course the most important step for the final issue. Resettlements projects must include adapted housing support.

Changes in livestock

«Changes in livestock may affect vector-home disease patterns in a complex manner. Increased animal populations may direct mosquito biting away from man, especially if the livestock pens are situated between the breeding sites and human settlements. On the other hand, the stock may act as amplifier populations, allowing a considerable proliferation of arboviruses normally transmitted at a lower level among wild birds or mammals. Livestock populations, by increasing food supplies for mosquitoes and tsetse flies, may also encourage larger vector populations» (86). Domestic animals may play a role in maintaining the parasite life cycle of Trypanosomes, Leishmania, *Schistosoma japonicum*. Pigs are the most important amplifier of Japanese encephalitis.

5. **Intersectorial approach for vector borne diseases**

There is a growing awareness that intersectorial collaboration is needed for a harmonious rural development enhancing the quality of life of people, a broad concept where not only health is involved. Particulary for vector-borne diseases, coordination is necessary not only between personnel in health sector and agronomists, but also engineers, economists, educators and sociologists will be required in order to solve specific problems. This can be done at international, national or regional levels. Interagency collaborative efforts of the United Nations (WHO/FAO/UNEP) lead to the etablishment of the PEEM (Panel for Experts on Environmental Management for vector control). Institutional arrangements/ exist throughout the world : Interim Committee for Coordination of Investigations of the Lower Mekong Basin, the Zambesi Plan, the International Rice Research Institute (Philippines), the Tennessee Valley Authority (USA), the Mahaweli Authority (Sri Lanka). National intersectorial collaboration are developed in different countries (e.g. Philippines, Sri Lanka, Burundi).

Yet, intersectorial collaboration which is so often a vow expressed in conferences, is rarely applied in the field for various reasons : communication problems, conflicting budgetary requirements, difficulty to identify the institutions and persons involved, and choice of operational priorities. Funding agencies can play a determinant role. Another problem in controlling vector-borne diseases is that development projects are already in operation which allows little flexibility for environmental management.

Intersectorial collaboration should be started at the planning phase of a development project for selecting infrastructures and agricultural methods to minimize subsequent health problems. During the implementation and operational phases readjustement of strategy may be necessary. The local community should be involved at all phases from the initial planning to the final operation and maintenance stage.

Although the health impact of a project can be predicted and preventive actions put forward, the proposed measures are not always implemented. The gaps between planning and implementation of development programmes have been illustrated for two irrigation programmes in Africa (1). The main reasons were : rising cost of local currency, long delays in equipping health services, poor information exchange, failure to stimulate active interest of irrigators and politicians.

We have to bear in mind that agronomists and farmers will be receptive to hygienists proposals only if the new activities will be economically feasible, without diminishing the agricultural production.

Community participation is now an evidence. Health education and awareness stimulating programmes are the first steps. But the community-based approach for the control of vector-borne diseases is slow, and it takes many years before human behaviour is enough modified to have an impact on disease transmission. Long-term programmes are the imperative. As has been pointed out recently by Sawyer (67), with regards to community participation in malaria control on the Amazon frontier, the main problem facing community participation is to know exactly what the community can or should do. There is a severe shortage of technical know-how about which self-help measures are effective in different settings. Moreover we must know which are economically feasible and socially acceptable.

6. **Epidemiological approach for control**

A good understanding of the local epidemiological situation is the first step to a successful control project. The best way to achieve this are longitudinal surveys in the field in order to select place and time for specific control interventions. Transmission studies request new tools, that can be used in the field. Studies on colonization capacity of vectors to new man-created environments are useful to adapt adequate control strategies in development projects. New tools, like remote sensing (34), computer analysis, are now developed in order to improve predictability of health impact resulting from agricultural development programmes. But this will not replace an experienced eye in the field. Predictability is not mathematical and epidemiologists are often epidemiometrists, who do not disentangle the interrelation responsible for the disease. Priority must now be given to fine analysis of the phenomena in the field.

Collaborative research with agricultural and public health scientists has to be developed in the near future. In this context, the great effort of the International Rice Research Institute and the PEEM (36) should here to be underlined.

It is evident that endemic countries need their own epidemiological services, which should have been developed as part of the referral system of health infrastructures (57). More specific demands can be supplied by laboratory networks. On the other hand, scientists should devote more attention to improve control activities in the field (19).

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