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Source: Journal of Orthoptera Research, 10(2) : 277-291

Published By: Orthopterists' Society

URL: https://doi.org/10.1665/1082-6467(2001)010[0277:RPIDAM]2.0.CO;2

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Synthesis:

Recent progress in Desert and Migratory Locust management in Africa. Are preventative actions possible?

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Abstract

Locust control in Africa has been the focus of considerable controversy over the last 15 y. Many control aspects were called into question following the last large plagues of 1987-88 (Desert Locust) and 1996-2000 (Malagasy Migratory Locust): recommended preventative strategy, environmental impact of insecticides used, socioeconomic importance of the locusts. Many projects were launched to improve survey and control methods and find alternative solutions to chemical pesticide treatments. Recent progress is reviewed. Survey and application techniques showed dramatic improvements with GIS, GPS technology and precision spraying. Barrier applications are again available, thanks to new persistent pesticides. Biological control with mycopesticides now appears very promising and undoubtedly the technique will gradually be adopted. The environmental aspects are taken into better account and an IPM approach is now possible. The EMPRES program of FAO is committed to reinforcing national early warning and early reaction capacities for preventative control of the Desert Locust. In Madagascar, a new National Locust Center has recently been set up. In many places local research capabilities are improving.

However, certain very fundamental aspects remain unsolved. Among others, the sustainability of preventative control systems is an important concern. Many affected countries are amongst the poorest in the world. They currently do not have sufficient financial resources to fund intensive control campaigns, nor even the basic minimum to ensure prevention. A realistic solution to prevent locust plagues requires stronger commitment of governments and donors, sustainable small but flexible national locust control units for prevention, and especially the creation of emergency action plans, ready to quickly mobilize and organize complementary resources in the event of an upsurge. Emergency funds are thus essential and should be created. Locust control seems now to depend more on political and institutional choices than on scientific and technological innovations.

Key words

Acrididae, locust control, outbreaks

Introduction

Throughout history, humanity has always been affected by locust plagues, and these plagues have always been particularly devastating for Africa. During the past centuries, this remained a recurrent theme for travelers, missionaries and naturalists, who all bore witness to the severity of the problem and its effect on food supplies in Africa. Means of controlling these plagues long remained rudimentary: noise, fire, prayer, *etc*. Even today this is still all that certain human populations can do.

Organized control of locust plagues started as soon as agricultural resources were methodically exploited in colonized countries (Roy 2001). The first scientific study on the subject and the first control campaigns took place in Algeria during the second half of the 19th century (Buj Buj 1995). Jules Künckel d'Herculais' pioneering work (1905) marked the first European action against the locust in Africa. This research helped to increase international awareness of the problem. However, it was not until October 1920 that there was a first attempt at international co-operation through the International Conference on the Organization of Locust Control in Rome, which was held under the patronage of the International Institute of Agriculture. The development of this international co-operation and the resulting progress are well known. All this was, of course, boosted by the efforts of Boris P. Uvarov and other pioneers, among whom especially Boris N. Zolotarevsky (Uvarov & Zolotarevsky 1929) and Paul Vayssière played a fundamental role in the internationalization of locust control in Africa (Vayssière 1924).

Alongside this co-operation and as early as the second half of the 19th century, scientific knowledge on the subject increased and modern control techniques appeared and were continuously improved. The greatest progress was achieved between 1930 and 1950 (Jago 1998). Within a few decades, a good understanding of the locust problem in Africa and constant improvement of its management were achieved, both from a technical and institutional point of view. This period experienced the setting-up of national and regional locust management organizations, the development of international co-operation and the enforcement of a preventative strategy as well as more effective control techniques.

Yet the current situation is paradoxical. While we have never had so much scientific knowledge on the causes of locust plagues, nor such (evermore) sophisticated means of control, the last few years have shown that locust control in Africa is much questioned. Many people, especially in donor countries, estimate that too many key and basic problems in locust control are not sufficiently documented.

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A significant locust plague shook numerous African countries in the late 80's with substantial grasshopper outbreaks, followed by a plague of Desert Locusts. More recently, a plague of Migratory Locusts and Red Locusts heavily affected Madagascar. As a consequence of these events, techniques for handling pest locust populations, the extent of the locust problem and the effectiveness of locust control operations were questioned (*i.e.*, US Congress 1990). However, it is certain that these questions have led to extensive research work and to substantial progress over the last 15 y.

The Desert Locust and the Malagasy Migratory Locust may be used as examples to explain recent progress, prospects for the future and to highlight some key questions that remain unsolved.

Basis and hazards of plague prevention

Regarding both the Desert and Malagasy Migratory Locusts, prevention is based on a wide understanding of the biology and ecology of these species, and particularly on precise knowledge of their outbreak areas (progressively acquired from the thirties of the last century (Fig. 1)).

There are two broad approaches to locust control (Posamentier & Magor 1997): plague suppression and plague prevention. The first is a "reactive strategy", occurring as an emergency operation if plague status is reached and when swarms and hopper bands are disseminated in many countries, far from their initial breeding and outbreak areas. This reactive strategy has been divided into "curative" and "palliative", according to the possibility of eliminating the plague by intensive control operations or simply trying to protect threatened croplands (Mbodj & Lecoq 1997). Plague prevention can be divided into three components: outbreak prevention, upsurge prevention and upsurge elimination (Posamentier & Magor 1997).

Concerning the Desert Locust, the currently implemented strategy is a "preventative" one. More precisely it is an "upsurge prevention strategy" (Bennett 1976, Magor 1994). It seeks to achieve plague prevention through population reduction, by trying to eliminate the appearance of the first gregarious populations. These localized outbreaks occur during recessions or represent the beginning of a plague upsurge sequence. Inaccessibility, lack of resources, and slow reactive response however, lead in practice, to control activities throughout upsurges (Posamentier & Magor 1997). Thus, the current "preventative strategy" is in fact a combination of outbreak and upsurge prevention and upsurge elimination, that relies on control operations at the earliest possible stage. Decades of experience of field operators have shown that the longer we wait, the more serious the problems become, and the difficulty in solving them increases exponentially (Lecoq *et al.* 1997).

In practice, this preventative strategy against the Desert Locust requires: 1) monitoring and early warning capacities, 2) early reaction capacity to control "dangerous" locust populations or, in other words, transient-to-gregarious populations (Bennett 1976, FAO 1985). However, this definition is very often extended to any dense and large locust population without any reference to its phase status (Roffey 1982).

In the case of the Desert Locust, given the great number of countries involved, this strategy also supposes effective international co-operation, regarding both monitoring and control. Therefore, there is a basis for prevention founded on research that first began nearly one century ago. This strategy has been used for approximately 40 y, particularly by the FAO[1] (FAO 1968, 1972; Hafraoui & McCulloch 1993).

The enforcement of this preventative strategy has helped to prevent great plagues and to reduce the frequency of upsurges (Skaf *et al.* 1990, Roy 2001). Fig. 2 shows, for the Desert Locust, successive periods of plague and upsurge over the last 120 y. From the 1960's — a time when control techniques became more effective and when prevention was implemented— we can observe a significant drop in the frequency of plagues. This fact is usually mentioned as proof of success in preventative management, even though the influence of climate changes and extreme dry conditions that prevailed in Africa during the period should not be forgotten (Magor 1994).

Nevertheless, the same phenomenon can be observed in Madagascar in the case of the Migratory Locust, a species which evolved in an ecological environment strikingly different from that of the Desert Locust (Fig. 2) (see Lecoq 1995 for the scientific basis of plague prevention in that country). In this case, it is impossible to incriminate dry conditions. Similar developments, both in Africa and in Madagascar, strongly support the preventative control and modern control methods, to the detriment of the climate change theory. In one case as in the other, the end of large plagues in the early 1960's corresponds to better knowledge on the subject, the implementation of a preventative strategy, a more effective monitoring system and new control methods, especially ULV drift applications, barrier applications and the use of a persistent organochlorine insecticide, dieldrin. Thus, within a few years, all these improvements fundamentally changed the operational problem and led to greatly improved outbreak control (FAO 1968, Roy 2001).

Yet recently plagues have made a comeback. The last 15 y have once again seen Africa under serious attack by locusts; from 1987 to 1989, a Desert Locust plague (Skaf 1988, Skaf *et al.* 1990, Showler & Potter 1991) affected numerous countries. Swarms from the Red Sea region migrated to the Sahel and North-West Africa, following seasonal winds and rains. In October 1988, some swarms crossed the Atlantic to reach the Caribbean and the northern part of South America.

Between 1996 and 2000, this was the case in Madagascar for the Malagasy Migratory Locust (World Bank 1998, Duranton *et al.* 2000). Within 3 y, the whole country was invaded; even the eastern forest zone was affected and only the far North of the island was spared (Fig. 1b). Massive swarms were observed. In 1998, at the height of the plague, average swarm size was 4000 ha (Fig. 3). Wide-scale control operations were relentlessly carried out for 3 y, with substantial air means and significant international assistance and obviously, intensive use of insecticide; this had consequences for the Malagasy environment, both very rich in endemic species and very protected (Schulten *et al.* 1999).

Globally, the costs for combating these plagues were

[1] Food and Agriculture Organization of the United Nations

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colossal: over US$300 million for the Desert Locust, and over US$50 million for the Malagasy Migratory Locust. Huge surface areas had to be treated (incomparable to what could have been preventively treated). Between 1986 and 1989, 26 million ha were treated against the Desert Locust in 23 countries. The banning of dieldrin necessitated full coverage sprays, often used in a repetitive way and with non-persistent insecticide such as fenitrothion and malathion. Such treatments possibly had a more serious environmental impact than the organochlorine-based treatments they replaced (Rowley & Bennet 1993). In Madagascar, more than 4.2 million ha were treated during the latest plague (1.2 in full coverage mostly with deltamethrin, propoxur and fenitrothion and the remaining 3 million ha in barrier applications with fipronil) (Lecoq 2000a).

What are the reasons for the return of the plagues and what lessons can be drawn? Is it a failure in strategy, inappropriate control methods or a lack of knowledge of the problem? The answer is extremely straightforward: it is the consequence of an overly long remission period. Both in Africa and Madagascar, from the 60's, the relative calmness of the locust situation gradually brought about a decline in support to regional management organizations (such as OCLALAV[2] and DLCO-EA[3]) and to national locust control units (Gruys 1994, Lecoq 1991). In fact, these recent plagues were forecast at a very early stage. However, the countries' reaction capacity was substantially weakened, which made it impossible to stop upsurges when they started. They then had to accept the gravity of the situation, the need for action through chemical control due to a lack of other methods, by going beyond such issues as product choice and mobilizing the required international resources. By the time all conditions were met, the problem had already increased in scale and there was a plague. Africa witnessed exactly the same scenario in 1987 as did Madagascar in 1997. Obviously, other reasons could be put forward, especially, as regards the Desert Locust; security problems, wars, terrorism *etc.*, made access to certain zones difficult or even impossible (Showler 2001a). Nevertheless, the basic problem remained the global weakening of control organizations.

The consequence of the return of the plague, and especially of this first "locust shock" in 1987, was global questioning, mainly influenced by the so called "donor" countries, financially solicited during periods of plague (Joffe 1995, Rowley & Bennet 1993, US Congress 1990, Van Huis 1994b). Questions, among others, were centered on: 1) the real economic importance of locusts (numerous decisions were said to be taken on the basis of political and emotional considerations rather than on objective risk assessment regarding agricultural production and food safety), 2) the preventative strategy (blamed for lack of clarity and consistency) and its efficacy, 3) leadership and the FAO view of the problem, 4) the choice of the all-insecticide solution given its impact on the environment, 5) the feasibility and efficacy of biological control methods, 6) countries' capacities for long-term control given their financial resources, 7) the true point of control in the face of possible alternative solutions,

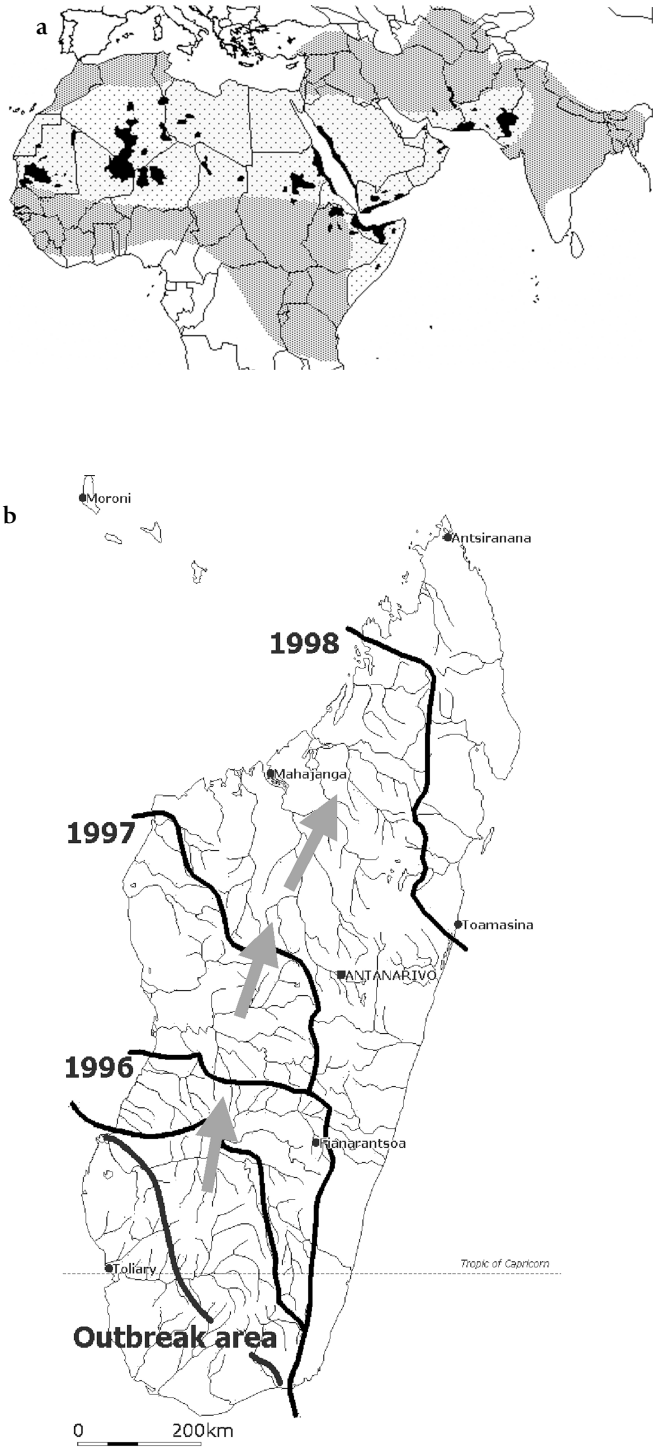


Fig. 1. Plague sequence of the Desert Locust and of the Malagasy Migratory Locust. **a.** Desert Locust: black, outbreak areas; light plus dark grey, invasion area ; light grey, recession area (modified from Popov 1997). **b.** Migratory Locust: outbreak area in Madagascar and spread of the last invasion from 1996 to 1998 (modified from Lecoq 1995 & Duranton *et al.* 2000).

[2] Organisation commune de lutte antiacridienne et de lutte antiaviaire (Joint Locust and Bird Control Organization)
[3] Desert Locust Control Organization for Eastern Africa

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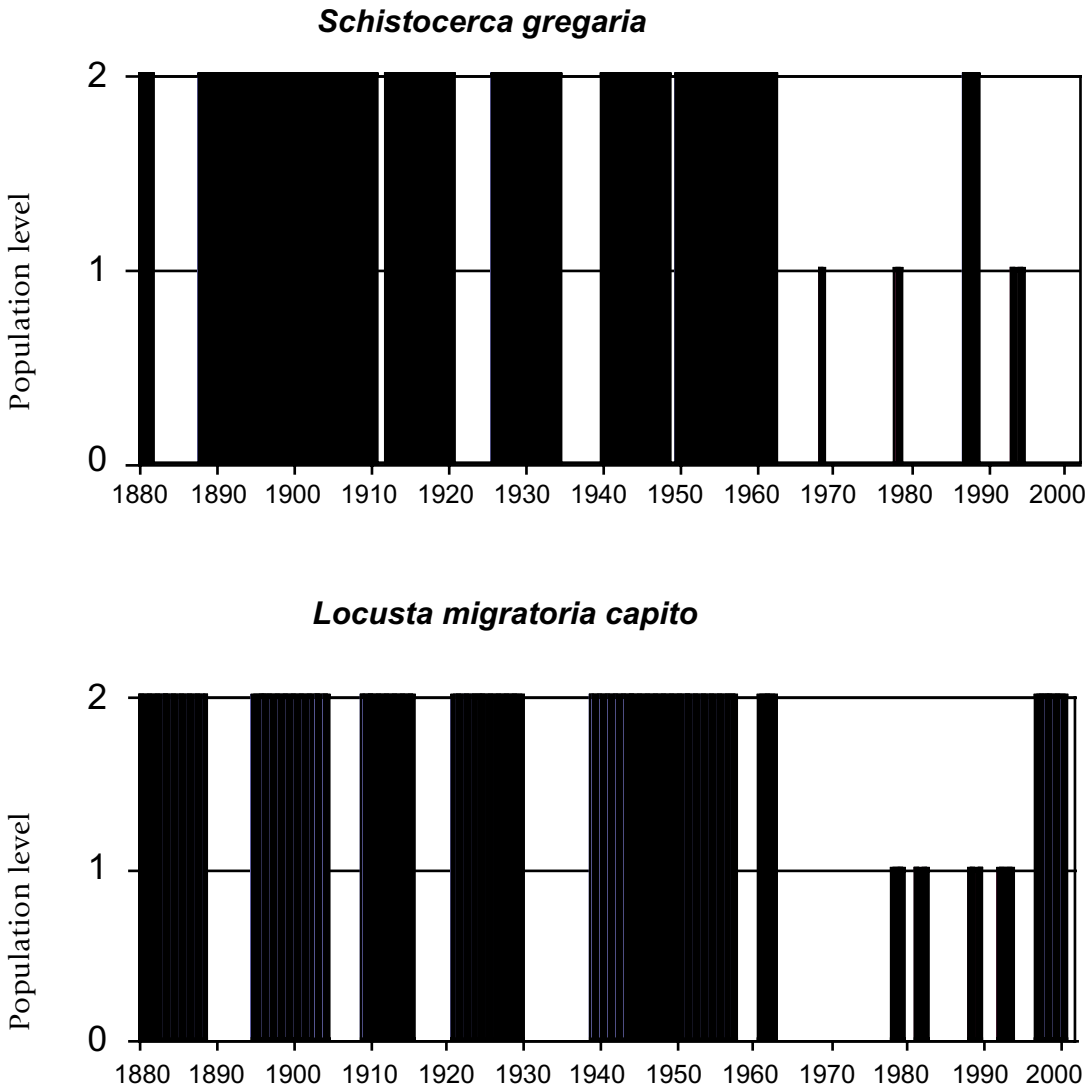


Fig. 2. Plague and recession periods of the Desert Locust and of the Malagasy Migratory Locust, 1880-2000. Population level: 0, recession; 1, upsurge ; 2 invasion (source of data : *Schistocerca gregaria*, FAO 1994b; *Locusta migratoria capito*, Scherer & Lié Fong Hong 1995).

and finally, 8) the advantages of not reacting to an outbreak.

Rightly or wrongly, in the 1990's, many estimated that the time had certainly come for a change of approach to the locust problem.

Recent progress in Desert and Migratory Locust management

Economic impact of acridids.— The economic impact of acridids has become a subject for much discussion and study. The aim was to better assess impact and especially to discover whether or not acridid impact is exaggerated, given the spectacular nature of the plague phenomenon and the resulting inevitable political pressure. It was also necessary to ascertain whether preventative control is an economically viable option.

Numerous stories, data, and evidence attest to the social and economic importance of locusts and grasshoppers in Africa during the past centuries as well as during recent years. Locusts are capable of causing total crop loss within hours at a local level (FAO 1994b, Steedman 1990). However, this information on damage was recently considered too outdated or too imprecise, particularly when used for cost-benefit analyses (Krall & Herok 1997), and the economic importance of locusts has been questioned. Some now consider that locusts and grasshoppers are relatively minor pests, even during upsurges, in terms of overall crop losses, although localized damage may be devastating for

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short periods (Rowley & Bennet 1993, US Congress 1990). A model developed by Herok & Krall (1995) attempts to compare the potential damage prevented with the actual cost of intensive control measures against the Desert Locust. They conclude that the strategy being pursued today does not make economic sense in terms of costs and benefits. They ask for a prompt reconsideration of the currently applied locust control strategy (Krall & Herok 1997).

This position is not a new one. As early as 1970, from a large study to determine the economic importance of the Desert Locust, Bullen (1969, 1970) concluded that "locusts and grasshoppers, even at their worst, constitute only a very small proportion of the overall crop protection problem" and asked, "has man been emotionally blinded by the spectacle of locusts' invasions and deluded into believing that they are pests of major importance?"

These conceptions were reinforced by the fact that during the recent invasions in Africa as well as Madagascar, damage was generally considered as low. For example, USAID[4] country reports reveal little overall crop damage by the Desert Locust during 1988, the height of the recent plague, although some localized severe damage was recorded (US Congress 1990).

However, we must not forget that despite all the weaknesses observed in the organization of locust control during the recent plagues, control measures are now much more efficient than in the past. Invasions are better controlled and they last generally for a shorter period of time. Upsurges and invasions observed since 1960 cannot be compared with the invasions during the first part of the 20th century, when control measures were not very efficient. Obviously, recent damage can only be lower than in the past, where we have records of much more severe and frequent attacks. For Roy (2001) to deny the problem and the importance of damage shows a complete lack of knowledge of the reality — in the field, at the level of the village — during a locust plague.

Opposition between these two conceptions currently continues. Locust-affected countries generally consider the problem as a major one (and we can consider that they are in the best position to assess it). Donor countries involved in locust control require, more and more frequently, a better estimate of locust damage and a better justification of control measures.

It is extremely difficult to precisely ascertain crop losses by locusts, although some methods are available (Krall 1994). The cash value of the crops must be taken into account, but also the crops' social value in subsistence agrarian societies. Classic cost-profit analyses are inaccurate in the case of migratory insects, since control operations can be funded by certain regions to benefit very remote regions. It is also necessary to estimate not only the real damage, but also the potential damage avoided by control measures. Considering the difficulties, some believe that "accurate estimates of the benefits of the control are unlikely to be possible in Africa" (Lomer *et al.* 2001).

However, a recent and extensive study on this subject has been realized by Joffe (1998), which provides better estimates of the economic risk regarding the Desert Locust. Although damage is unlikely to pose a threat to global food supplies in any country, on the local scale the damage can be considerable. The probability of annual damage running into tens of millions of US dollars is far from negligible. In addition, damage to pastures is not taken into account in current models. Furthermore, even though the value of lost harvests is low in financial terms, the consequences of plagues can be serious in certain cases and cause significant disruption in the local economy.

All these studies of the economic impact of locusts are far from concensus. They should be considered as a first approximation and they will have to be pursued further. The economic impact of locust control remains a key point, since numerous donors base their financial support on this information. But it remains a controversial issue. This debate did not begin today. At the end of the 19th century, Kunckel d'Herculay (1905) already struggled to justify control operations against the Desert Locust in Algeria. Five large plagues occurred during the 20th century and in one century there were 50 y of plague. The problem is still major. However, risk estimates, reliable and accepted by all, are not yet widely available, and the same problem of economic justification periodically arises.

Lastly, it seems that whatever the cost-profit relation, locusts should and will be controlled since other aspects, particularly social and thus also political, have to be considered, the economic aspect being only one of the elements.

Management strategy for the locust problem.— Over the years, management strategy has been a main focus of controversy. There have been many debates held on which strategy to adopt in order to reduce the economic and environmental costs of locust control to acceptable levels. The current claimed preventative strategy was questioned (Symmons 1997) both on practical grounds — Does it work? — and on theoretical grounds — Can it work?

Many questions were raised concerning the feasibility of this preventative strategy (see *e.g.*, Van Huis 1994ab, Krall *et al.* 1997), such as: Is it possible to have an efficient strategy without dieldrin? What are the consequences of security problems in key outbreak areas? Is it possible to survey large desert areas efficiently? Have we any data concerning the efficiency of the preventative strategy? Do the concerned countries have contingency plans and sufficient resources to conduct the survey and control operations? Will the donor countries continue to support locust control operations? Will it be more efficient to fight the plague instead of the first stages of an upsurge?

In opposition to the current preventative strategy, Krall & Herok (1997) think that control should be focused only on protecting crops and that preventative control measures in the most remote areas should be reconsidered.

As well, some experts have advised the treatment of developing swarms as the most cost-effective option (Symmons 1992, 1997). The proposed treatment is mainly a reactive strategy, trying to solve the problem at the late upsurge/early plague stage. Such a strategy was suggested as early as 1970 by MacCuaig. It was suggested that control operations be delayed until the majority of the locusts are in

[4] U.S. Agency for International Development

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dense and large targets, which would allow a better efficacy in terms of number of locusts killed per pesticide unit and so minimize wasting of pesticide.

An interesting concept was recently introduced: proaction. Between strictly preventative control (locust control occurs at or prior to the onset of gregarious behavior, at the initial outbreak stage) and reactive control (through emergency operation during the plague status, if reached), Showler proposed (1995, 1997) the notion of "proactive control". According to Showler (1997), proaction entails intervention against localized outbreaks before plague status is reached. Proaction relies on early detection of bands and swarms, preferably in breeding areas, and strategic prepositioning of resources. It seems, in fact, that this concept is not very different from the preventative strategy that is currently recommended by FAO and applied by plague-troubled countries, particularly in the western part of the Desert Locust habitat area or in Madagascar against the Migratory Locust.

After many debates over management strategy, the direction currently pursued is the development or the reinforcement of national monitoring and early reaction capacities in order to treat the "dangerous" locust populations as quickly as possible, *i.e.*, to better apply, in a sustainable manner, the preventative strategy (FAO 1994a, 1995, 2001; Lecoq 2000a; Martini *et al.* 1998). Past experience has always shown that the longer we wait, the greater the risk of being overwhelmed by the plague. Furthermore, in regard to the Desert Locust, a comparison of recent control campaigns has shown that early reaction in the first breeding zones is directly linked to better control of upsurges (Showler 2001b).

Finally, after a decade of questioning, it seems that preventative control is still considered to be the most effective option; it is the least costly and the least damaging to the environment, and it is also a strategy which helps maintain and develop the required skills and infrastructures in the countries concerned. This issue is of prime importance, for it can, in the long run, help these countries to manage the locust problem and diminish their dependence on external support (FAO 1994a, 2001; Martini *et al.* 1998; Showler 1997; Showler & Potter 1991).

Monitoring and early warning.— In terms of monitoring and early warning, recent progress has been made in the fields of biogeography, GIS, space remote sensing and communications.

The long remission period made it possible to obtain a much more precise image of the distribution of the plague-generating transient populations. This was particularly the case for the Desert Locust, where identification of potential zones for gregarisation improved: zones which require priority monitoring as part of a preventative strategy (Popov 1997, Popov *et al.* 1991). Therefore, better tools are now available to monitor the most important zones.

Means of communication have undergone improvements, thus benefiting locust control. The locust situation in a given country can now be transmitted via the Internet in data-base form. In addition, FAO signaling and forecasting updates are transmitted by e-mail and available and regularly updated on the Internet.

A great amount has been done in the field of geographic information systems (GIS). It is now possible to integrate into a computer system the various data on locusts and their environment, particularly rains. These data can be better used and interpreted for more effective forecasting. GIS already exists for the Desert Locust. There are two versions; the more sophisticated one, developed on a workstation, is managed by the FAO in Rome and covers the entire breeding area of the Desert Locust [SWARMS, *Schistocerca* Warning Management System]. Simplified versions, which work from portable computers, are being installed in each country [RAMSES, Reconnaissance and Management System for the Environment of *Schistocerca*] (Cressman 1997, Magor 1993, Magor & Pender 1997, Rosenberg 2000). A geographic information system is being developed for the Malagasy Migratory Locust. Along with a forecasting model of risk situations, this should be a real decision-support tool to organize monitoring and treatment operations.

Space remote sensing is also a technology that has brought about substantial advances. For the Desert Locust, satellite data — SPOT VEGETATION, METEOSAT and NOAA satellites — are used to better localize zones of rain and developing vegetation which may favor locust breeding, thus guiding the ground survey teams (Cherlet 1993, Cherlet & Di Gregorio 1991, Voss & Dreiser 1997). Various problems continue to impede early identification of the low vegetational cover typical of the Desert Locust breeding areas. This desert vegetation is often very sparse or very localized, at the heart of small wadis. Much improvement can still be made, but this is a key point. The prevention issue is, above all, a question of information. In both the case of the Desert Locust and the Malagasy Migratory Locust, prevention lies primarily in efficient real-time data entry of field information on the quality of the environment. Ground networks are not sufficient and only more precise interpretation of satellite imagery will bring improvement. Despite a few recent failures, it is one of the directions to pursue and all the more so since technology is constantly evolving and new sensors appearing.

Locust control.—

Main pesticides: as a result of the banning of organochlorines and especially dieldrin, current locust control operations are mainly based on organophosphorous pesticides (such as fenitrothion and malathion), carbamates (such as bendiocarb), pyrethrinoids (such as deltamethrin and lambda-cyhalothrin), but also on more recent products such as insect growth regulators (IGR; *e.g.*, dimilin, triflumuron, fipronil and imidacloprid, FAO 1999). Therefore a wider range of chemicals, less toxic than previous products, especially organochlorines, is available — even though, obviously, they continue to raise risk issues for the environment, particularly in sensitive and protected zones.

Application techniques: application techniques have become more efficient and safer both for operators and the environment. The recent invasion of the Migratory Locust in Madagascar was the opportunity to put this new technology into practice on a wide scale.

Applications are usually made according to the Ultra

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Low Volume treatment technique (ULV), which is certainly the most effective way of applying insecticides (Matthews 1992). This is not a recent innovation, since it dates back to the 1950s. What is new, on the other hand, is the attempt to evaluate and minimize the impact of locust control on the environment. Chemical control generated wide environmental concern, due to the large amounts of insecticides used and to their negative impact on nontarget fauna (Berger & Assoc. 1991, Ritchie & Dobson 1995). Much data relating to this impact have been obtained in Africa, especially through the LOCUSTOX project (Everts 1990; Everts *et al.* 1997, 1998, 1999). In fact, the most harmful side effects could be avoided by following the FAO directives for application and by carefully selecting insecticides (Ritchie & Dobson *op. cit.*). Furthermore, over and beyond the impact of products is the strategy pursued, which is undoubtedly as important, if not more so. The best environmental safeguard is obtained by applying a preventative strategy which, through applications over small surface areas, prevents the outbreak of plagues and thus the need to treat much wider areas.

Undoubtedly the greatest progress made recently was in the precision of application. The use of GPS[5] technology (and especially of differential GPS or DGPS), *i.e.*, a positioning technique guided by satellite, has revolutionized locust control by: 1) securing navigation, particularly in the case of desert zones frequented by the Desert Locust, 2) improving the survey by recording the precise co-ordinates of target locusts and transmitting them to spray aircraft, 3) substantially improving precision spraying. Precision to within a few meters can be achieved both in locating targets and guiding pilot spray aircraft (the GPS guides the navigation of the plane so it follows exactly the desired route to within a few meters, at the desired speed, respecting precisely the width between each passage without using ground beacons) (Figs 4, 5). As far as on-board computing is concerned, it automatically controls the rate of the insecticide and reaches great precision in the doses spread over one hectare. The use of these navigation systems is likely to become general in locust control (Ottesen *et al.* 1999, Dobson 1999).

Another issue in recent years is the reintroduction of barrier applications (Cooper *et al.* 1995, Rachadi & Foucart 1999, Scherer & Rakotonandrasana 1993). It was claimed by many people with responsibilities in locust control that the preventative strategy had been weakened as a consequence of the banning of dieldrin (Roy 2001, Skaf 1988, Skaf *et al.* 1990). The recent launch onto the locust control market of chemicals such as IGR or fipronil, which also present persistence properties, now makes it possible to reintroduce the barrier technique and thus reinforces the efficacy of the preventative strategy.

There are numerous advantages to the barrier application technique: 1) rapid treatment of a much wider surface area (and for prevention, the time factor is known to be fundamental in curbing upsurges), 2) the amount of chemicals spread on a protected hectare is lower, 3) given the nontreated zones between barriers, the impact on nontarget fauna is lower, 4) substantial savings can be made by reducing both flight time and the amounts of insecticide spread.

Efficacy of chemical control: several questions have arisen regarding the efficacy of chemical control to manage locust outbreaks (*i.e.*, Pesticides Trust 1998). However, chemical control methods have shown their efficacy many times over. As was said previously, during the last 40 y, large plagues were prevented and the frequency of upsurges reduced, obviously as a consequence of better chemical control methods (Skaf *et al.* 1990, Roy 2001). At the present time, conventional chemicals still offer the only available and reliable option (Meinzingen & Kooyman 1997). There has never been a confirmed case of resistance, as is sometimes stated (such would-be cases are very often due to bad application techniques). Furthermore, although various natural factors may stop the course of invasions, the results of control operations must also be taken into account. These natural factors played an important role in the early curbing of the Desert Locust plague in 1989; the real impact of massive operations of chemical control remains in this case difficult to estimate and all reported evaluations are still very biased. The positive impact of chemical control can be more easily demonstrated in the case of the recent Malagasy Migratory Locust plague. From 1998 to 2000, as control effort was pursued and better organized, a gradual reduction was seen in the contaminated surface area, and in the number, size and density of swarms. The average size of swarms was 4000 ha in 1998, down to 1000 in 1999, only 250 ha in 2000; swarms were eliminated in 2001 (Lecoq 2000a).

In addition, it was observed that recent plagues, of both Desert and Malagasy Migratory Locusts, ended or were stopped within 2 or 3 y, whereas they lasted much longer in the past (10-20 y). In Madagascar it was the first time an invasion was reduced in such short period (in comparison the previous plague lasted >18 y). Moreover, over the last 40 y, several major upsurges were quickly nipped in the bud, thanks to timely chemical control campaigns. However, despite the efficacy of chemical control, there is still high demand for alternative solutions.

Alternative methods.—

Botanicals: varied research on vegetal extracts (Neem and *Melia volkensii*) have been, or are being, carried out (*e.g.*, Krall & Wilps 1994). They are still at the experimental stage as far as locust control is concerned. Large-scale production is still problematic and difficulties with the registration of a variable product will limit adoption (Meinzingen & Kooyman 1997). The use of such products seems to be aimed at protecting crops locally.

Semiochemicals: Recent research, in particular by the ICIPE[6] teams in Kenya, revealed in the Desert Locust a very rich system of neurotransmitters that act at all levels of the insect's life. At the monitoring stage, the use of pheromones may be considered. Pheromone traps could detect population growth at the transient stage, which is very difficult to study, and thus improve the preventative strategy by better forecasting the outbreak of upsurges. Moreover, pheromones

[5] Global Positioning System

[6] International Centre of Insect Physiology and Ecology

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may be used as a means of control, by making locusts transient and more sensitive to predator attack or by increasing their sensitivity to sublethal doses of insecticide (Hassanali & Bashir 1999). The pheromone phenylacetonitrile inhibits pheromonal communication among gregarious hoppers and induces stress which can lead to high mortality. This pheromone could be an alternative control agent to conventional pesticides. It costs very little per hectare treated and could cut control costs enormously. Field experiments have already been carried out, but there is nonetheless still much to do in this area. Practical applications seem far off and an operational strategy based on the use of such products is still to be defined.

Mycopesticides: currently, the best solution to replace synthetic insecticides is undoubtedly the use of mycopesticides (Goettel M.S. & Johnson D.L. 1997, Lomer & Prior 1992, Prior 1992, Prior & Greathead 1989). These products are composed of spores of pathogenic fungus. The recent development of effective oil formulations of *Metarhizium anisopliae* spores in Africa, Australia and South America, opens up new possibilities for environmentally safe control operations. *Metarhizium* biopesticide kills 70-90% of treated locusts within 14-20 d, with no measurable impact on nontarget organisms (Kooyman *et al.* 1997, Lomer *et al.* 2001). These products act slowly and are thus inappropriate for emergency situations. However, they should have a role in an integrated control strategy alongside classic insecticides (Lomer *et al.* 1999). They are now available on the locust control market and are part of the FAO (1999) list of products recommended for locust control.

Other alternatives: some consider that there has been overemphasis on locust control, mostly using chemical pesticides, and that control of locust populations by chemical or nonchemical means is only one of several options of risk management (Joffe 1995, 1998). Some other alternatives for the locust problem are: 1) do not react and instead use locust control funds to intensify agricultural production, 2) supply food or other more appropriate assistance, 3) have farmers acquire antilocust insurance policies.

Such alternatives are still studied and some consider farmer insurance as a competitive strategy (Krall & Herok 1997, Hardeweg 2001). For many involved in locust control, they nonetheless appear somewhat unrealistic, and little adapted to the economic and social reality of most countries concerned.

An IPM approach ?: a few years ago, it could be said that the ultimate objective of locust control was to adopt an Integrated Pest Management (IPM) approach. During the last 10 y, great progress has been made and now it is possible to apply some of the principles of integrated management to Desert and Migratory Locusts. For this, the following tools are available: 1) a good knowledge of the dynamic of populations, 2) monitoring and forecasting networks to better control the evolution of populations and react in time, 3) models that determine the efficacy and cost of different control options, 4) action thresholds, 5) a diversity in insecticides that makes it possible to select them appropriately to limit impact on the environment, 6) biological products, 7) follow-up methods to monitor the environmental impact of control operations.

Thus, a full range of complementary methods are available, which supposes that we are now progressing towards an integrated approach (in the IPM sense) to the locust problem in Africa.

Recent institutional developments and the sustainability of preventative control

Institutional aspects.— Roy (2001) recently gave an extensive presentation of the institutional aspects of locust control in Africa during the 20th century. In the 1950s many control responsibilities of the colonial period were shifted to FAO, along with the mandate to co-ordinate bilateral and multilateral activities. Newly formed national crop protection agencies and regional organizations supplanted colonial structures as African nations achieved independence in the 1960s. Currently, most affected countries have their own locust unit. FAO plays a key role: it hosts the Desert Locust Control Committee (gathering most of the countries concerned by the Desert Locust), assists coordination of the regional organizations, sponsors three Regional Desert Locust Commissions (Northwest Africa, Near East and Southwest Asia), supports donors co-ordination meetings in case of emergency campaigns, follows the Desert Locust situation, and edits a forecasting bulletin.

As we have seen above, a progressive decline in the efficiency of many locust control services or regional organizations occurs after a long recession period. With the comeback of large plagues by the end of the 1980s, it became obvious that a reorganization of locust control in Africa was necessary. Institutional and political aspects have recently been widely discussed, mainly as a consequence of donor implication in emergency operations (US Congress 1990, Rowley & Bennet 1993). It has been noticed, in particular, that: 1) many countries lack financial resources and trained personnel to fully support their locust service, 2) most institutions, whether African national or regional or donor, are not equipped to deal with locusts on a long term basis, 3) development needs are often sacrificed in favor of crisis management, 4) disputes within, between, and among African countries and donors constrain the effectiveness of short-term emergency programs and longer-term preventative ones.

As a logical consequence of the 1987-1989 plague, mainly due to the gradual weakening of states' capacities to carry out preventative operations, and as a response to the problems perceived during the recent emergency operations, the last 10 y have seen a positive development with an institutional renewal and the reinforcement of regional co-operation. This was largely possible due to the strong commitment of many donor countries.

As far as the Desert Locust is concerned, the most remarkable fact is undoubtedly the launch of the huge EMPRES[7] program initiated by the FAO. One of the priorities of this program is to strengthen the monitoring and control capaci-

[7] Acronym for Emergency Prevention System (Abate *et al.* 1994)

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Fig . 3. Some pictures of the recent Migratory Locust invasion in Madagascar. Swarms : a, b, c d, f (photos M. Lecoq) and hopper band: e (photo J.-F. Duranton).

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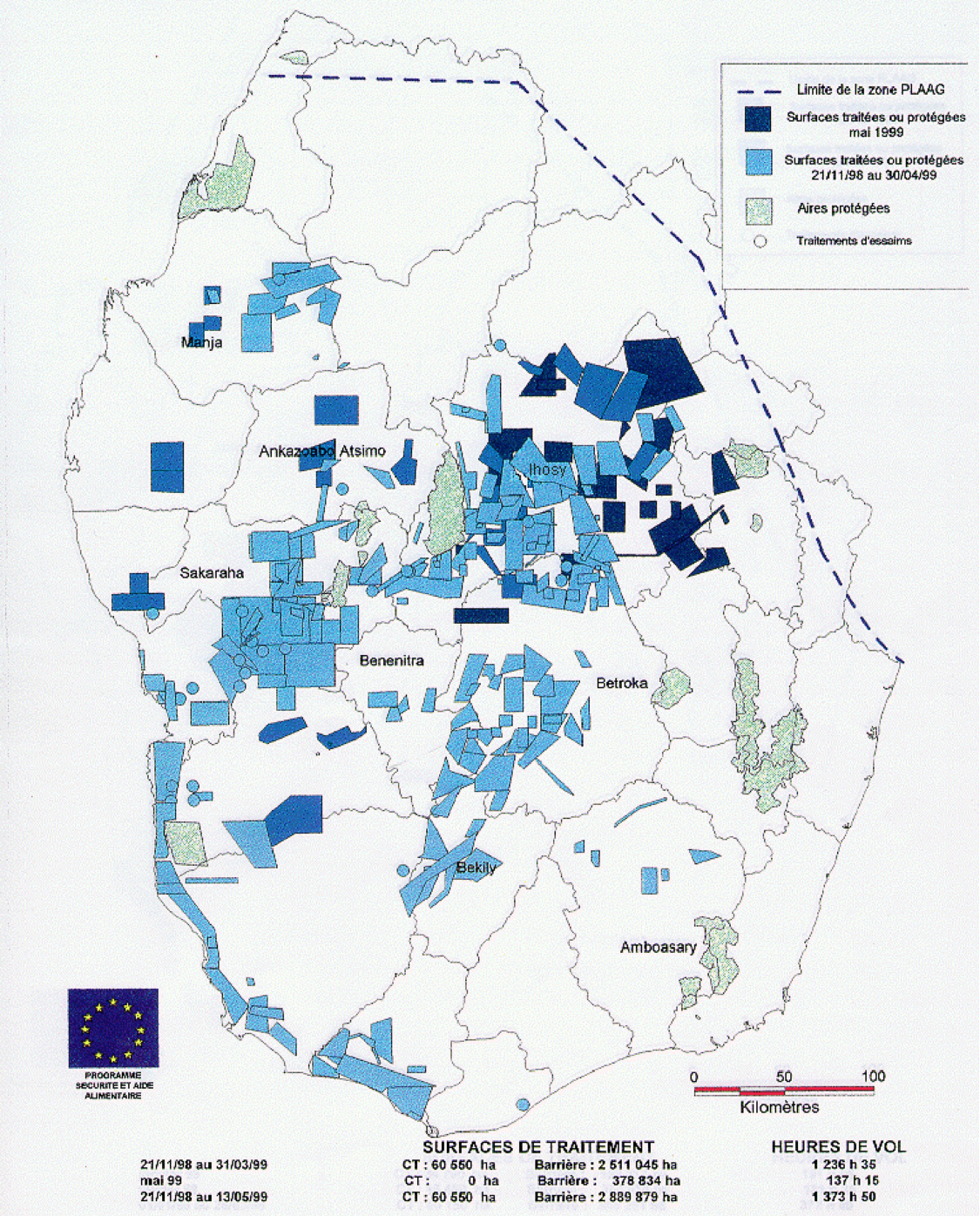


Fig. 4. Map of areas sprayed in 1999 in the southern part of Madagascar: an example of the utilization of the GPS technology in locust control. (Source : J.-F. Duranton, PLAAG - Project for locust control in the outbreak area, and European Union - Food security program in Madagascar). This map of the southern part of the island depicts areas that received locust treatment between November 1998 and April 1999. For each area, details on sprays and the precise route of spray aircraft are available. All areas submitted to special environmental protection have been preserved, as shown on the map. These maps may be quickly and easily sent via internet anywhere in the world, allowing donors to follow current operations. They then can be used as proof of the quality of work carried out.

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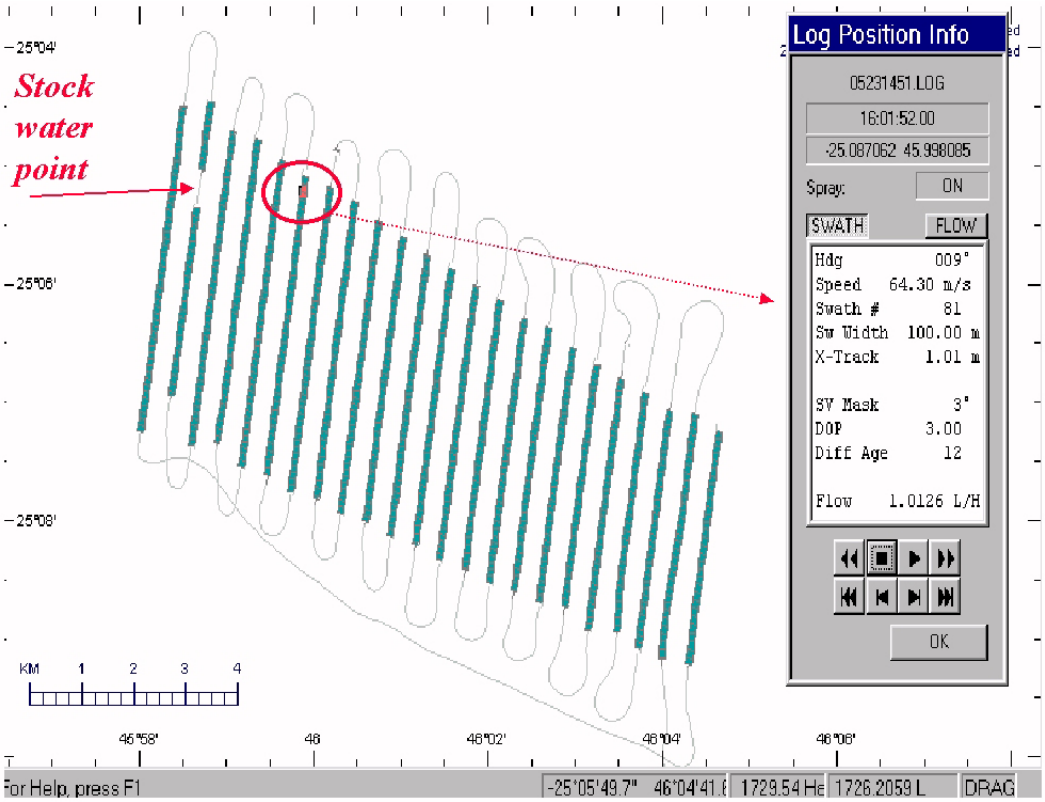


Fig. 5. Recent example of aerial barrier spraying in Madagascar using DGPS technology (courtesy of AGRICAIR, Zimbabwe).

ties of countries in which there are outbreak areas, in order to help them conduct efficient preventative control (Abate *et al.* 1994, FAO 1994a, 1995, 2000; Martini *et al.* 1998). A first component of the program has been operational since 1996 in the central region of the breeding area of the Desert Locust, in countries around the Red Sea. A second component concerns west and northwest Africa and began in 2001.

The other EMPRES priority is the development of regional co-operation. From this point of view, the second important and highly significant event of the last few years is the creation of the "Commission de lutte contre le Criquet pèlerin en région occidentale" (CLCPRO[8]) which, in the long run, should play the role of two former organizations for regional co-operation: the "Commission de lutte contre le Criquet pèlerin en Afrique du Nord-Ouest" (CLCPANO[9]) and the "Organisation commune de lutte antiacridienne et de lutte anti-aviaire" (OCLALAV[10]) for Sahelian countries (FAO 2000, Lecoq 2000b). It is one of the major events in recent years. The Commission created in 2000, should provide much improved cooperation between the nine countries of the occidental region directly involved in the coordination of Desert Locust preventative control. This change in the institutional system is an important factor demonstrating the will of interested states to preserve, with the support of the FAO, an operational system of Desert Locust preventative control.

In Madagascar, after the last plague, positive institutional developments were also made, with the creation in 1999 of a new "Centre National Anti-acridien" (National Locust Center) aimed at replacing the former structure with more independence and wider possibilities of action.

Sustainability of preventative control— Obviously scientific and technical progress, as well as positive institutional development, have been visible over the last decade. A number of indicators show things are moving in the right direction. But are we not making the same mistakes as in the past, mistakes represented by what has been referred to as the anti-locust vicious circle: periods of plague and motivation alternating with remission periods that provoke gradual disinterest? This classic scheme has been regularly mentioned over decades but is, nevertheless, the real and recurrent problem that weighs on the efficacy of preventative strategy. Hence: 1) some donors who fund locust control question the setting-up of a system that will certainly collapse during the remission period, 2) the countries' long-term capacity to bear the weight of the recurrent costs of the preventative control system is also questioned.

How can sustainability be ensured? The following important points should be considered as being vital for sustainability: 1) continuous commitment of the states involved; 2) locust control structures as small as possible, and thus less costly and sustainable for countries involved;

[8] Desert Locust Control Commission for the Occidental Region
[9] Desert Locust Control Commission for Northwest Africa
[10] Common Organization against Locusts and Bird Parasites

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3) a system that can be modulated to the locust situation and rapidly reinforced when necessary; 4) emergency plans for exceptional situations, essential given the extent of lands to monitor and the diversity of those involved; 5) identified reserve funds; 6) in the case of the Desert Locust: coherent regional co-operation both at technical and financial levels (certain countries carry out preventative control without benefiting, others do not, but do benefit); 7) modest, but continuous, funding from donors, for whom an efficient preventative system means less frequent, less costly and better organized emergency action.

Difficulty in ensuring long term support for programs of preventative control from governments and donors is a major problem. Failure to solve it could lead to failure in controlling future upsurges and to the development of new plagues. The support of donors will remain particularly problematic as long as the current debate on the economic importance of locusts and the best pest management strategy is unresolved. The risk is that the differing views of experts, donors and affected countries on the subject will slow down the implementation of coherent actions.

Conclusions

After several decades of a relatively calm situation, the recent return of great locust invasions, in Africa as well as in Madagascar, starting from the end of the 1980's, caused a questioning of antilocust control. As a result, over the last 10 y, much research has been done, resulting in great progress in very diverse fields.

The economic impact of locusts was widely discussed. The studies carried out still remain mostly disputed. They will have to be continued and refined to better take into account the social consequences of locust outbreaks. The essential support of donor countries in locust control now largely depends on a better estimate of the economic and social impact of these insects.

The preventative control strategy, after many debates and the examination of other possibilities, is still regarded as the most effective option. The recent programs of support for affected countries tend to reinforce those countries' capacity to lead preventative control operations. It will, however, be advisable to continue to accumulate data for better documenting of this approach.

The area of application technologies has greatly progressed, particularly with the appearance of GPS technology. In both monitoring and early warning, the greatest need is for better quality of survey information coming from the ground, both on locusts and their environment. Satellite remote sensing should continue to be developed and improved to mitigate the insufficiency of ground observation networks.

With the creation of mycopesticides for locust control the existence of replacement products for pesticides is now a reality. But these products should find their place in complement with traditional pesticides in integrated control strategies that still largely remain to be defined.

Beyond scientific and technical aspects, and despite its recent progress, the future of Desert and Malagasy Migratory Locust control seems now to depend mainly on financial, institutional, and political aspects that cannot be controlled by scientists, but are the true key issues of locust control.

A main problem is the long term sustainability of locust control, which should certainly be better considered and investigated. If solutions to ensure sustainability are not found, any progress made in other areas will be in vain. This sustainability can obviously only be obtained with the regular support (financial and technical) of the donors, an existence of locust control units (smaller but flexible, according to the gravity of the locust situation), and the creation of emergency action plans and emergency reserve funds for exceptional situations at the national level.

At the end of the Second World War, during a period of plague when control methods were much less effective than today, the failure to manage the locust problem was attributed, not to a lack of scientific knowledge and technical means, but to a problem of socio-political organization. Fifty years later, we are still faced with the same situation.

It is advisable to find the financial, social, and political conditions that allow a sustainable, preventative locust control, — undoubtedly more difficult than the realization of simple technical progress. Otherwise, the locust problem will continue to be managed as a series of crises, with all the human, financial, and environmental consequences that crises imply, and that one could observe during recent plagues.

Acknowledgments

We would like to thank the Food and Agriculture Organization of the United Nations for allowing us to follow the development of locust control during recent years in Africa, and in Madagascar through numerous field missions, and to play a modest part in current developments.

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