PLANT PRODUCTION AND PROTECTION DIVISION
LOCUSTS AND OTHER MIGRATORY PESTS GROUP No. AGP/DL/TS/27

DESERT LOCUST TECHNICAL SERIES

FAO/EMPRES Workshop on Economics in Desert Locust Management
Cairo, September 1997

Economic and policy issues in Desert Locust management: a preliminary analysis

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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by Steen R. Joffe

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 1998

CONTENTS

Foreword

The Desert Locust is an international transboundary pest which affects agricultural production and livelihoods in many countries in Africa, the Middle East and south and southwestern Asia. Its migratory nature and capacity for rapid population growth present major challenges for control, particularly in remote semiarid areas, which characterise much of the distribution area.

Studies on the economic and social dimensions of Desert Locust management started in 1995 at the suggestion of a number of donor countries. The work recognises that national and international resources are limited and management efforts need to be economically justified. There is a particular need to pay attention to issues of sustainability. Countries should develop policies, capacity and systems that are effective, reliable and affordable in the long term.

This document explores the main economic and associated policy issues in Desert Locust management based on the best currently available information. Only limited data are available on the crop damage Desert Locusts can cause, and on the environmental and biological parameters that influence the development of upsurges and plagues. Because of these limitations, the analysis uses recognized methods for working sparse data, namely case studies, historical analysis, simulations and risk analysis, in order to provide 'best bet' estimates. The results provide a useful indication of the economic impacts of Desert Locusts and an improved understanding of the interaction between the various environmental, biological and economic factors involved.

The preliminary nature of the analysis needs to be stressed, and there remain many areas for which better data are needed. For example, a more detailed understanding of specific local economic and institutional factors is required, depending upon country specific studies with a high degree of stakeholder participation.

This paper was discussed at a Workshop in Cairo in 1997 and is published together with the findings of the Workshop in order to open up informed debate and to encourage the necessary further work in this field. It is hoped that the analysis will be regarded as a beginning of a process in which economic dimensions are woven fully into Desert Locust management strategies.

FAO is indebted to the author, Mr Joffe for having overseen the collection of the data and its analysis; for having acted as the focal point for economic studies during his attachment to FAO and for having written this paper.

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Proceedings of the FAO/EMPRES Workshop on Economics in Desert Locust Management Cairo, 21-22 September 1997

Introduction

1. The Workshop on Economics in Desert Locust Management was hosted by the Regional Office for the Near East of the Food and Agriculture Organization of the United Nations. It was held in Cairo on 21 and 22 September 1997. Participants came from ten locust-affected countries, five donor nations, from regional locust control organizations, research institutes, interested universities and from FAO (see Annex 1). The workshop was convened to discuss the findings of a preliminary economics study on the losses caused by locust plagues and the economic implications of control operations. The study originated in a recommendation by the 33rd Session of the Desert Locust Control Committee (DLCC) in 1995 that FAO should include an economic assessment within the EMPRES Desert Locust Programme. The study was supported by France, Germany, the Netherlands, the United Kingdom, the United States and FAO.

2. The workshop was opened by Mr A. Bukhari, Assistant Director-General, Regional Representative for the Near East. He welcomed participants and expressed his concern at the risks to agriculture posed by the Desert Locust and the high cost invested in countering them. He emphasized the urgent need to identify improved management strategies that balance costs and benefits of Desert Locust control. He welcomed the initiative of the DLCC in recommending the economics studies that were to be discussed at the Workshop. Mr Bukhari asked participants to consider the findings in the framework of their social and economic dimensions and in the context of experiences of Integrated Pest Management (IPM). He closed his speech by thanking the Ministry of Agriculture of Egypt for their constant support for FAO activities.

3. After the adoption of the agenda, Mr Allan Showler, Coordinator of the EMPRES Central Region Programme, gave a short overview of this programme. He highlighted the main aspects of the EMPRES concept, namely to promote and catalyse the most appropriate tactics and strategies for Desert Locust control in the most economical way. The main responsibility for implementation lies with Central Region member countries. FAO EMPRES, with donor support, is working with these countries to strengthen their capacity to contain locust upsurges.

Economics and policy issues in Desert Locust management

4. Mr Steen Joffe, Lead Technical Adviser, Desert Locust Economics, presented the preliminary results of the study, ‘Economic and policy issues in Desert Locust management: a preliminary analysis’. A main finding of the study is that the circumstances under which the Desert Locust poses a severe risk to livelihoods and food security are unusual. The results generated by an economics model appear to indicate that control can reduce the risk substantially but that control operations are currently an uneconomic proposition in most circumstances. In principle, the efficiency of control could be improved by understanding farm level risks better and employing a more selective management response. This will require improved information flow and decision tools. There may also be scope for complementary tactics such as insurance or other risk mitigating measures. These aspects deserve further evaluation through field studies.

5. In the discussion following the presentation, four main themes emerged: the quality of data used; the appropriateness of simulation modeling; the need for affected countries to participate and the imbalance in the study between market and subsistence agriculture. The workshop sought clarification on whether poor data quality had affected the validity of results. It was pointed out that historical damage data include reports of questionable accuracy. Authors working on cost-effectiveness studies also identified constraints in the availability and quality of data. Mr Joffe stressed that much effort had been put into obtaining datasets and using methods that could provide a fair assessment and avoid any systematic biases in the study. Some participants found the use of a simulation model problematic. They felt that the information provided did not describe the model sufficiently well for them to interpret the results. The workshop felt it important to ensure that full details of the model are made available for further development and

validation. The general conclusion was that the main emphasis, in the future, should be on collecting new and better data from field studies and evaluations.

6. The workshop stressed that affected countries need to participate in designing information systems to guide economics studies and to develop decision tools.

7. The workshop questioned whether the analysis had the right degree of emphasis between market oriented and subsistence agriculture, suggesting there was too much emphasis on the former. It was felt that the analysis had not sufficiently explored the social factors and food security implications of Desert Locust crop damage and that the analysis was biased by the concentration on market oriented agriculture. It was also felt that food security impacts may not be measured well by cost benefit analysis. Key issues for participants were how to identify circumstances threatening local food security and what was the most cost effective response to them. They suggested that useful links might exist with related work on food security monitoring.

8. Some participants felt that losses caused by Desert Locusts in pastures were not adequately addressed and should be included in future studies.

9. The workshop sought clarification on whether the analysis should refer to benefits and costs specifically of *preventive* control as this was not the predominant mode of control during the study period. Progress was being made towards a more cost effective response. The workshop agreed that the analysis should refer only to ‘control’.

10. The general conclusion was that the analysis offers many useful findings but that it should be considered preliminary and not definitive. The analysis points the way towards a better incorporation, in future, of economic and social dimensions in management strategy. The analysis also highlights the priority of obtaining concrete data from detailed field studies.

Campaign evaluation

11. Mr Butrous summarized results of Desert Locust control evaluations undertaken in Eritrea, the Sudan and Yemen earlier in the year (1997), and included additional information from Saudi Arabia. He gave a brief review of survey and control methods, as well as the resources of the countries concerned. He then discussed modalities for conducting survey and control operations. He described a number of constraints and made recommendations.

12. Mr Said Ghaout gave a short presentation of the approach on campaign evaluation in Morocco and the lessons learned.

13. The workshop suggested that in the future that all control campaigns should be evaluated. These evaluations should amongst other goals provide a better picture on the effectiveness of the impact on the Desert Locust populations. The question of how to fund these activities was raised. The representative of GTZ gave an example of having given technical support to campaign evaluations in Malawi, Mauritania and Mozambique. The Swedish Cooperation Agency’s (SIDA) representative said that, in principle, Sweden may be interested in supporting campaign evaluations in the future.

Damage assessment

14. Mr Krall and Mr Pantenius covered different approaches to damage assessment, and the opportunities and constraints for assessing Desert Locust damage. They reviewed a variety of alternative approaches relating to pests of semi-arid zones that could have relevance to Desert Locust studies. They described a method for a rapid damage assessment developed in Niger on pearl millet.

15. Participants discussed the distinction between damage and crop losses. They felt that losses are best defined by their effects on final yield, and noted that these tend to be related to the type and timing of the physical injury. They also noted that the income effect felt by the farmer, depends on farm management choices and socio-economic factors as well as crop loss. Consequently, they decided that damage assessment may better be termed impact assessment and felt that new ways of undertaking assessment through interdisciplinary rapid rural appraisal approaches could have relevance.

16. The workshop then discussed Desert Locust impacts in the context of assisting farmers to manage risks. To what extent should Desert Locust impacts be understood in relation to other on-farm risks, decisions and priorities? Other on-farm issues mentioned were water and nutrient management and drought related risks.

17. Participants raised the question of the severity and impact of pasture losses. Different views were expressed on whether competition exists between Desert Locusts and livestock. Evidence was cited suggesting that nomads do not always perceive control to be advantageous because chemicals can contaminate grazing. The workshop agreed that further field work is necessary to understand these questions.

IPM and the Desert Locust

18. The Chairperson welcomed the participation of Mr Kenmore of the Global Integrated Pest Management (IPM) Facility at the workshop.

19. Mr Kenmore described progress made in IPM towards a major policy shift away from reliance on chemical management in crop protection. He showed a number of examples of how progress was made by involving policy makers and other stakeholders directly. He also emphasised the central importance of farmer training and of the role of farmers as decision makers.

20. Participants highlighted a common thread between the IPM experience and FAO EMPRES schemes to work with and involve farmers and nomads. Of particular relevance was the scheme to provide a complementary means of monitoring Desert Locust breeding areas. They cited studies already underway in Egypt, Eritrea, Ethiopia, Sudan and Yemen. The workshop endorsed the importance of involving and gaining the support of all stakeholders.

21. The wider relevance of the IPM experience to Desert Locust management was raised, because the migratory nature of the Desert Locust poses particular problems. The example of work with villagers to map and define risks posed by *Locusta migratoria* in the Philippines was cited as one example of IPM working in a related context. More broadly the point was made that farmer based strategies could also embrace complementary means to combat risks and strengthen the farmer’s hand against the Desert Locust. In common with the IPM experience, it may be considered that Desert Locust management is at a stage of starting to develop towards a knowledge and information based strategy with less reliance on chemical management.

22. Some participants asked if a move away from a chemical based strategy for Desert Locust management might create risks for farmers and demands for compensation. In the IPM experience this question was also raised, although the need for compensation has never arisen.

Future economic studies

23. Mr Joffe began by summarizing the previous day’s discussions on the findings of the preliminary study. He highlighted the need for further detailed analysis on risks, costs and benefits of Desert Locust control operations and stressed that better data and a better

understanding of socio-economic dimensions were required. He emphasized the importance of the different stakeholders participating in Desert Locust management. Finally, he introduced some preliminary ideas for future studies that were to be considered by a working group later in the day. Their conclusions are at Annex 2.

24. Ms Bedouin presented the general findings of the economic study in the context of disaster management. She stressed the need for a better understanding of vulnerability to disaster. She emphasised the importance of conducting vulnerability assessment in areas at risk because they form the basis for country specific risk monitoring systems and disaster management schemes. She felt that Desert Locust control should be viewed as part of an integrated disaster management strategy comprising a whole range of measures relating to prevention, preparedness and response. She suggested that measures considered should be examined for their cost-effectiveness. This would lead to the issue of resource allocation and the need to seek innovative means of financing Desert Locust management.

25. In the discussion that followed, participants stressed the humanitarian dimension of this approach. They also identified the operational challenges raised as: concentrating more on local case studies and increasingly involving the affected rural community in the Desert Locust prevention strategy.

26. Participants stressed that the purpose would not be to replace Desert Locust control, but to broaden the strategy to embrace novel and complementary approaches. They felt that it should be possible to learn from examples of risk management in which community based approaches or insurance schemes were part of the available tactics.

27. Mr Fleischer summarized an approach to economic studies of Desert Locust management through micro case studies. He underlined the need for farmers' involvement to find appropriate solutions for local as well as regional problems. Some participants raised the concern that public goals often overshadow farmer perceived needs and local strategies. Mr Fleischer also emphasized the need for better information including a comprehensive assessment of Desert Locust control costs and negative impacts of operations on the environment. He described possible case studies in Eritrea, designed to fill knowledge gaps on economic losses and to examine the potential for effective risk management and self help. He noted that GTZ had approved funding for such studies.

28. In the discussion, it was mentioned that donor pesticide contributions to Desert Locust control might sometimes undermine efforts to promote IPM or cause a build-up of obsolete pesticides. Donors should, therefore, consult with FAO before approving large shipments of pesticides. A question raised was how to encourage farmers' involvement? Participants felt that the idea of undertaking case studies with farmers and nomads was a good way forward. They emphasised the importance of close contact and discussions with all parties concerned before such studies begin.

29. Mr Wiktelius, Mr Belhaj and Mr Forsund focused on the economic assessment of environmental impact that is the proposed contribution of the Swedish Government to EMPRES. They first discussed the need for further information on the direct and indirect effects of control campaigns on the environment. Then, they outlined draft proposals for filling these gaps. They presented the first results from a contingent valuation survey carried out in Ethiopia and a possible model to integrate economic assessment of environmental impacts.

30. During the discussion that followed, Mr Wiktelius mentioned that the budget for the support of environmental impact studies had not yet been approved by SIDA.

31. Participants were then invited to suggest how to define future goals for enhancing the role of economics in Desert Locust management. They were asked to prioritize future tasks and to suggest how the identified objectives may best fit into the EMPRES programme. The following items were identified as future priorities:

- to start cost-benefit analysis of control campaigns;
- to develop a general and simplified crop and pasture loss assessment methodology, that is applicable to different conditions;
- to carry out field and case studies with farmers and nomads;
- to understand the environmental impact of Desert Locust control operations better;
- to include food security dimensions in the context of risk management;
- to evaluate alternatives to chemical control;
- to evaluate the economic benefits of different strategies and tactics.

32. Participants were concerned to formulate practical goals and ways of reducing the cost of control operations. They again emphasized the need for better cooperation with farmers and nomads in the context of Desert Locust management.

33. The workshop agreed that economics could contribute usefully to assessing effectiveness of different tactics and they stressed that the importance of social and humanitarian aspects should be borne in mind.

Annex 1

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Working group recommendations

Goal
Improve Desert Locust management by fully incorporating economic, social and environmental information.

Outputs
1. Practical information on economic, social and environmental factors relevant to sustainable Desert Locust management at local, national and regional levels.

2. Optimal and practical approaches to risk management including novel ones.

Activities

- Establishment of protocols and collection of better information on impacts of Desert Locust infestations and costs of control.

- Case studies and farmer, nomad and village surveys to establish costs, benefits and strategies from a local perspective.

- Studies on food security and risk management dimensions.

- Investigation of economic dimensions of Desert Locust management tactics and how these relate to strategy.

Coordination
These outputs and activities should be coordinated through FAO/EMPRES.

Economic and policy issues in Desert Locust management: a preliminary analysis

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The findings, interpretations and conclusions expressed in this paper are entirely those of the author and are not necessarily those of FAO or of other funding agencies. This study was supported by Ministère de la Coopération et du Développement, France; Federal Ministry for Economic Cooperation and Development (BMZ), Germany; Directorate General for International Cooperation (DGIS), the Netherlands, Ministry of Foreign Affairs; Department for International Development, UK; United States Agency for International Development (USAID); the Arab Organization for Agricultural Development and by FAO.

Contents

List of figures

List of tables

List of boxes

Technical annexes

Acknowledgements

Funding sources

FAO wishes to express its gratitude for the financial and technical support received from the following governments and agencies:

- France, Ministère de la Coopération et du Devéloppement;
- Germany, Federal Ministry for Economic Cooperation and Development;
- The Netherlands, Directorate General for International Cooperation;
- United Kingdom, Department for International Development;
- United States, United States Agency for International Development;
- The Arab Organization for Agricultural Development.

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The author wishes to acknowledge the contributions and advice received from the following people. Without their contributions the study would have been impossible.

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Executive summary

Since early in 1996, FAO has been undertaking a programme of studies on economic and policy issues in Desert Locust management. These studies were started following discussions with stakeholders who identified a need for better incorporation of economic dimensions in management strategy.

This study represents one key stage in that process. It responds to the widely acknowledged need for a document to collate and analyse the best currently available information in this sphere. Given the quality of available data, this report does not attempt to arrive at specific recommendations for Desert Locust policy or control strategies. Based on broad consultation, the analysis uses field case studies, literature review, historical analysis and simulations to arrive at 'best bet' estimates relevant to the following key policy issues.

- The scale and distribution of the economic threat posed by the Desert Locust. Who is affected and by how much? What are the risks in terms of impacts on the livelihoods and food security of those affected?

- Is Desert Locust management as currently practised an appropriate response to the economic risks posed? How do the economic benefits of control campaigns look in relation to the costs?

- Are there other practical policy responses available to affected countries to reduce risks, which would compete with control in terms of effectiveness and costs?

Main findings

The Desert Locust has the capacity to cause substantial damage to agriculture but the circumstances under which this will occur are unusual. Historical analysis indicates that damage caused by Desert Locust attack shows great variation. Serious impacts are rare on a national scale but can occur locally and for particular subsectors of the community. Simulations using current agricultural data suggest that economic impacts of a hypothetical uncontrolled plague would usually have minor effects at a national level in terms of percent normal production and associated price effects.

The economic impacts associated with the presence of Desert Locust populations depend both on the locusts' behaviour and the nature and dynamics of the affected economy. A significant threat to rural food security may occur if a Desert Locust population causes severe and widespread impacts in marginal subsistence areas at a time when they are vulnerable to production shocks.

Under 'favourable' conditions, control campaigns can be expected to prevent most damage that would otherwise have occurred in the event of a plague. Control may sometimes be hampered by logistical and other constraints (e.g. low detection rates, spray efficiency). In this case significant economic damage may still occur.

Surveillance and control campaigns are capable of reducing risks substantially but, in general, will only be an economic proposition (i.e. generate net economic benefits) if they successfully prevent severe economic or food security impacts. Such impacts are unusual.

Countries with substantial production in areas subject to Desert Locust infestation, particularly high value export crops, e.g. Algeria, India, Morocco, Pakistan and Saudi Arabia have a major economic interest in regionally effective preventive control. They are currently the primary financiers of Desert Locust management and are largely selfsufficient in this respect.

For many other affected countries, that have relatively low values of production at risk, the results of the analysis indicate that the net benefits in economic terms will rarely justify

expensive control efforts. In terms of food security, control efforts will usually be an ineffective means of targeting the most vulnerable, with the benefits of control often being captured largely outside the rural sector.

Conclusions

The findings suggest that current strategies are highly risk averse and that affected countries and the wider international community are absorbing substantial net economic costs.

The challenge for the future is to improve understanding of the dynamic and highly variable economic risks associated with Desert Locust and find new and cost effective strategies to match risk and response in a more efficient way. There is significant scope for affected countries, donors and other stakeholders to work together and:

- develop decision tools and tactics which allow a more selective and progressive strategy based on an assessment of economic risks;

- explore all available short and longer term risk management instruments in an integrated way, including insurance and community based approaches as appropriate;

- look anew at sustainable financing mechanisms which match risks and benefits for affected countries, with a key role for countries with dominant economic interests in preventive control.

Appropriate interventions are likely to differ from context to context and country to country. A better understanding of economic benefits, costs and management options from a local perspective, based on appropriate case studies, surveys etc., is a priority for the future. This information will both help affected countries to identify appropriate capacity and systems, and enhance the development of national and international strategies that balance the valid issue of domestic self interest with wider transboundary concerns.

Making progress in these areas will necessitate looking beyond conventional approaches. There is a need to seek new disciplinary and professional alliances with social scientists, risk management and food security specialists; also to work closely with farmers, nomads and other stakeholder groups.

Next steps

This analysis was discussed in Cairo on 21 22 September 1997, at an FAO EMPRES Workshop on Economics in Desert Locust Management, by representatives of ten affected countries, five donor nations, biologists and economists from FAO, regional organizations, research institutes and interested universities.

A Working Group within the Workshop recommended that studies on economic and policy aspects of Desert Locust management continue under EMPRES (Annex 1) with an emphasis on field work. A Next Steps Framework for future action has been drafted. Two major themes are proposed. The first concerns the need to generate better information and decision tools for evaluating the actual economic risks posed by the Desert Locust to affected communities, including the costs and effectiveness of all practical interventions. The second recommends working in a ‘bottom up’ way to evaluate local level risks and options as the basis for sustainable national and international intervention strategies.

The Next Steps Framework will now be further elaborated and put to stakeholders as the basis for a continuing initiative. This will aim at ensuring that economic, social and environmental dimensions are fully incorporated into future Desert Locust management strategies.

Introduction

The FAO programme Economics in Desert Locust Management was started in 1996 and responds to a widely identified need for incorporating economic dimensions in management strategy. The aim is to provide decision makers in governments and donor agencies with improved knowledge, data and methods for the economic evaluation of Desert Locust interventions.

This report represents the first key step in that process. It aims to fulfil the widely acknowledged need for a document to pull together the best available current information in this sphere. Given inherent problems in the data identified during these economics studies, this report does not attempt to arrive at specific recommendations for Desert Locust policy or control strategies. The report sets out preliminary findings on the economics of Desert Locust management, identifies gaps in knowledge and prioritises future studies.

The findings summarised herein represent the combined efforts of a number of collaborators, who are acknowledged in Box 1.

Policy issues

A good place to start on a study on economic aspects of Desert Locust management is to ask some basic questions about the nature of the problem and available policy responses.

- We need to know about the scale and distribution of the economic threat posed by the Desert Locust. Who is affected and by how much? What are the risks in terms of impacts on the livelihoods and food security of those affected?

- Is Desert Locust management as currently practised an appropriate response to the economic risks posed? How do the economic benefits of control campaigns look in relation to the costs?

- Are there other practical policy responses available to affected countries to reduce risks, which would compete in terms of effectiveness and costs?

Coverage of this analysis

Farmers in affected areas have always lived with the threat from the Desert Locust as one of the sources of risk and uncertainty affecting their livelihoods. Well documented examples exist of Desert Locust swarms causing substantial losses and sometimes food shortages (see case studies on the Sudan and Ethiopia in Annex 5).

Events such as these have contributed to the fearsome reputation of this pest, but since they are not common, there is no reason to expect calamitous events during every future upsurge or plague. A database of historical damage compiled by the Natural Resources Institute, UK (Annex 7) shows that damage is often scattered and fragmentary, and that large locust populations often develop without causing significant damage.

This degree of uncertainty poses a real problem for decision makers. Despite the great improvements that have been made in the sphere of forecasting, there is little guidance currently available on the real extent of the economic problem associated with any particular status of the Desert Locust population.

The current strategy of outbreak and upsurge control aims (FAO 1995a) to destroy all 'dangerous' populations in order to try and prevent large swarming populations or plagues developing. 'Dangerous' is usually interpreted as meaning gregarious or gregarizing populations, but is sometimes extended to include all numerically large populations, irrespective

• Box 1 Principal sources of data and advice

Studies of control costs and effectiveness

Algeria:	B.Chara	**Morocco:**	S. Ghaout
Eritrea:	Woldu Teklegiorgis	**Sudan:**	Abdallah Ali Abdallah
Mali:	L. Soumaré	**Yemen:**	S.A. Ba-Angood and Abbas A.A. Mughni
Mauritania:	Mohamed. A.Ould Babah.		

A. Harvey (1997) produced a summary analysis (Annex 4)
P. Gruys and L. McCulloch provided expert technical assistance.

Other commissioned country case studies:
Nurein (1995) Study on the economic significance of Desert Locust in the Sudan
El-Gammal (1995) The economic significance of the Desert Locust in Egypt.

Donor financing
Countries responding to a request for information on financing of Desert Locust management: Canada, Germany, Luxembourg, Netherlands, Norway, Switzerland, UK, USA (see Annex 4).

Population parameters
J. Magor led studies on population dynamics that form the basis for parameter estimates used in this analysis (Annex 6).

Historically recorded damage
Case studies and a database were compiled by NRI, UK (Annex 5 and Annex 7).

Simulation model
A dynamic simulation model was developed by D. Vanzetti and others, suitable for analysing the economic benefits and costs of Desert Locust control (Annex 3).

Crop vulnerability index
An updated GIS-based version of FT Bullen's original crop vulnerability index was produced by J. Rutter (NRI) and FT Bullen (Annex 8).

Environmental economics and the Desert Locust
The above review paper was commissioned from Mohammad Belhaj, Finn R. Førsund, Åsa Lundberg and Staffan Wiktelius (Annex 9).

Socio-economic valuation of Desert Locust risk
D. Vanzetti advised on the welfare analysis. A. Harvey produced a review paper on conceptual aspects. Earlier work was undertaken by W. Ellenbroek.

Peer reviewers and principal sources of written comments and advice
FAO: R. Bedouin, S. Bie, J. Cooper, K. Cressman, J. Dixon, C. Elliott, A. Hafraoui, B. Huddleston, P. Kenmore, R. Marsili, G. Pantanali, D. Wilcock.

External: J.T. Awad, S. Chandra, L. Coop, S. Krall, R. Lamboll, J. Pender, L.J. Rosenberg, J. Seaman, D. Swanson, P. Symmons, A. Van Huis, H. Waibel, D. Wright.

of their phase One of the aims of this study is to try to estimate the economic benefits and costs associated with defined locust scenarios that are compatible with the current strategy.

When considering benefits and costs of control, we have to take into account distributional issues. Firstly, between countries: amongst those countries within the Desert Locust distribution area are some of the poorest and least food secure in the world; there are also a number of middle income countries with more substantial resources that can be brought to bear. Secondly, within national borders, any impacts on agricultural supply will filter through the economy via price effects, with differential impacts on different groups. Those directly affected may lose a significant part of their on farm income; subsistence farm families may lose a large part of their food supply for that season; it is normal to see requests for emergency assistance for Desert Locust management justified on the basis of a threat to food security.

Another aim of this study is to try to shed some light on these distributional issues; in particular the circumstances under which Desert Locust damage can be expected to threaten livelihoods and food security of the most vulnerable.

A third policy area of some importance concerns the environmental and health impact of control activities. In the context of an economic analysis, we are interested in the extent to which our valuation of the net benefits of control should be adjusted to 'internalise' these effects. This whole area is already the subject of ongoing work by the FAO LOCUSTOX Project; *here we briefly review some of the available information on health and environmental aspects of Desert Locust management and potential contributions of economics to this field.*

Regarding alternative or complementary policy responses to the Desert Locust, it was not possible in this preliminary study to do justice to this topic. In the conclusions we suggest that there are sound reasons for undertaking a more considered analysis as a follow up activity.

Methods

There are large holes in the data needed to undertake studies on Desert Locust economics; existing datasets and analyses of basic relationships between population size, crop damage and control effectiveness are highly incomplete where they exist at all, reflecting in part the low priority which economic considerations have received in the past.

The first priority, then, was to identify and assemble datasets that would provide a workable basis for analysis. This was done via a number of individual component studies including those undertaken in Algeria, Egypt, Eritrea, Mali, Mauritania, Morocco, the Sudan, and Yemen. The full set of studies is listed in Box 1.

Even with the improved data it remains clear that the quality and coverage of the information require that some compromises be made in the analytical approach. The first and obvious one is to reject the idea that a single unifying 'solution' is or could be available. The considerable unpredictability of Desert Locust ecology and behaviour, combined with the variation in the affected economies, mean that there is a large range of possible outcomes associated with any particular 'Desert Locust situation'; average values are of limited usefulness. At the same time, decision makers will differ in their perceptions and attitudes to risk and may have different views about the appropriate action to take (Anderson and Dillon, 1992; Dixon et. al., 1989).

In these circumstances our principal methods: case studies, historical analysis, simulations and risk analysis, were chosen as the most appropriate means of working with the sparse data available, and as a useful means to explore issues about decision making, given uncertainty about potential economic risks, costs and benefits.

In order to integrate the data from various sources in a usable way, and as an aid to the policy analysis, a simulation model was developed called Economics of Desert Locust Simulator (ELS). The model allows the user to generate population dynamic sequences over a period of 60 months, intervene with control measures, and assess likely levels of damage across 40 locust affected countries in the four main Desert Locust Regions (see Figure 1 and Table 25). To ensure transparency, the model has been designed to allow the user to experiment with different settings for key parameters such as detection rates, costs, etc., according to their own data or beliefs. A description of this model is attached as Annex 3.

The results set out below reflect the best available data and expert opinion; they represent our best estimates of the scale and nature of economic risks posed by the Desert Locust and the chances of achieving economic control within different plausible scenarios.

Some notes on methodology

Damage potential

By this we mean the levels of damage that would occur in the absence of organised efforts at regional population reduction (see also ‘control strategy’ definition below).

One key source of information was an analysis of historically reported Desert Locust damage by country and year in terms of its frequency and relative severity, in relation to different scales and duration of infestation. From these data we get a useful picture of the nature of the damage that might occur in modern times during an ‘uncontrolled’ upsurge and plague sequence.

Quantitative analysis of Desert Locust damage potential must include very clear and defensible assumptions about population dynamics. For this analysis, population dynamics were simulated by ELS over five years based on parameter values estimated from 1940 -1969 data. The result is effectively to mirror the conditions during a period in which environmental conditions supported development of regular and sizeable plagues. This approach was chosen in order to ensure that the study includes risks associated with very large Desert Locust populations (and also because there are available damage data for the same period).

The simulated populations were then distributed by the model according to probabilities derived from the relative frequencies of reported Desert Locust incidence (again 1940 -1969). Where the populations coincided with areas known to be cropped, they were assumed to destroy some part of the production of those crops, depending on the size of infestation in relation to the cropped area.

’Damage’, impact and welfare analysis

The economic impact of any losses should properly be measured in terms of the difference in household incomes with or without Desert Locust attack. This is not the same as simply multiplying estimated physical crop loss times market price, which method will tend systematically to overemphasise the likely economic impacts of damage. One reason for this is because end of season crop yields may recover, depending on the nature and timing of attack[1]. Also, the method fails to account for the way that farmers and wider communities will in practice manage risks by adjusting livelihood strategies before, during or after the event (e.g. replanting, substituting between enterprises, releasing stocks or selling assets, earning off farm income, transfers, etc.); also even remote agricultural areas are likely to see some supply response from neighbouring areas in the event of shortages and price rises.

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[1] . Yield loss from defoliation, the most common form of locust damage, depends on when the crop is defoliated. In cereals, loss may be complete at the seedling stage, although farmers will usually be able to adjust farm management strategies to some extent at this stage. Losses become high again if the plant is damaged after the ear emerges. Yield may be unaffected during the intervening vegetative period. Bullen (1969) summarised the likely effects on frequently damaged crops: wheat, barley, maize, sorghum, pennisetum, rice, sugar-cane, citrus, coffee and cotton.

For this global analysis we have necessarily adopted the simple method (multiplying estimated crop loss by price) despite the drawbacks, because the more comprehensive approach requires detailed local information which was unavailable. Welfare impacts are then estimated for a general scenario of losses to domestically traded goods for which demand is inelastic to price changes and supply response is weak; alternative scenarios are discussed in the event of losses in the export or subsistence subsectors. The latter scenario acknowledges that impacts may be poorly measured by price effects and focuses on identifying the conditions under which social and food security impacts could be significant. Future work should include local level case studies in which economic costs and benefits can be evaluated on the basis of actual information on supply and demand, impacts of production shocks and available management strategies.

Control strategy

The interventions referred to here as 'control' relate to publicly funded surveillance and control campaigns. There is no account for private actions and adjustment strategies by affected communities themselves. This latter subject is an important area for future work and could lead to an improved understanding of ways to assist affected communities.

The analysis cannot and does not delineate or comment on the merits of alternative technical strategies. The simulations are based simply on costs and effectiveness of organised campaigns to 'remove' Desert Locusts from a regional population. Simulation parameters approximate a preventive strategy since control is initiated at an early stage, when a regional population is defined as still being in recession (for parameter values see Annex 3).

Data on costs are based on case studies undertaken by affected countries covering the ten years between 1987 and 1996. Estimated per hectare control costs and fixed costs provide parameter values from which ELS generates quantitative estimates of regional and global control costs over a simulated five year period. These estimates are shown to be consistent with the available field data on total control costs.

Economics of Desert Locust Simulator, ELS

The scarcity of good quality data ensures that ELS will be subject to some errors and biases. These are discussed in Annex 2. Overall, the combined effect of the various known or potential sources of bias is to suggest that the results presented here are fair at a regional and global scale. The model is well suited to evaluating and comparing costs and benefits in the context of scenarios which the user can define on the basis of appropriate parameter values. It is not suggested that the model, in its present form, should be used as the basis for absolute predictions of damage for individual countries or crops.

In general the use of bioeconomic simulations could be a valuable tool for decision makers in Desert Locust management. On a national level, such models could provide the means of comparing the costs of control operations with the expected short term effects on population reduction and benefits in terms of the value of saved crops.

Bodies like the FAO Desert Locust Control Committee or the FAO Regional Commissions for Controlling the Desert Locust might find regional or global risk analysis useful. There are several outputs of the model which could be of importance to such bodies. For example, a comparison of the average control costs in a given country or region with the benefits it can expect from effective preventive control could be the basis for discussions on how regional and international cooperation in Desert Locust management could be improved.

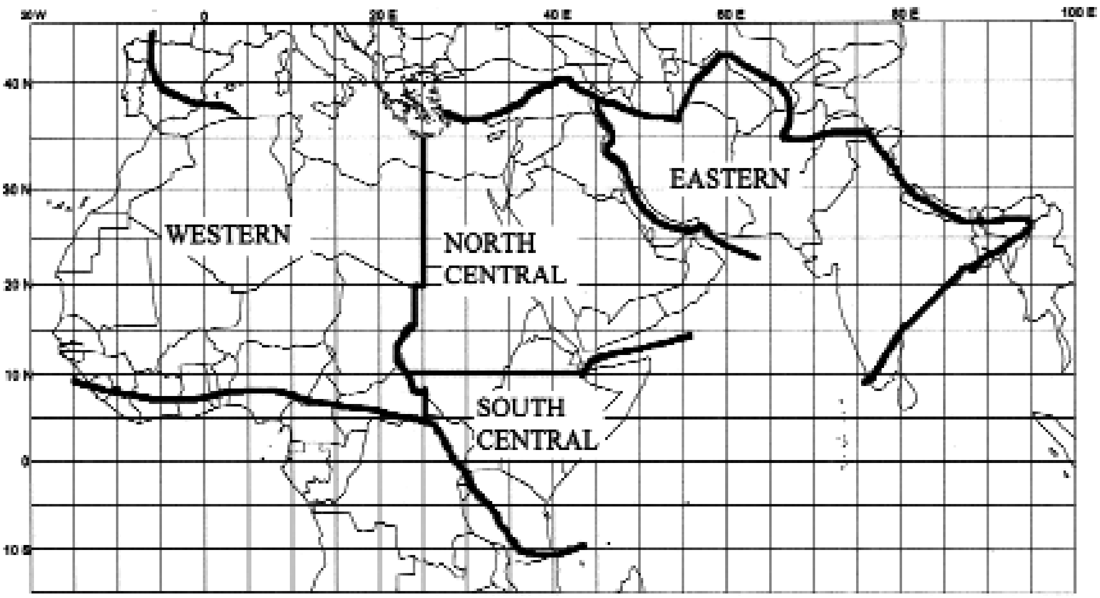
Data and assumptions

Population dynamics

The data and assumptions used to estimate population sizes and migration patterns were drawn mainly from a review study on population dynamics parameters led by J. Magor (see Annex 6). They were supplemented by written comments from P. Symmons. A detailed description of the methodology used to estimate populations is included in Annex 3.

Populations in each of the four main Desert Locust regions (Figure 1) are assumed to range between 10^7 and 2×10^{11}. Equivalent, at a mean density of 50/m^2, to up to 4 000 km^2 (400 000 ha) of swarms. Populations can be in any of four numerically defined levels or states – recession, low, medium and high. The population in each region grows or declines seasonally according to randomly determined growth rates estimated on the basis of historical records for 30 years between 1940 and 1969, and move between regions along seasonal migration routes.

Figure 1 *Desert Locust invasion area and regions*



Control costs

Data and assumptions regarding control costs and effectiveness are drawn primarily from a synthesis of campaign evaluation case studies (as listed in Box 1) undertaken by A. Harvey (see Annex 4). These were checked against relevant literature (e.g. Van Huis [ed.] 1994) and available expert opinion on the subject. A summary of control costs from the country case studies is given below in Table 1.

Total costs

The total costs of Desert Locust management (in 1990 US$) were estimated for the ten year period 1987 to 1996. For the case study countries, these range from around US$3.2 million in Yemen to US$129 million in Morocco.

When all available donor financing data were included (see Table 33) the overall ten year total for (primarily) the case study countries totalled US$376 million (1990 US$), or about US$38 million *per annum* on average. This total includes a small amount of aid benefiting other countries, and US$14 million intended for both locust and grasshopper control. The degree of self-financing varies, ranging, for those countries where data are available, between 12 percent (Mauritania) and 95 percent (Morocco).

It is not known to what extent these data are representative of the Desert Locust-affected countries as a whole. Considering that the Saudi Arabia figures are known to be incomplete, the absence here of data for the Eastern Region, and the incomplete donor data, it is reasonable to suggest that total global expenditures over the last ten years have probably been in excess of US$500 million. This figure is somewhat more than previous official estimates, although this is unsurprising given the more inclusive nature of methods used here (see notes attached to Table 1 and also Annex 4).

Fixed costs

These are the costs that are being expended to maintain a fixed capacity for Desert Locust survey and control including costs of regional organizations, research and development, training, etc. They are distinct, at least in the short term, from campaign costs, which vary with the scale of the operations. Western Region countries participating in case studies report around US$5.65 million *per annum* fixed costs. On this basis an estimate of US$6 million is taken for the region as a whole. There are not enough data to support similar conclusions about the other regions. For this study, the same figure is taken as a proxy for the Eastern Region and for the Central Region (North and South).

Variable costs

These are the costs of control campaigns. Ground and aerial spraying operations will tend to have distinct cost functions and the proportions in which these two methods are used is an important factor in determining unit variable cost. There are reasonable a priori grounds for suggesting that economies of scale would operate; for example larger campaigns would make more efficient use of expensive aerial resources. However there is no evidence of this in the reported figures.

Amongst the case studies, reported per hectare variable costs vary considerably, between US$5/ha at one end of the scale, and US$42/ha at the other. For this analysis it is assumed that campaigns employ a combination of ground and aerial control methods at a standard US$19 per swarm equivalent hectare. This is a simple average of the reported figures. Note that case study authors have assumed very efficient application rates equivalent to approximately 0.5 litre/ha.

Environment and health costs

The control case studies yielded limited information on indirect costs of Desert Locust management. Table 2 summarises the information reported by the authors of the country case studies (see also Annex 9).

The most detailed experimental studies of ecotoxicological impacts of Desert Locust management have been undertaken in Senegal by the Netherlands funded FAO LOCUSTOX Project, which has been operational since 1991.

The contribution of environmental economics in estimating quantitative values of ‘externalities’ associated with chemical pesticides is a relatively new but growing field of study. A commissioned review of environmental economics and the Desert Locust (Belhaj et al., in preparation), discussed different valuation methods that might be employed, with special attention given to those external effects generated from pesticide use. These were: *contingent valuation methods, preventive expenditures, change in productivity approach,* and *methods to measure health effects.* They found that, in the case of Desert Locust management, the data shortages and methodological complexities will pose some limitations on what can be achieved, but that the subject warrants further study. Although costs and benefits would necessarily be calculated under uncertainty, they could provide valuable information for development of improved decision tools. A more thorough assessment is required of the suitability of different approaches in the field.

TABLE 1. **Summary of Desert Locust control costs (1990 US$) for selected countries**

Country	Total costs[1] 1987-1996 (US$ 000s)	Degree of self-financing %	Mean annual fixed-costs[2] (US$ 000s)	Campaign evaluated	Ha treated	Swarm equivalent[3] ha	Variable costs US$/ha swarm equivalent with different chemical costs[4]: as reported	Variable costs: @ US$5.5/ha[5]
Algeria	104 800	87	1 830	no data	no data	no data	no data	no data
Eritrea	no data	no data	157	1993	27 378	18 888	no data	33.49
				1995	51 897	53 657	no data	9.07
Mali	no data	no data	256	1988	503 098	205 046	32.35	31.22
				1996	1 600	2 122	41.60	45.55
Mauritania	30 600 *	12	779 **	1992	12 575	24 950	7.75	7.89
				1994	834 400	854 400	8.26	8.53
				1996	12 857	20 128	13.04	13.22
Morocco	128 700	96	2 773	1988	2 855 905	2 909 145	no data	18.77
				1995	139 106	137 134	no data	24.45
Saudi Arabia	25 700 ***	no data	2 573 ***	no data	no data	no data	no data	no data
Sudan	8 100	28	366	1993	86 083	89 947	8.05	8.69
Yemen	3 200	29	188	1993	192 405	292 405	4.96	5.54

* 9 years corrected to 10; ** 9 year average; *** government annual budget.

[1] Includes both government and external financing.

[2] Fixed costs are: depreciation costs of capital equipment such as vehicles, applicators and aircraft (where purchased specifically for locust control) plus the recurrent costs of maintaining the establishment, such as staff salaries, services and recurrent purchases.

[3] Assumes aerial spraying of hopper bands is block spraying and ground spraying is target spraying. One ha target-sprayed hopper band achieves same kill as two ha adult swarm. Twenty-five ha block spraying equivalent to one ha adult swarm (after Symmons, 1992).

[4] Variable costs are expenses incurred above fixed costs by field operations (survey and control). Include vehicle running costs (fuel and repair), hire of aircraft, subsistence, medical and travel costs, casual/seasonal labour and pesticides.

[5] Pesticide costs of US$5.5 per hectare is an estimate based on figures reported by authors.

TABLE 2. **Environmental and health costs reported by selected countries**

Country	Period	Human health	Environment
Eritrea	1992/93	Protective clothing not supplied from MoA due to shortages. Farmers used plastic bags, tarp and old clothes to protect themselves. MoA supplied powdered milk. No reports of poisonings.	'Likely some mortality' of honeybees in beekeeping areas, although application personnel were told to stay away from water resources and bee breeding areas.
Sudan	1992/93	Some incidences of poisoning associated with bird control and in cotton growing areas, but none during the Desert Locust campaign.	No monitoring of pesticide application or environmental impact has been undertaken. 'No adverse effect was observed.'
Mali	1988	'Not rare to see applicators suffering from headaches, vomiting, fevers'. Hospitalisations rare.	no data.
Mauritania	1988	'Some intoxications caused by accident", generally during transport or handling rather than during spray campaigns.	Mortality observed in non-target insects especially Coleoptera, and on birds feeding on sprayed locusts. Levels of beneficial insect *Chilocorus bipustilatus,* was suppressed in Nouakchott market gardens.
Morocco	1988/89	Costs of medicines and medical personnel for 1988/89 campaigns totalled 5 989 000 Dhrm or US$795 600 (1990 US$). (On the basis of regular blood testing, more than 1 000 persons removed from spray operations temporarily or permanently during 1986-1989 period*).	no data.
Yemen	1992/93	No incidences of human poisoning reported.	Control teams hampered in Al-Jouf and Mareb areas by nomads and beekeepers who gave misinformation and forbade access to some areas for fear that spray operations would cause harm and losses to their animals and bees.

* this information has been added for completeness, from Belhaj et. al. citing Showler 1996.

Control effectiveness: scenarios

There have been very few reliable studies undertaken of the extent to which control operations reduce the size of a regional Desert Locust population. For this analysis we have had, necessarily, to adopt a theoretical approach, in which effectiveness is assumed to be a function of the following factors.

Logistical factors

There are always some places where survey and control should be mounted but where it is prevented or curtailed by logistical factors, lack of resources, security problems or combinations of these factors. The places vary over time. In some recent years, areas of restricted access have included northern Mali and Niger, northern Somalia and parts of the Sudan. For this analysis, over a simulated 60 month sequence, we assume that control is actually taking place, in 80-90 percent of months in which control is indicated (see next section).

Detection rates
Following successful breeding, the gross infested areas may be measured in tens or even hundreds of thousands of square kilometres. There are clearly limits on the extent to which survey and control teams can be expected to find and treat a high proportion of these populations.

Here we assume that there is a regional population threshold above which control will take place; this was set at 50 million locusts, equivalent in the context of an early preventive control campaign to an actual infested area of around 50 000 hectares. This assumes that the population is not fully gregarious and exists at a mean density of around 1 000/ha, containing some clumped populations at higher densities presenting treatable targets.

From 50-75 percent of this regional population is assumed to be detected. In the absence of empirical evidence otherwise, this analysis has used constant detection rates; i.e. no improvement as populations increase in size, although this is a debatable assumption. Generally, as populations increase in size, become increasingly gregarious and form swarms, it is reasonable to suggest that detection rates would improve.

Mortality of the population once treated
Again there is a shortage of sound empirical evidence. The percent kill of treated populations in actual field operations probably varies a great deal depending on the extent to which applicators are well trained, and the prevailing environmental conditions. Here we assume a mortality rate of between 70 to 80 percent.

Control scenarios
On the basis of the above assumptions the control analysis is based on two possible levels of effectiveness, with the parameters set as indicated in Table 3. The 'favourable scenario' represents a good control result in terms of regional population reduction. Under the 'less favourable scenario', operating conditions and logistical factors are placing constraints on the effectiveness of control.

TABLE 3. '**Favourable' and 'less favourable' control scenarios**

Scenarios	Favourable	Less favourable
Period/Area Control Possible	90%	80%
Detection Rate	75%	50%
Mortality	80%	70%

Crop damage [2]

Crop damage is a function of locust numbers, their feeding behaviour and the length of time they remain in a crop but it should be noted that Desert Locusts are frequently not in cropped areas. The economic impacts of crop losses depend on income and consumption effects. These in turn depend upon how end of season yields have been affected, the extent to which farmers have compensated either by replanting or through other on or off farm income generating activities, and the costs of any adjustment (see also page 30). Most available reports of damage do not mention methodology; they are generally based on subjective estimations of physical losses rather than income effects. There are effectively no reliable

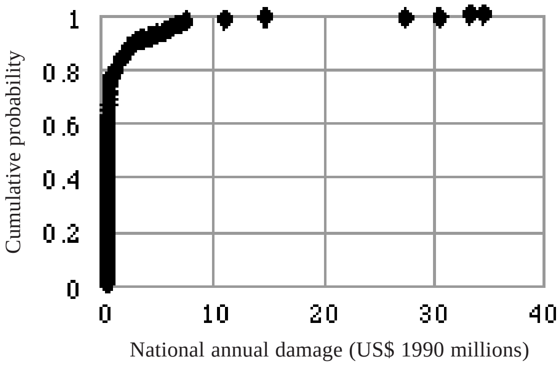
[2] . In the time available it was not possible to include information on pasture losses and any associated economic impacts (see also Annex 2).

data by which it would be practical to include crop damage functions for modelling purposes at this scale of analysis. Other means were used.

Historical evidence
Historical data on damage caused by the Desert Locust, known to be incomplete, were compiled by the Natural Resources Institute, UK (see Annex 7). The resulting database has over 600 entries describing damage in 38 countries. Where possible, information on parameters useful for economic analysis have been included, for example: estimates of the regional population size at the time of the damage, the duration of the infestation, the maximum possible area of the infestation, etc. Case studies of damage occurring in Morocco (1955), Ethiopia (1958) and the Sudan (1988) were also undertaken and are attached as Annex 5.

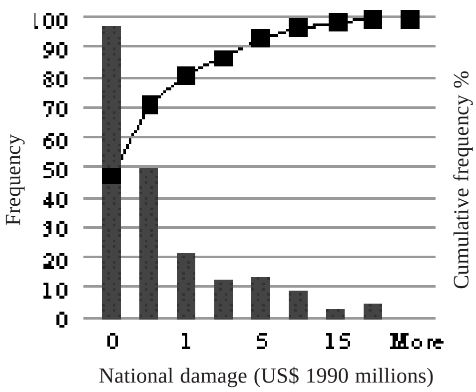
Where financial valuations were reported, historical exchange rates were used to convert these to US Dollars, and the Grilli and Yang (1988) commodity price index used to inflate to 1990 values. From this database a dataset of 208 unique national annual damage estimates were calculated. The sources of most of these data are official questionnaires or published and unpublished literature describing observations by survey teams or citing questionnaire results. The data can be taken as generally representative of the value of Desert Locust damage as reported by affected countries. Out of the dataset used, approximately 80 percent of the reports, and all the most serious reported damage occurred before the widespread use of modern chemical agents from the mid-1950s. As such, the data are representative of the damage potential of the Desert Locust at a time when control efforts would have been of limited success in reducing crop damage, especially when large populations were present.

Figure 2 *Cumulative distribution function: national annual Desert Locust damage*



The 208 national annual damage estimates are charted in Figure 2 and Figure 3. The data are strikingly skewed; the modal reported value (about 50% of all reports) is of zero or negligible damage; about 80% of all reported damage is of $1 million or less. There are 6 reports in excess of US$10 million. The simple average value is about US$1.37 million.

Figure 3 *Estimates of national annual Desert Locust damage*



Sorting the same data by year shows that the highest recorded single year's damage, measured in current (1990) dollars, occured during the 1925-1934 plague, at US$46 million. In total, this plague caused a reported US$103 million of damage between 1925 and 1934, while reported damage in the years 1950-1959 totalled US$160 million.

Reported damage greater than US$10 million

India	1929	10.66
India	1950	14.66
Pakistan	1952	27.43
Morocco	1930	30.35
Ethiopia	1958	33.33
Morocco	1955	34.21

'The top ten'
(worst plague years - damage in US$ million)

1930	45.95
1955	40.38
1958	33.99
1952	30.00
1954	17.10
1929	16.78
1950	14.99
1932	14.98
1928	14.05
1957	11.25

There are 145 data points for which estimates of present day financial value can be compared with estimates of the regional locust population size, the maximum possible area infested and the maximum possible duration of infestation. When the reports are sorted according to regional population size the modal value remains zero in all classes. In other words the presence of large populations is neither an indicator that there will be damage caused in all infested countries nor of the value of any damage that is caused. Neither does the maximum area nor duration of infestation show any relationship with the amount of damage caused (see Figure 4 and Figure 5).

These findings suggest that there is no simple or linear relationship between the size or duration of Desert Locust populations present in an area, and crop damage; thus, substantial damage may be caused by small populations and zero or negligible damage by large populations. There seem to be location specific environmental factors, such as the population being trapped in a heavily cropped area by low temperatures or topography, that are primary determinants of damage potential (see Annex 5).

Figure 4 *Desert Locust damage versus potential period of infestation*

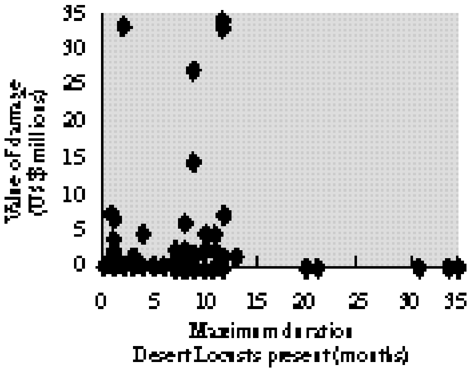
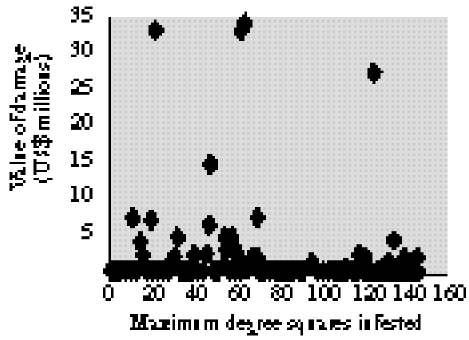


Figure 5 *Desert Locust damage versus potentially infested area*



Damage assessments

Details of how Desert Locust damage has been simulated and its value estimated are included in Annex 3. The following summarises the salient points:

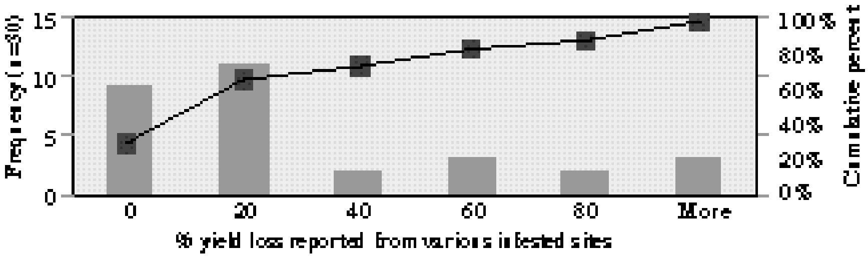
Production data were extracted from the CVI/GIS (see Annex 8) at a resolution of one degree square (1° latitude x 1° longitude), for 40 countries in the Desert Locust distribution area; as were the growing seasons when crops will be vulnerable to attack. The production data includes area and yield of eight different crop aggregations, representing major food grains, fruits, vegetables, pulses, oilseeds and cotton.

For any given month, a regional population is assumed to be spatially distributed according to either a ‘recession/upsurge’ or ‘plague/decline’ distribution, depending on its absolute scale in that month. The distribution in each of these cases is determined according to relative frequency maps generated from the GIS, SWARMS (Annex 11). The relative frequencies are used as the basis for probabilities indicating the relative likelihood of a monthly regional population infesting alternative one degree square units of area.

Once within a cropped degree square, for each of the eight crop aggregations, the probability that locusts will infest the crop is calculated as a function of the area of each crop proportionate to the total area of a degree square. Degree square data are then aggregated to national level, weighting according to production. The result is a set of probabilities by country and commodity group which determines, month by month, the relative propensity to infestation by a given regional population.

If a commodity group is infested, the remaining question is the extent of damage measured in terms of the end of season yield loss. There will clearly be considerable variation depending on several factors including growth stage, locust life -stage, time on crop, etc. Case study information from the Sudan, illustrated below, shows that yield losses varied between 0 and 100 percent, with most reports in the lower end of this range (see Figure 6).

Figure 6 *Yield loss estimates for Kordofan Region, Sudan, 1988*



Based on estimates of yield loss reported from Bara, Sodiri, El-Obeid, Umm Ruwaba and En Nahud Districts (n = 30) (see Annex 5)

For this analysis we have used a beta distribution to determine a yield factor between 0 and 1. The use of this distribution implies that most damage will be in the low range but may be very severe, i.e. up to 100 percent. This accords with the available field evidence discussed above. This approach allows for a range of different possibilities for yield loss associated with a given crop infestation. Since populations are redistributed monthly, a seasonal population of, say, 10 km^2 of locust swarm could completely destroy up to 40 km^2 of crop during a four month cropping season.

Market prices of crops

In order to assess the impact of simulated physical production losses on a mutually comparable basis, an adjustment was made to take account of the variability of the yield per unit area and the variability of the cash value per unit of weight among different crops (Annex 8). This was achieved by calculating a ‘yield factor’ for each crop giving its average cash value of production per unit area in terms of equivalent wheat grain. The calculation is based on prices received by farmers (FAO 1995b). For actual prices see Annex 3. For economic analysis read on.

Results and analysis

Returning to the policy questions raised at the start of this paper, we are now in a position to make some preliminary statements about the damage potential of the Desert Locust in the hypothetical scenario of no organised control efforts being undertaken.

Global damage scenarios

ELS can be used to predict damage levels over a five year period with no control intervention (see Annex 3). The results of 100 simulations are shown in the following tables. Table 4 shows the Desert Locust population spending most of the time in a plague status, which is to be expected given the use of 1940-1969 data. At a standard density of 50/m^2, regional mean area infested by monthly populations range from 756 to 1 553 km^2, with a global mean of 4 481 km^2.

TABLE 4. **Simulated uncontrolled Desert Locust populations**

	Mean (km^2) (x100 for ha)	Standard deviation	Recession months* %
Global	4 481	1 946	18
West	756	632	31
North Central	1 054	600	16
South Central	1 553	711	9
East	1 118	592	18

* defined as months during which the population remained below 10^9 individuals (about 20 km^2, or 2000 ha at 50/m^2).

Table 5 shows the mean global (40 countries) US$ valuation of damage predicted for a five year plague sequence, and the same data by region. The mean global damage estimate is US$179 million with a worst case (i.e. a 1 in 100 chance) outcome of US$628 million.

TABLE 5. **Predicted damage (current US$ millions) during a hypothetical uncontrolled plague period**

	Mean	SD+	95% CI*	Minima	Maxima
Global	179	110	22	20	628
West	11	21	4	0	170
North Central	50	61	12	1	347
South Central	39	31	6	0	150
East	79	50	10	4	219

+ standard deviation; * confidence interval.

There is considerable variation in the predicted outcomes. Figure 7 shows the predicted damage over five years, characterised by a skewed distribution with most global damage estimates in the lower range. Figure 8 shows the relationship between mean monthly population size and the damage predicted by ELS. The general trend is for higher damage to be associated with higher populations, but there are many occasions when large populations cause relatively little damage, and vice versa, as would be expected from the historical evidence.

For simplicity, the same data are represented in Table 6, to show outcomes that would be associated with light, moderate, or severe degrees of potential risk, along with the estimated probability that each of these three scenarios would occur. The bases for these figures are 30th, 75th and 95th centile losses out of 100 simulations. The light risk scenario would cover likely outcomes in approximately six out of ten (five year) plagues. The moderate scenario a further three out of ten. The severe risk scenario might occur in one plague out of ten.

Figure 7 Global predicted damage (5 years)

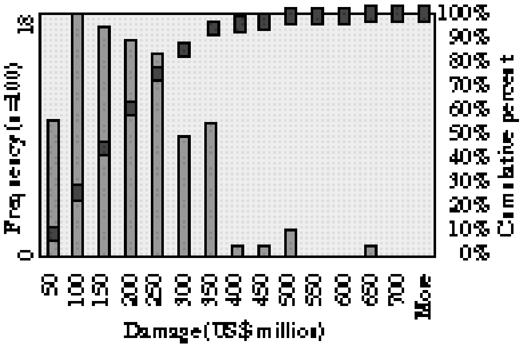


Figure 8 Relationship between global predicted damage and population size

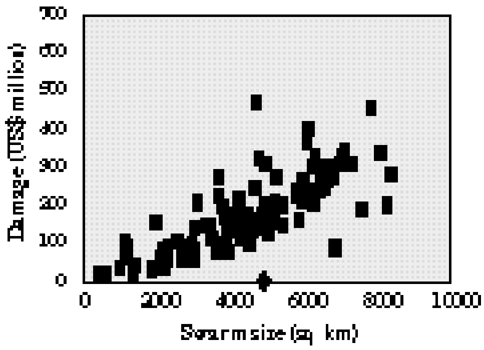


TABLE 6. **Global damage: risk scenarios**

Risk	Light	Moderate	Severe
Probability	0.6	0.3	0.1
Loss (US$ million)	104	246	362

Potential damage: country specific examples

A limited analysis was undertaken of results at a national level, with Morocco and Ethiopia chosen as case studies[3]. The historical evidence suggests that both of these countries would be amongst those most at risk if plague conditions similar to those during the 1940-1969 period were to reoccur. Table 7 shows the value of damage in current US$ that might be expected during an uncontrolled five year plague period for each country. Table 8 shows the value of damage that might be experienced by Morocco during a single peak year (based on the worst single year in each of 100 simulations). Table 9 shows how much food grains production might be lost by Ethiopia during a single peak year.

TABLE 7. **Predicted value of damage (current US$ millions) during a five year plague period: selected countries**

	Probability	0.6	0.3	0.1	(0.002)
	Mean	Light	Moderate	Severe	Worst
Ethiopia	7.24	0.86	8.33	32.49	82.50
Morocco	7.63	0.70	7.57	36.51	192.63

TABLE 8. **Predicted value of damage (current US$ million) in a single peak year: Morocco**

	Probability	0.6	0.3	0.1	(0.002)
	Mean	Light	Moderate	Severe	Worst
Morocco	6.98	1.05	6.70	33.64	98.33

TABLE 9. **Predicted loss of food grain production (tonnes) in a single peak year: Ethiopia**

	Probability	0.6	0.3	0.1	(0.002)
	Mean	Light	Moderate	Severe	Worst
Ethiopia	14 078	2 166	22 560	42 306	153 962

[3]. In principle, national level analysis could be undertaken for all countries in the model: data processing constraints and time limited the scope of this preliminary analysis.

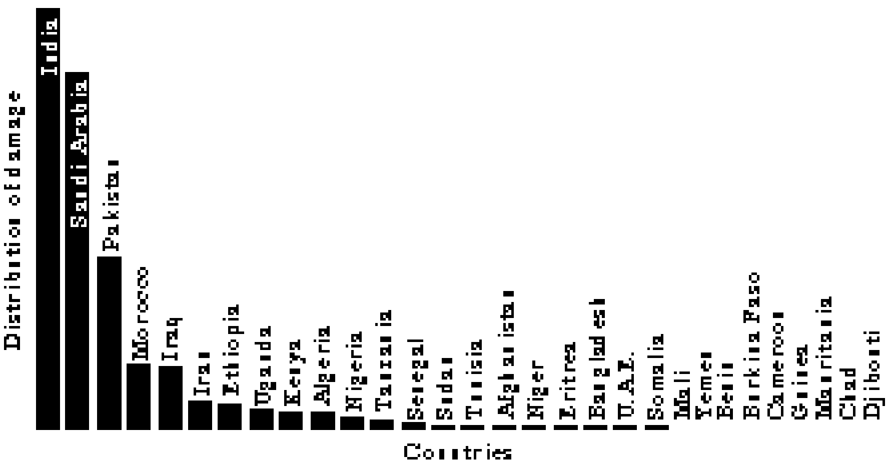
Economic and social analysis of potential damage

Distribution between affected countries

A simple rank order of predicted physical production loss is shown in Figure 9, representing the damage that could be expected if Desert Locusts were spread through the invasion area consistent with the historical frequency data for plague years between 1940 and 1969. The 'y' axis shows the proportion of the total damage predicted by the model which would be sustained by each country. The figure shows that most damage would take place in relatively few countries, with India, Saudi Arabia, Pakistan and Morocco, the most at risk. It should be noted that Figure 9 ranks by physical losses, rather than value and does not indicate the proportion of the national agricultural production affected. When the value of production at risk is taken into account the top part of the rank order remains substantially unchanged, with the exception that Algeria increases its rank order.

Table 10 shows the predicted rank order of damage (tonnes) 'versus' the UN human development index (HDI) (ranked amongst sample countries) – converted for simplicity to interquartile ranges. Countries in the top half of the ranked predicted damage are generally also in the top two quartiles for ranked HDI. The most significant exception to this rule is Ethiopia which is both at high risk and amongst the poorest countries in the sample.

Figure 9 *Predicted damage: rank order of sample countries*



The simple implication of figure 9 is that the burden of Desert Locust risk is falling mainly on the more developed countries in the sample, with many of the least developed countries being less prone to production losses. It is, however, important not to attach too much significance to this rank order, which represents only an average expected level of damage over a long period (see also Annex 2). In reality all countries represented could experience significant damage during a plague and many have done.

National welfare effects

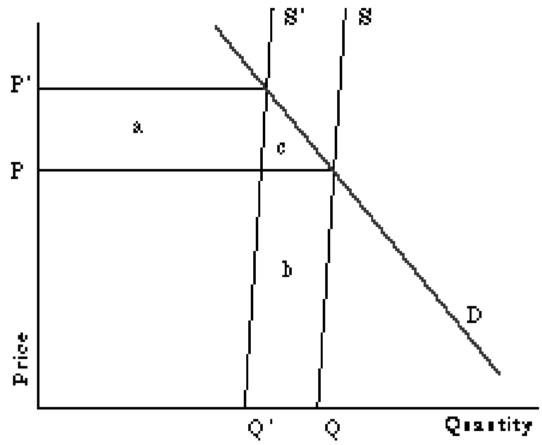
Where losses to locusts are large enough to affect the supply of food and other goods in the markets, a rise in price will occur, all other things being equal. This change in price will transfer some economic losses to consumers, while producers who still have produce to sell, i.e. were unaffected by the locust attack, will benefit from the higher price gained. In the case of locust attack, especially where this takes place late in the season, there may be limited potential for producers and traders to respond to higher prices by bringing additional supplies to market, so these price effects may be quite marked.

These distributional effects are illustrated in Figure 10. They depend on how the demand for a particular good alters as prices change, in other words the price elasticity of demand. A low elasticity (implying a steeply rising demand curve in Figure 10) means that consumers continue to purchase similar amounts in spite of the price rise, and as a result they bear most of the costs. Products regarded as necessities, such as food staples, are likely to have these characteristics. Products with readily available substitutes, such as horticultural products, are characterised by higher elasticities, and thus producers incur more of the burden of price rises as consumers switch away from their products.

TABLE 10. **Ranked national damage versus ranked human development index (HDI)**

Country	Rank damage	Rank HDI quartile
India	1	2
Saudi Arabia	2	1
Pakistan	3	2
Morocco	4	1
Iraq	5	1
Iran	6	1
Ethiopia	7	4
Uganda	8	3
Kenya	9	2
Nigeria	10	2
Algeria	11	1
Tanzania	12	no data
Senegal	13	3
Sudan	14	2
Tunisia	15	1
Afghanistan	16	4
Niger	17	4
Eritrea	18	no data
Bangladesh	19	no data
UAE	20	no data
Somalia	21	4
Mali	22	4
Yemen	23	2
Benin	24	3
Burkina Faso	25	4
Cameroon	26	2
Guinea	27	3
Mauritania	28	3
Chad	29	3
Djibouti	30	4

Figure 10 *Impact of production shock on producers and consumers*



The demand curve D represents the quantity of a particular good purchased by consumers, and the slope indicates responsiveness to a change in price. Price P indicates the market clearing price given the supply curve, S, assumed to be only weakly responsive to price changes within a season (i.e. steeply inclined). A shift in supply from Q to Q' induced by an exogenous yield reduction leads to an increase in price to P'. In aggregate, producer returns are reduced by the area b *but increased by* a *due to the increase in price. Consumers are made worse off by the area* a *plus* c.

To illustrate the distributional impacts of a typical production shock, the predicted losses indicated above for Morocco and Ethiopia are further evaluated in Table 11, using elasticities obtained from FAO's World Food Model (FAO 1996)[4]. These production losses are by commodity group valued in current prices, and correspond to a 'severe loss' scenario (i.e. occurring with a frequency of perhaps 1 plague year in 20). The net transfer from consumers to producers is shown.

[4]. For simplicity, cross price elasticities are assumed here to be zero, in other words changes in prices of one good do not affect the production or consumption of others. Including these cross-price effects would reduce the overall welfare losses by allowing the burden of adjustment to be spread over a greater number of crops. Likewise, if allowance were made for the interaction between agriculture and other sectors, the welfare effects would be further reduced. Finally, it has been assumed that producers cannot respond to locust damage (the elasticity of supply is zero in the short term). The effect of these various assumptions is to overstate the economic cost of the damage.

The results show that Ethiopia and Morocco might lose between 0 and 2.8 percent of national production of the selected crops in the event of severe losses occurring, leading to estimated price increases of between 0 and 11 percent. In all cases the percentage rises in price are greater than the losses in production. A very similar pattern emerges when the same analysis is undertaken for several other countries (Eritrea, India, Mali, Mauritania, Pakistan, the Sudan, Yemen), assuming a hypothetical one percent loss in national production (see Table 29).

These results above hold for a general case in which the production lost to Desert Locust would otherwise have been traded in domestic markets. In this scenario, they imply that urban consumers would bear a large part of the economic burden, while producers as a whole may benefit as a sector. The same picture would not hold where the ‘lost production’ would otherwise have been destined for export. In this case, and more generally when changes in supply have no impact on prices, producers bear a much higher proportion of the economic burden, with consumers being relatively unaffected. This might be the case for example for much of Maghreb citrus production threatened by Desert Locust attack. Here the primary losers are the producers of these crops.

Food security and livelihood issues

Rain is the most important influence on grain yields in rainfed agriculture and major locust outbreaks and upsurges occur, by definition, in years of higher than average rainfall. In these years, at a regional or national level, yields will usually be higher than when Desert Locust are in recession. This has been well demonstrated by Krall and Herok (Krall et al. eds, 1997). The picture may be more complicated during plagues, since they do not require above average rains to continue. Plague declines, when many swarms may still exist, are normally associated with below average rains. Higher than average rains and grain yields during upsurges will tend to mitigate against any widespread threat to food security in rural areas and also buffer price mediated impacts on urban consumers. An illustration of the buffering effect of higher than normal rainfall is provided by the following insight from the Sudan:

“... when rains are good and well distributed some farmers cultivate more land to ensure a good harvest while knowing that locusts may come and do damage, but at least there remains some crop at the end which may be harvested” (Nurein, 1995).

• Box 2 **Desert Locust years and crop prices – an example from the Sahel**

Mali’s production of coarse grains in 1985/86 (a year of locust and grasshopper outbreaks) was up 44 percent on the previous year; after another good harvest the next year, coarse grain prices on local markets collapsed and the rural poor benefited as net buyers of cereals (USAID, 1993). Concomitant with the 1993 Desert Locust upsurge, record harvests were forecast for Burkina Faso, Mauritania and Senegal, above average harvest for Niger and about average for Mali and Chad (FAO, 1993). As the Desert Locust upsurge continued through into 1994, food markets in West Africa were reported to be well supplied following generally above average harvests in 1993, the exception being some areas of Chad and Niger.

However this broad picture becomes more complex at a District or village level. For example, damage in the Bara and Sodiri Districts in the Kordofan Region, Sudan, in 1988 resulted in up to 50 percent of production being lost (see case study 3 in Annex 5). Since this area normally produces only around seven percent of national production the aggregate effects on food availability can be presumed to be slight, but local effects will have been more significant, with some producers losing a large part of their crop. In Ethiopia in 1958, a significant proportion of the reported damage of 26 500 tonnes (27 000 imperial tons) occurred in the Tigray area: combined with a disease epidemic, and failure of the rains in the previous year this damage contributed to severe localised food shortages (Joyce, 1962; Webb et al., 1992).

It is often the case that Desert Locust damage is highly localised, and the pattern of economic impacts that result from losses in the subsistence subsector will be quite different from the picture at a national or regional level. These more marginal areas are often poorly integrated into national or global markets, placing constraints on the movement of additional supplies to meet any production shortfalls. Additionally, for the most vulnerable, there may be only limited scope for releasing stocks or generating off-farm income to purchase supplies at market.
Under these circumstances, losses of production *that are severe enough to lead to a generalised, area-wide depression in average yields,* may have a significant impact on consumption.

Economic and social dimensions: scenarios
Clearly, the nature of the economic impacts associated with Desert Locust damage is determined as much by the characteristics and dynamics of the economy where the damage takes place, as by its absolute scale. Given the variation between affected countries, a comprehensive assessment of these impacts would be a substantial task. It is possible, to characterise three broad scenarios describing how economic impacts of Desert Locust could pan out: the reality would probably lie somewhere in between.

General case – The general case is that the losses occur to production normally traded in domestic markets - in this case, producers as whole will gain as a sector (other things being equal) as prices rise, while urban consumers bear the brunt of the impact. Late season losses with little supply response may lead to quite marked price effects. In practice the likelihood of generally elevated yields will tend to protect consumers, rural and urban, from price rises and buffer against any widespread impacts on food security.

Subsistence production – Where losses are concentrated in subsistence production areas a more complex pattern will emerge. The capacity to absorb such a shock depends on the availability and status of a variety of coping strategies. Where yields in the area are generally elevated those directly affected will have a relative abundance of opportunities to mitigate losses through off-farm income, transfers, etc. If losses account for large part of local production there will be fewer opportunities. Likewise, if the area has experienced a sequence of bad years the local ‘food economy’ will already be stretched and less able to compensate. The worst case scenario is where losses are both severe and widespread and occur at a time when capacity to absorb shocks is low –for example after several years of drought. It is this combination of circumstances that could lead to problems of food security consistent with historically recorded events in, for example, Ethiopia 1958 and the Sudan 1988 (see Annex 5).

Export production – Where losses occur in production otherwise bound for export there are no compensatory price effects (assuming a negligible effect on global supply) and the export subsector will bear the brunt of the economic impact. This scenario goes some way to explain the priority that major exporters such as the Maghreb countries place on preventing Desert Locust invasions and why producers in, for example, the Souss Valley, Morocco, are great supporters of locust control service.

TABLE 11. National economic impacts of production losses in selected countries

		Mean	Severe risk	% Nat. Prodn	Base price	Value of lost production	Demand elasticity	Change in price	Producer gains	Consumer losses*	Net losses
Country	**Commodity**	tonnes	tonnes	%	$/t	$		%	$	$	$
Ethiopia	Millet and sorghum	12 308	31 739	1.43	125	3 967 362	-0.2	7.19	19 674 905	19 896 403	-4 074 096
	Wheat and barley	5 013	12 927	1.33	137	1 770 976	-0.45	2.91	3 897 378	3 929 612	-1 791 220
	Maize	5 211	13 436	0.84	121	1 625 769	-0.2	4.16	8 047 445	8 124 111	-1 666 390
	Rice	10	25	0.01	185	4 620	-0.2	0.03	22 850.27	23 065	-4 732
	Fruit and nuts	0	0	0.00	433	0	-0.5	0.00	0	0	0
	Other fruit and vegetables	3 029	7 812	1.37	193	1 507 634	-0.5	2.77	2 984 493	3 004 625	-1 522 394
	Pulses and oilseeds	1 019	2 627	0.57	395	1 037 721	-0.5	1.14	2 053 148	2 066 331	-1 047 313
	Cotton	4 568	11 780	2.49	742	8 740 715	-0.5	4.96	17 316 510	17 428 396	-8 833 171
Morocco	Millet and sorghum	290	921	0.77	125	115 102	-0.26	2.94	439 088.2	441 341.2	-117 533
	Wheat and barley	15 965	50 670	1.50	137	6 941 780	-0.15	9.99	45 830 217	46 414 305	-7 175 438
	Maize	2 300	7 299	2.19	121	883 151	-0.2	10.83	4 371 535	4 396 117	-905 218
	Rice	1	2	0.00	185	403	-0.3	0.01	1 329.556	1 336.478	-410
	Fruit and nuts	13 858	43 984	1.71	433	19 045 112	-0.5	3.44	37 684 251	37 940 919	-19 222 775
	Other fruit and vegetables	3 179	10 090	1.22	193	1 947 298	-0.5	2.46	3 854 847	3 876 510	-1 966 362
	Pulses and oilseeds	331	1 050	2.76	395	414 735	-0.5	5.53	820 558.6	824 725.3	-418 567
	Cotton	177	562	2.16	742	416 719	-0.5	4.31	825 575.5	829 759.5	-421 128

* The measure of consumer welfare used here, known as equivalent variation, takes into account the impact of price changes on real purchasing power.

Costs and benefits of control

Having looked at some likely outcomes associated with an uncontrolled plague, we can compare these with the situation when control is undertaken.

As discussed above, the effects of two possible degrees of control-effectiveness were simulated. The results were termed, 'favourable' and 'less favourable' control scenarios (see Table 3). Analysis of these results follows.

Table 12 shows mean treated areas versus costs, globally and for each of the four regions. Table 13 shows how successful each of the two control scenarios is at preventing plagues, their relative costs, and the amount of damage that occurs despite the control effort.

TABLE 12. **Simulated global and regional mean treated areas and costs over a five year period in conditions supporting development of a plague**

CONTROL SCENARIOS		Global	Western Region	North Central	South Central	Eastern Region
Favourable	Mean treated areas (million ha)	8.69	1.49	2.02	3.35	1.82
	Mean costs NPV (US$ million)	231	53	49	71	58
Less favourable	Mean treated areas (million ha)	12.58	2.28	3.4	3.73	3.18
	Mean costs NPV (US$ million)	288	65	70	75	79

TABLE 13. **Control costs and effectiveness over a five year period in conditions supporting development of a plague**

CONTROL SCENARIOS	NPV costs (US$ million)		Months recession (%)			NPV damage (US$ million)			
	Mean	95 CI	Mean	SD±	Min	Mean	SD±	Severe	Max
Favourable	231	14	94	6	71	1	1.6	5.15	8.1
Less favourable	288	20	80	22	28	8.5	17.8	36	127

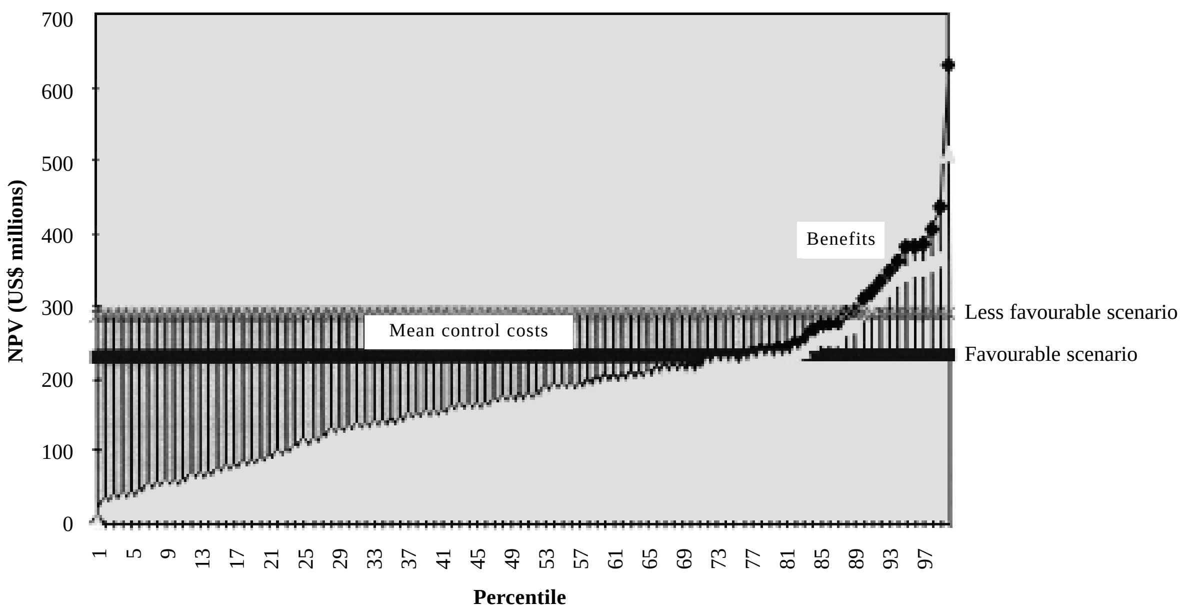
These results show that under 'favourable' conditions control is generally effective at preventing development of plagues: a global mean of 18 percent recession months without control (see Table 4) increases to 94 percent when control is effected (see Table 13).

A less promising result occurs under 'less favourable' conditions; in this case a mean of 80 percent of months is in recession, but the variation is much greater, and in the worst case control is generally ineffective, with only 28 percent of months in recession. Moreover the control efforts are more costly, with a mean cost increase of 25 percent (see Table 13).

Under the scenarios considered here, control is generally very successful at reducing damage, from a mean of US$179 million without control (see Table 5) to between US$1 and 8.5 million with control undertaken. If control conditions are less favourable, there is greater variation in the potential outcome; under a severe risk scenario US$36 million of damage would still occur, with a worst case of US$127 million (see Table 13).

Figure 11, shows the relationship between achievable benefits of control and the mean costs of control operations. The lines rising from left to right indicate the benefits of control calculated as the difference between the net present value (NPV) of damage with control ('favourable' or 'less favourable' scenarios) and without control, resulting from 100 simulations. The horizontal lines indicate mean costs of control associated with 'favourable' and 'less favourable' control scenarios.

Figure 11 *Global costs and benefits of Desert Locust control*



Benefits are similar over most of the range for the two scenarios, but diverge at the margins when, as indicated above, 'less favourable' control conditions may result in substantial damage still occurring.

Costs are greater than benefits in most circumstances. Control operations could be expected to generate net benefits in around 20 percent of cases under a 'favourable' scenario; or ten percent of cases under a 'less favourable' scenario (see also Figure 12).

Cost effectiveness
In principle the production risk posed by the Desert Locust is not qualitatively different to that posed by other natural or man made factors that might lead to localised crop failure and food shortages. Costs and benefits of control should be compared to alternative or complementary means of managing economic risks. In areas prone to food insecurity the range of possible public interventions is diverse and can be characterised as covering prevention, preparedness or response measures (see Annex 10).

Here we look briefly at relative costs of preventing Desert Locust damage by control operations versus the costs of emergency relief operations. Table 14 presents the simulation results in terms of costs per tonne of food grains saved (millet, sorghum, wheat, barley, maize, rice) under three different levels of risk and two control scenarios.

By comparison, rough estimates provided by the World Food Programme indicate that costs of providing food aid (coarse grains) in semiarid areas affected by the Desert Locust may range from US$500 to US$700 per tonne.

TABLE 14. **Unit costs of Desert Locust control in preventing loss of food grains under three different levels of risk**

RISK	Light	Moderate	Severe
PROBABILITY	60%	30%	10%
COSTS PER TONNE OF FOOD GRAIN SAVED (US$)			
Favourable scenario	547	265	183
Less favourable scenario	681	332	236

This suggests that, other things being equal, costs of Desert Locust management compare favourably to costs of relief operations. There are, however, other factors relevant to this question. Only a minor component of damage caused by the Desert Locust would be likely in practice to lead to a situation where relief operations were necessary; in other words Desert Locust management is relatively unselective in targeting those areas and communities most at risk. Control campaigns also have negative environmental and health disbenefits. On the other hand the beneficiaries of these two particular alternatives would presumably prefer preventive efforts to relief operations. No operational conclusions can be drawn from the limited analysis here. However, more detailed and locally specific studies are clearly indicated to assess the relative merits and costeffectiveness of all potential interventions against Desert Locust risk.

Risk analysis and decision making

Another way to look at the above analysis is in terms of decision making. Firstly, for illustrative purposes, let us assume that a 'hypothetical' global decision maker is present at the beginning of a potential plague and is uncertain about how events will unfold in terms of the economic risks and the likely returns to control efforts; the results presented above, which are based on long term average probabilities, are assumed to be the only available information.

Figure 12 presents the same simulation data as Figure 11. This time the achievable net benefits are shown on the 'x' axis; they rise depending on the degree of risk – in other words the severity of the Desert Locust damage that would have occurred had control not been affected. The probability of achieving different levels of net benefit can be read off the 'y' axis on the left hand side of the chart.

From the chart it can be seen that there is an 80-90 percent chance that net benefits of control will be negative. A 'risk-neutral' decision maker might decide that committing resources to control is clearly not an economic proposition on the basis of the available data.

There is, however, a 10-20 percent chance that a 'no-control' decision would be wrong, in fact very wrong, since a large amount of damage would have been caused within the Desert Locust distribution area, most of which could have been prevented. If the decision maker is risk averse, he or she might place a premium on trying to prevent any chance of this scenario occurring. Such a strategy is sometimes referred to as 'Maximin' – a risk-averse tactic, aimed at putting a floor under the worst possible outcome. If this strategy is selected in the case of Desert Locust management then the decision maker would control unselectively all potentially threatening populations. This 'risk premium' comes at a cost, estimated from our simulations to be around US$53 million in a 'favourable' control scenario and US$117 million in a 'less favourable' scenario (the difference between NPV of mean benefit and mean cost).

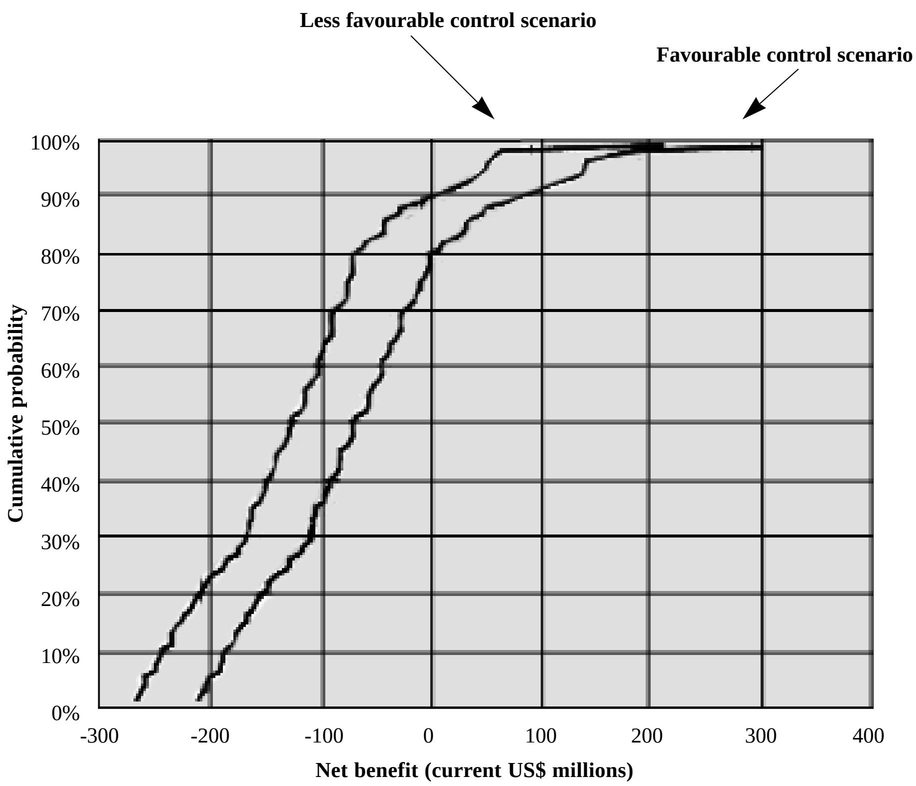
Earlier we estimated the expenditures that have been made over the last ten years on Desert Locust management to be at least US$50 million per year or perhaps US$250 million over five years. At a global level, this scale of expenditure indicates that relevant decision makers are expecting 'the worst' and spending accordingly.

The decision problem illustrated above is of course a hypothetical one. For one thing no global decision to stop control all together could or would be taken; individual affected countries will continue to mount control efforts as long as they perceive control efforts to be an attractive and costeffective response to Desert Locust.

At the same time, management decisions in practice are more complex than the simple scenario above. They are likely to be based on some combination of long term knowledge about the frequency and severity of risks, together with more immediate information in relation to current forecasts and prospects for control. Further, management choices may be based on multiple criteria and reflect the perceptions of those involved in or affected by the decisions as much as the available 'objective' information on long term trends.

For the future, more detailed studies are needed, working with those affected by Desert Locusts and involved in management decisions, in order to generate better information about risks and available responses, and enhance decision making tools and capacity.

Figure 12 *Probability of achieving different levels of net benefit under 'favourable' and 'less favourable' control scenarios*



Overview and discussion

This study sets out to pull together the best currently available data on economic aspects of Desert Locust management. The aim is to reach some preliminary conclusions based on 'best bet' estimates of benefits and costs associated with current technologies and strategies, and to point the way towards an improved incorporation of economic dimensions in future practice.

At the beginning of the paper several fundamental questions were highlighted. The following revisits those questions in the light of the data and analysis presented above (and assumes that the reader has referred to the section on methodology and to Annex 2 on validity of results).

Scale of the Desert Locust problem

The Desert Locust has the capacity to cause substantial damage to agricultural production, but the circumstances under which this would occur are unusual. The damage that might occur in the *(hypothetical)* complete absence of control would be characterised by considerable variation. For simplicity we have banded our estimates according to 'light', 'moderate', or 'severe' risk scenarios. In each case the scenario is based on a period of five years in which there is a strong likelihood that plague populations would develop if unchecked. In most simulated cases the 'light' scenario would prevail; about one time out of ten the 'severe' risk scenario would prevail. The predicted damage in each case is shown in the following table.

Global damage: risk scenarios

	Light	Moderate	Severe
Probability	0.6	0.3	0.1
Loss (US$ million)	104	246	362

Past events show that damage would not be evenly distributed in space or time; the likelihood is of many small, localised incidences of damage with the occasional more significant incident when environmental and biological factors combine to hold a hungry locust population within a heavily cropped area.

For individual countries there would be considerable uncertainty whether to expect significant damage in any particular season. In many cases they would escape completely; should severe damage occur, this might account for two to three percent of production nationally, and a higher proportion of production for those Districts most affected.

Distribution of risk

There appears to be a small subset of affected countries (in particular India, Morocco, Pakistan, Saudi Arabia) that are bearing a substantial part of the risk, whether measured in production losses or financial terms. This results from a coincidence between two factors: a relatively high propensity to invasion of agricultural areas during the growing season, and relatively high production and yields in those areas.

Within the recession areas, several of the countries most at risk have invested in substantial permanent control capacity, and are largely self-sufficient in this respect. Their survey and control efforts are a key factor underpinning prospects for efficient regional preventive control, and clearly have spillover benefits for their neighbours; at the same time these countries are substantial, perhaps the principal beneficiaries of control efforts undertaken outside their borders, often financed from international assistance.

Economic and social dimensions

The nature of the economic impacts associated with Desert Locust damage is determined as much by the characteristics and dynamics of the local economy where the damage takes place, as by its absolute scale. Again much variation could be expected in terms of impacts associated with a hypothetical 'no control' scenario. In this type of analysis we cannot predict what economic and social impacts would result from an uncontrolled plague, but it is possible to suggest likely scenarios.

Because the Desert Locust is often associated with years of higher than average rainfall, the general case is that agricultural markets in affected countries are usually better supplied in ‘locust years’ than in non-locust years. In this case the presence of Desert Locust populations will not represent a substantial threat to food security in *most circumstances*. In fact the main beneficiaries of control efforts will often be urban consumers, who are protected from any associated price rises, rather than the ‘rural sector’ which would, overall, have gained from such price rises. Those directly affected are obvious exceptions to this scenario, as may be landless and other net buyers in rural areas; however these groups will, in this general scenario, find that the net impact is mitigated by the robust off-farm income earning opportunities and (still relatively) lower food prices.

This general scenario could not always be relied upon. There may be, and have been, occasions where the Desert Locust damage is concentrated in subsistence areas, and this, under some circumstances, may be associated with a real risk of localised food shortages. The worst case scenario would be where losses are both severe and widespread, in an area that is poorly integrated with markets and services, and which, as a result of previous ‘bad years’ is already highly vulnerable to production failure. Such a coincidence of factors has occurred in the past, for example most recently in Ethiopia in 1958.

Although much attention is paid to food security issues, the threat to another vulnerable subsector, namely exporters of high value commodities such as market vegetables and fruits, is probably of equal importance to some affected countries. In the event of Desert Locust damage occurring, losses of export production will hit government revenues directly and economic losses will generally not be mitigated by domestic producer gains. This scenario goes some way to explain the priority that major exporters such as the Maghreb countries place on preventing Desert Locust invasions.

Control

This study has not placed emphasis on attempting to evaluate control strategies. There are a number of activities planned within EMPRES to address this subject. However the analysis has produced some indications of the costs and benefits likely to be associated with control efforts under defined ‘favourable’ and ‘less favourable’ control scenarios.

The simulations suggest that control efforts are generally effective at reducing the amount of time in which Desert Locust populations could exist at a scale sufficient to pose a serious threat to production. Without control, the global mean of recession months is 18 percent. This increases to 94 percent when a ‘favourable’ control scenario is effected.

A less promising result occurs under a ‘less favourable’ control scenario; in this case a mean of 80 percent of months are in recession, but the variation is much greater and, in the worst case, control is generally ineffective with only 28 percent of months in recession. Moreover the ‘less favourable’ control efforts are more costly, with a mean cost increase of 25 percent.

Under both ‘favourable’ and ‘less favourable’ scenarios, control is generally very successful at reducing damage, from a mean of US$179 million without control to between US$1 and 8.5 million with control undertaken. However under a ‘less favourable’ scenario there is greater variation in the potential outcome; under severe risk US$36 million of damage would still occur, with a worst case of US$127 million.

Overall, the simulations suggest that it would cost around US$231 million over five years to prevent plagues under ‘favourable’ conditions for control. Costs of ‘less favourable’ operations increase to US$288, with the increased possibility of residual damage occurring as described.

Environmental and health costs
The case studies undertaken by affected countries indicate that some health and environmental impacts occurred in the course of spray campaigns. This is an area in which work is underway. For now we are not in a position to be able to quantify the scale of this problem nor to place an economic valuation on these costs.

Some preliminary assessment was undertaken of potential methodologies from the field of environmental economics which may be useful for evaluating health and environmental impacts of campaigns as a contribution to development of improved decision tools.

Benefits, costs and risk analysis
Estimates of the probability of achieving different levels of net benefit from control operations over a five year period are shown in Figure 12. They are based on simulations using parameters derived from historical population data over 30 years, plus current agricultural and control costs. The results show control costs exceeding benefits in most cases. If a hypothetical risk neutral global decision maker, faced with a potential plague, was reviewing options over the next five years based on these results, he or she would make the 'right choice' in economic terms, on 80 to 90 percent of occasions, by choosing not to commit any expenditures to control.

The problem for the decision maker is that in 10 to 20 percent of occasions this choice would be wrong and possibly very wrong. Since, currently, the data and decision tools do not exist to shed much light on which scenario is likely to unfold, a risk-averse decision maker may prefer to select a strategy with the 'least bad' outcome, rather than the one with the highest expected monetary value. In this case the choice would be to undertake preventive control, doing all possible to ensure that it is undertaken cost-efficiently, and accept the economic losses that will usually occur as a 'risk premium'. The cost of adopting this strategy, that is the net economic cost of insuring against the small possibility of severe damage, is estimated here to lie somewhere between US$53 million and US$117 million over five years.

The above analysis holds globally; there will certainly be considerable variation in the net benefits of control at country level. Within the defined bounds of this analysis, we find that, *for countries with substantial production in areas subject to Desert Locust invasion*, the economic risks of letting a Desert Locust population upsurge go unchecked are sufficiently high that efforts to mitigate this risk are likely to be justified in many instances. We do not have any information on whether preventive control would represent the least cost means of doing so versus, for example, crop insurance or other alternative measures.

For many countries with relatively low value of production at risk the issues are more complex, and the net benefits in economic terms will very rarely justify expensive control efforts. In food security terms preventive control will protect against the possibility of impacts on particularly vulnerable groups. If it is believed that, under prevailing conditions, these impacts would be widespread and severe, then control efforts provide a relatively humane safety net versus the alternative of providing famine relief after the event. These circumstances are probably quite unusual; control efforts will usually be an inefficient means of targeting the most vulnerable, much of the benefit being captured outside the rural economy.

Conclusions – looking to the future

The results of this preliminary analysis suggest that Desert Locust-affected countries and development assistance partners are currently paying a high price to 'insure' against the possibility of severe economic impacts associated with plagues. Results indicate that, at best, simulated costs and benefits are of the same order of magnitude but that, in many cases, control costs exceed benefits.

Three areas are discussed below in which future initiatives to reduce costs could concentrate. There are a number of elements of work already proposed under EMPRES which focus on improving technology. It is proposed here that there is also much to be gained from an increased emphasis on decision tools, and more generally on management, institutional and policy issues.

Decision tools

It is important to find the means to provide decision makers with more accurate information on the economic risks associated with a particular Desert Locust situation as it progressively unfolds, including any health or environmental costs that might be associated with control efforts.

It has become the norm to accompany requests for assistance with standard statements about food security and impacts on the poor. Although such risks do exist, there is no need to assume the worst in all cases; the conditions under which food security implications may be relatively significant are quite specific and perhaps to some extent predictable. The treatment of risk and uncertainty in decision making has progressed a great deal in recent years; further effort to incorporate these new ideas into Desert Locust forecasting and decision making would help to reduce unnecessary effort and costs, both direct and indirect.

Such improved analysis is only possible if the extent and quality of the evaluation data that are collected on costs and effectiveness are greatly improved. Alongside this general effort, it is suggested that specific emphasis is placed on developing improved decision tools which are locally relevant and incorporate economic and environmental dimensions into operational practice.

Policy instruments – integrated management

The economic risks posed by the Desert Locust are not uniform; they vary from country to country and also within countries; they also vary across time in terms of crop cycles and other economic and social indicators.

Against these diverse and changing risks, Desert Locust population reduction should be considered as only one of several possible options. At the start of this study one of the questions raised was the extent to which there may be alternatives or complements to control. In intensive, high value production areas the scope for insurance against Desert Locusts has not been adequately evaluated to date. In subsistence areas, poorly integrated with markets, identification and support for diverse farm level risk-mitigation institutions could have a significant role in helping farmers faced with potential locust invasions (see Annex 10).

For now, we are not in a position to shed much light on these possibilities but would suggest that this topic receive more serious attention. On the basis of a more specific assessment of economic risks it may be possible to envisage a more diverse package of policy options available to governments and to donors, to be assessed against their relative costs, direct and indirect, and their efficiency in protecting the poorest and most vulnerable against Desert Locust risk. Such an integrated approach to management would sit well within the broader scope of schemes at sector level which aim to protect the rural poor against the effects of production shocks by various means.

It is proposed to undertake relevant studies and take necessary steps to explore the practicality and costs of broadening the range of policy responses to the Desert Locust problem based on an integrated risk management approach.

Financing issues

Where conventional control efforts are necessary, the means of financing these has an important bearing on costs. At least three areas warrant investigation for efficiency gains. Firstly, ensuring that control takes place when and where it will be most effective in the context of a regionally defined strategy. Secondly, ensuring that the incentive environment operates in a way that rewards efficient use of all resources and particularly pesticides. Thirdly, as the emphasis moves towards prevention as opposed to emergency efforts, increasing efforts to develop strategies that ultimately can be financed sustainably by the affected countries.

There are significant transboundary issues here. In a perfect world, each country would undertake adequate survey and control to minimise the collective risk. In practice a truly cooperative strategy tends only to occur where the financing mechanism effectively matches risks and benefits for each of the participants. The fact that member-funded regional organizations have experienced financial difficulties illustrates the difficulties here, but should also act as a spur to develop more effective financing approaches. In so doing, the dominant economic interests of some Desert Locust-affected countries, highlighted by this study (i.e. India, Morocco, Pakistan, Saudi Arabia), suggest that they could have a central role to play in helping to ensure the sustainability of future operations.

The incentive issue is straight forward: economic activities of all kinds will generally be undertaken more efficiently where those utilising scarce resources are aware of their true cost and have a stake in using them sparingly. In the context of a Desert Locust control campaign these conditions are very often absent, in fact reverse incentives may apply: the financial rewards to operators increase in direct proportion to the number of Desert Locust present but not in proportion to their efficiency in controlling them. The fact that evaluating control effectiveness is low on the agenda of many involved organizations is indicative of a situation where accountability in the use of resources currently has a low priority. Despite the best intentions and integrity of organizations concerned, this is a situation in which a degree of wastefulness is virtually inevitable.

It is suggested that the means of financing control efforts be reviewed in the context of efforts to build a sustainable, and efficient response to the Desert Locust.

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Technical annexes

Emergency Prevention System (EMPRES), Desert Locust component

FAO established the Emergency Prevention System (EMPRES) for Transboundary Animal and Plant Pests and Diseases in 1994 that currently focuses on the Desert Locust and on transboundary livestock diseases like Rinderpest. The primary goal of the Desert Locust component of EMPRES is to minimise the risk of Desert Locust plagues through well directed surveys and timely, environmentally sound interventions in order to mitigate food security concerns in locustaffected countries.

EMPRES is not active in all locust-affected countries, but focuses on those where past Desert Locust upsurges and plagues began. The countries bordering the Red Sea and the Gulf of Aden are the first priority and EMPRES pilot activities started there in 1995. A comprehensive, donor-assisted programme followed in 1997. EMPRES is also active in other regions and pays special attention to Sahelian countries like Mauritania that suffered two serious Desert Locust upsurges between 1993 and early 1997. A full EMPRES programme for West and Northwest Africa was formulated in 1998.

The Desert Locust component is a collaborative programme aimed at improving national and regional monitoring and preventive control capacities, as well as increasing international co-operation. EMPRES partners are national plant protection organizations, regional organizations that have a mandate for supporting desert locust control, as well as donor countries and research organizations.

EMPRES aims to strengthen early warning, early reaction, and research. It also aims to integrate economic and social dimensions into Desert Locust management. Its specific goals are:

- to improve capacities for monitoring and forecasting Desert Locust populations in areas where outbreaks are likely to originate, including giving the surveyors regular access to information on rainfall and vegetation distribution;

- to maintain fast and reliable information exchange networks linked to FAO, that has the global mandate for collecting, analysing and disseminating Desert Locust information;

- to improve capacities for early control in key countries through developing efficient organizational structures, well trained staff, and adequate aerial as well as ground control capacities;

- to improve the ability to monitor and evaluate the efficacy of control operations;

- to improve the collection and analysis of economic and social data and their use within an interdisciplinary decision framework;

- to develop environmentally friendly management methods and strategies that reduce and if possible replace chemical pesticides;

- to establish effective rapid deployment plans and contingency arrangements for critical situations.

Validity of results

Our principal means of checking the results against reality is to review the extent to which they are consistent with available literature, historical and case study data, and with expert opinion.

Uncontrolled damage

The actual scale and distribution of regional Desert Locust populations to be expected at any given time is unknowable. The simulated damage in our analysis is caused by regional monthly populations up to 4 000 km^2 in peak plague years, with a global monthly average (four regions) of around 4 500 km^2 over a five year period. These figures are consistent with expert opinion and available studies on the scale of infestations that might be expected during a major plague (Annex 6).

The scale of damage is consistent with available historical reported damage that is known to be incomplete. The two plague periods, 1925-1934 and 1950-1959 resulted in US$103 million and US$160 million of reported damage respectively or an average US$10-16 million *per annum*. Our simulations generate damage two to three times higher than this, at an average of around US$36 million *per annum*. The difference might be explained by under-reporting of historical damage; the effect of control in reducing damage in earlier periods and/or increased area and intensity of cropping in modern times.

At an individual country level, simulated damage caused during peak plague years reached a worst case of 154 000 tonnes of food grains in Ethiopia and US$100 million total value of losses in Morocco. Again, these results are consistent or somewhat higher than the worst recorded damage estimates from those countries. Mean damage simulation estimates for the same countries were considerably lower, reflecting the fact that damage of that magnitude is an unusual event.

Overall, the use of data from the 1940-1969 period has the effect of mirroring a period highly prone to development of plagues. It is not known to what extent this approach has accurately reflected risks in the present day. Any bias introduced is more likely to lead to an over valuation of damage potential than an under valuation.

Control

<u>Effectiveness</u> – In the absence of adequate data, there is an inevitable element of subjectivity in deciding upon the parameters for the ‘favourable and ‘less favourable’ control scenarios. Our simulations indicate that the control effectiveness parameters used would be consistent with effective prevention of plague populations and major damage in most if not all circumstances. More field studies and a generally improved quantity and quality of evaluation data will be required before these theoretical findings can be corroborated. In the meantime there is some further theoretical support for the potential to prevent plague development from J. Magor’s study of the 19921994 upsurge (Annex 6).

A sensitivity analysis showed that the most important parameter in terms of both control costs and effectiveness (proportion of years that a population remains in recession) is the detection rate, which accounted for 97 percent and 94 percent respectively of the difference between the result of the ‘favourable’ and ‘less favourable’ scenarios.

<u>Treated areas</u> – Under a ‘favourable’ control scenario the simulations generate predicted mean annual regional treated areas of between 300 000 ha and 700 000 ha. These areas appear to be consistent with the treated areas reported by campaign evaluation authors (Table 1) and other available FAO data on seasonally treated areas. Given that the simulations are representative of a period when conditions were generally very favourable for development of large plague populations, these estimated treated areas may be on the low side.

Unit variable costs – The figure of $19/ha is higher than many other estimates of campaign costs; for example a standard figure of US$5-10/ha pesticide costs is often used as a proxy for campaign costs (based on an assumed dosage rate of 0.5-1.0 litre/ha). The estimate used here however incorporates a much more comprehensive assessment of actual campaign costs (including per diems, fuel, vehicle maintenance, food and other provisions, medical equipment, etc.) as reported by case study authors. The US$19/ha estimate is based on an assumed pesticide cost of US$5.5/ha which suggest that the real unit variable costs would in many circumstances be somewhat higher in practice.

Total costs – The total global simulated costs of between US$231 and US$288 million over five years (or US$46-58 million *per annum*) may be compared to at least US$35 million average total costs known to have been spent on Desert Locust management in eight case study countries over the last ten years (there are gaps in the finance data). This fact combined with other indicators above suggest that the total costs estimated here of preventing development of plagues is more likely to underestimate than to overestimate.

Recognised and possible errors or biases

Conceptual – As noted in the main text, it is a somewhat speculative and hypothetical exercise to try and evaluate the impact of a 'no control' scenario. Firstly no global decision to stop control all together could or would be taken; individual countries with substantial production at risk will continue to mount self-financed control efforts as long as they perceive this to be a cost-effective policy response. Secondly farmers would continue to protect their crops against Desert Locusts as best they can and would, in the absence of institutionalised efforts adjust their farming systems to compensate; in other words a hypothetical valuation of potential production losses in the short term, following a cessation of formally organised control efforts, must significantly overvalue the true economic impact of such a decision.

Production data – The data sources and methodology for generating production data at an appropriate resolution for this analysis, i.e. assigned to individual degree squares (1° latitude x 1° longitude) for countries of the Desert Locust invasion area, are described in Annex 8. There are potential sources of error here: While the African data derived from the FAO AGDAT Global Food Production Database provided few problems, the rest of the data was compiled from individual country administrative district level statistical abstracts, which were very variable in the number and type of crops given for each country. Allocating the data to degree squares may also have generated some errors, particularly in the case of small countries. In order to check for erroneous degree square data a search was made for all production or yield values plus or minus 2.5 times the mean. Where possible, individual anomalous values were checked against data available in the FAO STAT database and adjusted as appropriate. Where errors were more systematic for particular countries, i.e. affecting several crops, these countries were removed from the analysis altogether (several countries in the Middle East: Jordan, Lebanon, Oman, Syria, Turkey). Additionally no production data at the requisite resolution were available for Egypt, Libya, Kuwait, and Qatar (see also Annex 8).

Crop vulnerability – The data indicating presence or absence of a given crop in a given month, i.e. vulnerability to attack, is subject to three sources of bias. Firstly the periods indicated as 'vulnerable' represent the potential rather than the actual growing period. Secondly, the approach by which the crop presence data were aggregated for this analysis was to sum the data, which may lead to unrealistically long vulnerable periods. Thirdly, for some countries, no data on growing periods was available, in which case a full 12 months was assumed to be vulnerable for all crops. These biases act to overestimate simulated damage potential.

Frequency data and damage estimates – The model allows for damage to occur within the same degree square in sequential months but is not able to adjust the vulnerable production data downwards after each infestation; this leads to an overestimate of damage potential, which is probably slight.

Pasture damage – No account has been taken of potential damage to pastures, which is known to occur. The extent to which pasture losses are likely to be economically significant is subject to some debate. There have been a number of recorded incidences when nomads have made their own assessment of the benefits of control in pasture lands clear by their opposition to these activities (Annex 9). The main reason why these impacts were not included here concerns lack of data and issues of methodology.

Desert Locust frequency data – The Desert Locust frequencies used as the basis for derivation of probabilities will not always generate a true result. From the way the original data are organised it is not feasible to determine where the frequencies represent independent observations and where, for example, a single population is being recorded several times in adjacent degree squares. This bias is probably random rather than systematic in affecting the results.

A more influential factor is reporting bias, which is probably affecting the predicted distribution of damage between countries (but not the absolute predicted damage). In other words if some countries have been relatively able or diligent in reporting locust presence then the model will be more likely to 'place' locusts within their crops, and *vice versa*. This may be contributing to the striking dominance of certain countries (particularly India, Saudi Arabia, Pakistan, Morocco) in the ranked predicted damage (Figure 9). However, the dominant reason for this effect is probably that these countries have a relatively substantial amount of agricultural production in areas that are also prone to Desert Locust infestation (or were prone during the 1940-1969 period). Two factors support this hypothesis. Firstly, although no figures are reported for India and Pakistan here, the scale of domestic resourcing of fixed Desert Locust survey and control capacity in these countries is consistent with the existence of high and regular threat of locust damage. Secondly, these countries have indeed been prone to relatively major and costly invasions according to the historical data.

The SWARMS GIS Desert Locust data contain errors incorporated at the input stage. These are still being checked. A rough estimate is that there may be a two percent random error in the degree square values. The extent to which these errors have affected this analysis is unknown. Where they do affect the analysis the effect will be to alter the distribution of damage between countries; the absolute values of predicted damage may also be affected although in which direction is unknown.

Costs – Economic costing of control (i.e. the opportunity cost to the national economy) was not undertaken for this analysis. There are areas where this will result in a significant divergence between the financial values used, and the true costs (see Annex 4).

Indirect costs – We were not able to identify any robust and reliable basis for incorporating environmental and health externalities into the cost data. On the basis of the qualitative discussion earlier in this paper, it is clear that such costs would be incurred during the campaigns that are simulated here. This results in a significant but unknown underestimate of costs.

Notes on the Economics of Desert Locust Simulator (ELS)

Overview

ELS is a simulation model suitable for analysing the growth and movement of Desert Locust populations and for assessing the likely damage and costs and benefits of control. It is divided into four regions to reflect the different population and control characteristics across 40 locust-affected countries. The delayed effects of locust control on population and crop damage are captured through the dynamic model structure, and the inherent uncertainty associated with locust damage is dealt with through a stochastic simulation framework.

The model integrates four modules:
1. Population dynamics
2. Cost and effectiveness of control
3. Estimates of damage
4. Valuation of damage

Locust population growth and distribution across four regions are simulated over five years in monthly periods. Given an initial recession population, locust numbers grow, remain static or recede randomly according to historically determined probabilities. Migration between regions occurs twice a year, in May and November, again in a stochastic fashion consistent with observed probabilities. Once within a region, locusts are distributed into degree squares according to historical incidence. Degree squares are the areas between latitude and longitude grids and are about 100 x 100 kilometres or a million hectares. The location and timing of locust infestation relative to the available crops determines damage. Once located within a degree square, locusts may or may not inflict damage depending upon the area of susceptible crop and the reported incidence of Desert Locusts within that degree square. Damage is valued according to estimated price and quantity effects. The effects of alternative control strategies on the locust population and crop production in four regions can be determined, based on degrees of effectiveness that the user can define.

ELS is located within an Excel 5 spreadsheet for transparency, portability and ease of use. This allows users who may wish to experiment with alternative parameter values or those who want to develop the model further the opportunity to do so. No particular programming skills are required to run the model.

This Annex describes ELS. Mathematical formulae have been kept to a minimum to maintain readability, but the key equations are presented to provide precision where necessary. This description is aimed at helping readers of the report interpret the results. It is not intended as a user’s guide to running the model. The notation differs in many instances, and the Excel equations are more complex then presented here. The model structure and the four modules are described below in greater detail.

Model structure

In structure, the ELS model is deceptively simple – there is only one feedback loop. This is illustrated in the flowchart in Figure 13. Rectangles represent the four modules, whereas ovals represent the parameters that determine the relationship between the variables (not shown) within the modules. Arrows represent the direction of causal relationships. Locust populations, depending on their growth and distribution, determine damage in a stochastic fashion, reflecting the inherent uncertainty in the relationship between population and damage. Whatever damage occurs is then valued depending on prices and the response of producers and consumers to the loss in production. The valuation of damage is also relatively straightforward with few interactions or feedbacks between the variables. Control is initiated when a regional population reaches a specified level. Control activities reduce population levels, sometimes below a threshold level, which in turn affects population growth and distribution. This is the feedback loop. The apparent complexity of the model derives from the volume of data – based on over 2 000 degree squares.

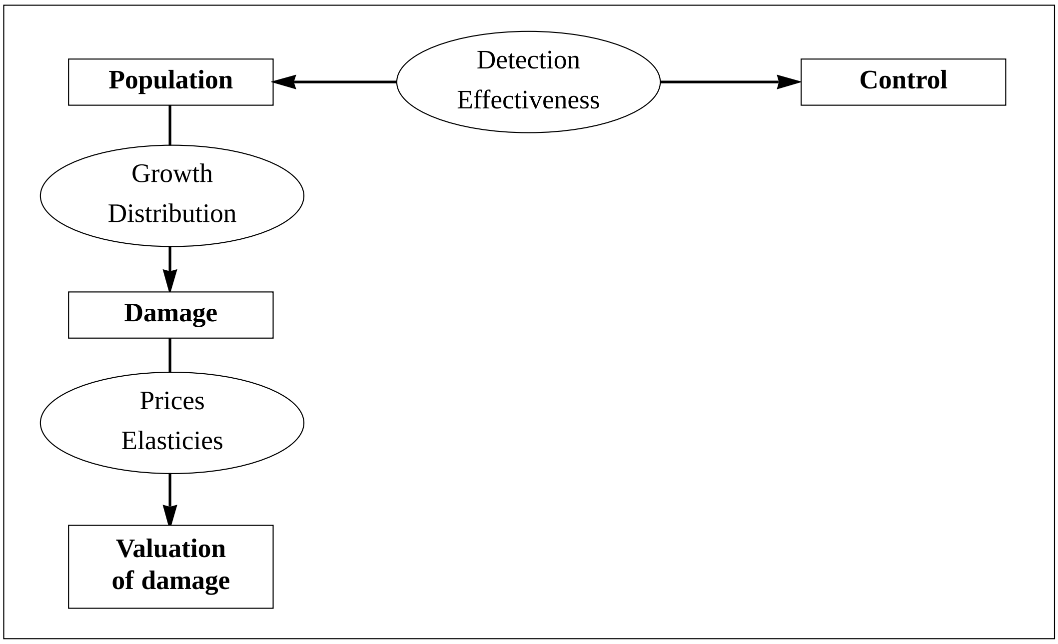
The stochastic elements in the model are:

- population growth and distribution to and within regions;
- the allocation of locusts in cropped areas, and
- the amount of damage resulting from an infestation.

Once damage occurs, its effects are deterministic. There is no uncertainty in the relationship between production loss and its economic and social effects.

There is only one policy variable or instrument in the model. This is the decision to control or not. In most simulations, control is initiated when the regional population reaches 50 million and continues at a constant rate until population falls below this figure once more. Alternative control strategies may be to initiate control at higher or lower population levels, not to control in certain or all regions, and to improve detection or effectiveness rates. Costs and benefits of alternative strategies can be compared.

Figure 13 *ELS flowchart*



Population

Locust populations typically exist at minimal levels for many periods before exploding when weather and other conditions are appropriate. If suitable conditions are maintained in a succession of periods, huge plagues can occur. However, this process is not sufficiently understood nor are sufficient data available to model locust populations accurately. Weather can be predicted only relatively poorly. To address this, populations are modelled as a stochastic variable, one that varies randomly in accordance with certain historical observations.

The population in each of four regions is modelled separately, reflecting the different breeding grounds and conditions. The regions are linked through locust migration, which decreases levels in one region and simultaneously increases it in others. Minimum levels in each region are assumed to be ten million, thus ensuring that extinction is avoided. At the other end of the scale a maximum of 200 000 million is permitted in each region. The population densities are assumed to vary between 1 000 (low density: not fully gregarious) and one million (high density: gregarious) per hectare (Table 15). The density depends upon the absolute number of locusts present in a region in a particular month, and influences the likelihood of detection and subsequent control in the model. For simplicity, the locust population is treated as homogenous. No distinction is made between locusts of different age or sex. Since it is the number of female of breeding age that is the crucial variable, this assumption essentially implies that the age structure and sex ratios are constant.

<u>Population states</u> – Population can be in any of four numerically defined levels or states – recession, low, medium and high (Table 15). Recession is between the minimum, 10 million, and 1 000 million locusts per region. Low levels are between 1 000 and 10 000 million, medium levels between 10 000 and 100 000 million and high or plague levels are over 100 000 million per region. These levels are associated with different probabilities of the population expanding or contracting.

TABLE 15. **Population state parameters** [a]

Regional population state	Million	Density/ha
Minimum	10	
Recession	less than 1 000	1 000
Low	greater than 1 000	10 000
Medium	greater than 10 000	500 000
High	greater than 100 000	1 000 000
Maximum	200 000	
Initial	1 000	

[a] Parameters apply to all regions.

To calculate the historically determined probabilities of progressing from one state to another, it is first necessary to classify previous populations. Annual values are shown in Table 16. The letter in the second column, labelled ‘DL area’ indicates whether the year is classified as a recession (R), upsurge (U), plague (P) or decline (D).

The choice of years 1940-1969 reflects a period when control was considered to be relatively ineffective, and thus population growth and distribution were determined primarily by biological and climatic factors in the absence of policy measures. To be able to assess the effects of control, it is necessary to have a population module that shows how locust populations may develop in the absence of control.

TABLE 16. **Desert Locust population classification, 1940-1969**

Year	DL area	Western	Central North	Central South	Eastern
1940	U	R/U	R	R	U
1941	U	U	U + inv	U by inv	P
1942	P	P	P	P	P
1943	P	P	P	P	P
1944	P	P	P	P	P
1945	P	P	P	P	P
1946	D	D	P	P	D
1947	D	D	D	D	R
1948	R	D/R	R	R	R
1949	U	R	U + invas	U by inv	U
1950	U	inv/P	P	P	P
1951	P	P	P	P	P
1952	P	R	P	P	P
1953	P	P	P	P	P
1954	P	P	P	P	P
1955	P	P	P	P	P
1956	P	P	P	R	R
1957	P	P	P	R/U + inv	R
1958	P	P/R	P	P	P/R
1959	P	R inv/P	P	P	P
1960	D	D	D	P	D
1961	D	R	D	D	D/P
1962	D	R	D/R	D/R	P
1963	D	R	R	R	D
1964	R	R	U	R	R
1965	R	R	D	R	R
1966	R	R	R	R	R
1967	U	U	U	R	R/U
1968	P	P	P/D	P	P/D
1969	D/R	D/R	D/R	D/R	R

U= upsurge; R= recession; P= plague; D= decline; inv= invasion.

The choice of years is quite crucial. Plagues were a lot less frequent after than before 1970. This has been attributed to two factors, the generally drier weather over the region and the greater effectiveness of control measures. It is not clear what importance can be attached to either of these factors. If the weather is an important factor, then the population projections simulated here may overstate the potential population growth unless weather conditions in the years ahead are like they were in the period 1940-1969, that is, wet and favourable to population growth. In other words, unless the current climate returns to the wet conditions of the sample period, the benefits of control will be overstated.

<u>Transition probabilities</u> – The regional populations present between 1940 and 1969 were then classified to show whether seasonal populations in spring, summer and winter fell into the recession, low, medium or high categories defined in Table 15. From these values (Tables not included) it is possible to calculate the likelihood of the population increasing, shrinking or remaining stable. The values in the matrices on the left of Table 17 show the number of seasons in which a regional population in a given defined state, e.g. ‘recession’, has either stayed in that state the following season or changed to a different state.

TABLE 17. **Population transition probabilities, 1940-1969**

Western Region

Following state	Initial state			
	R	L	M	H
R	34	2	2	0
L	2	0	2	0
M	2	2	19	6
H	0	0	6	12
Total	38	4	29	18

Following state	Initial state			
	R	L	M	H
R	0.89	0.5	0.07	0
L	0.05	0	0.07	0
M	0.05	0.5	0.65	0.33
H	0	0	0.21	0.67
	1.00	1.00	1.00	1.00

North Central Region

Following state	Initial state			
	R	L	M	H
R	20	4	0	0
L	2	1	3	1
M	1	2	14	8
H	0	1	8	23
Total	23	8	25	32

Following state	Initial state			
	R	L	M	H
R	0.87	0.5	0	0
L	0.09	0.12	0.12	0.03
M	0.04	0.25	0.56	0.25
H	0	1.13	0.32	0.72
	1.00	1.00	1.00	1.00

South Central Region

Following state	Initial state			
	R	L	M	H
R	25	2	2	1
L	4	0	2	0
M	1	3	19	7
H	0	1	7	15
Total	30	6	30	23

Following state	Initial state			
	R	L	M	H
R	0.83	0.33	0.07	0.04
L	0.14	0	0.07	0
M	0.03	0.5	0.63	0.31
H	0	1.67	0.23	0.65
	1.00	1.00	1.00	1.00

Eastern Region

Following state	Initial state			
	R	L	M	H
R	28	2	2	0
L	3	3	2	1
M	2	3	17	6
H	0	0	7	13
Total	33	8	28	20

Following state	Initial state			
	R	L	M	H
R	0.85	0.25	0.07	0
L	0.09	0.38	0.07	0.05
M	0.06	0.37	0.61	0.3
H	0	0	0.25	0.65
	1.00	1.00	1.00	1.00

For example, recessions occurred in 38 seasons in the Western Region. The recession continued on 34 occasions and lows and mediums each followed a recession season twice. From this, it can be inferred that given a recession exists, the probability of the recession continuing is 89 percent. On the right of the page the same data are expressed as conditional probabilities. A medium state has a 65 percent probability of continuing the next season, and a high population state has a similar likelihood of following a high.

The population in each of the four regions grows or declines each month at rates that are determined seasonally (every four months) according to the current population state. So far, the population classifications have been described and the probabilities of moving from one state to another ascertained. Given the transition from one state to another occurs, it is necessary to determine the rate of growth or decline.

Population growth – The normal maximum growth is 12-fold in a season and maximum decline is by 75 percent of the total. However, the model allows for the possibility that these rates may be doubled in a given season, due to unusually favourable, or unfavourable conditions. This occurs ten percent of the time. In Table 18 the first row illustrates the growth rate necessary to get the population back to recession levels in the following season. For example, from a high level, the population will be reduced to 25 percent of its initial level. No growth occurs if the same state is maintained. Hence, the diagonals in the table are zero. When increases occur, for example from recession to low or medium, populations grow by 6 or 12-fold. The zero in the bottom left element of the table indicates that it is not possible to progress from a recession state to high in a season. The seasonal (four month) growth rates are converted into monthly rates, which are presented in the lower part of the table.

TABLE 18. **Transitional rates of growth**[a]

Seasonal growth rates		**Initial state**			
		Recession	Low	Medium	High
Following state	Recession	0	0.5	0.5	0.25
	Low	6	0	0.75	0.5
	Medium	12	6	0	0.5
	High	0	12	6	0
Monthly growth rates		**Initial state**			
		Recession	Low	Medium	High
Following state	Recession	0.00	0.84	0.84	0.71
	Low	1.57	0.00	0.93	0.84
	Medium	1.86	1.57	0.00	0.84
	High	0.00	1.86	1.57	0.00

[a] Parameters apply to all regions.

Migration – Migration between regions can occur twice a year, in the northern hemisphere mid-summer and late autumn, along defined seasonal migration routes, once the population in the region reaches a particular density. Migration patterns are not determined, but depend on weather conditions and other unpredictable variables. Hence, movement from one region to another is a stochastic variable determined in the model by given probabilities (see Table 19). These probabilities vary across regions and over time and are based on available expert opinion. The rows show the lower and upper bounds of the percentage of the initial population in one region that migrates to another. For example, between 10 and 20 percent of the Western population migrate to North Central in June, given that the initial Western population exceeds a certain threshold. The exact percentage within these bounds is randomly determined each time migration occurs. The migratory flows tend to be circular, moving easterly and southerly in June (as evidenced by zero elements below the diagonal), and westerly and northerly in November. However, swarms do not necessarily return to the breeding grounds from whence they came. Some of the regions have several breeding grounds, perhaps over 1 000 kilometres apart.

TABLE 19. **Migration between regions, percent**[a]

June

From\To	Western Lower	Western Upper	North Central Lower	North Central Upper	South Central Lower	South Central Upper	Eastern Lower	Eastern Upper
Western			10	20				
North Central					10	30	10	30
South Central								
Eastern								

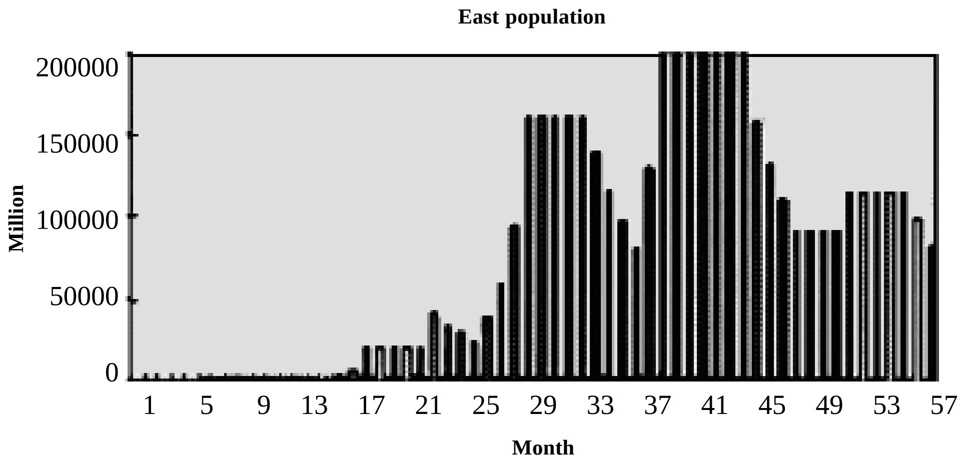
November

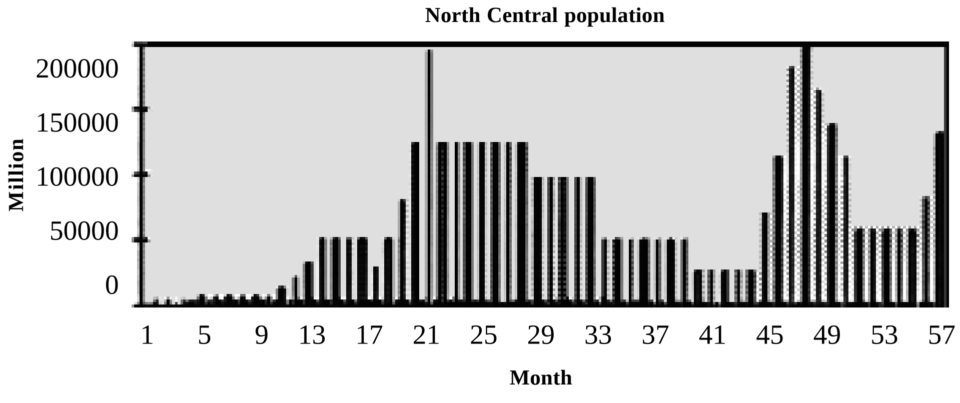
From\To	Western Lower	Western Upper	North Central Lower	North Central Upper	South Central Lower	South Central Upper	Eastern Lower	Eastern Upper
Western			0	20				
North Central	10	30			10	30	10	30
South Central			10	20				
Eastern			0	20				

[a] If migration is to several destinations, the same percentage applies to each. This percentage is randomly determined between the lower and upper estimates.

So far population growth and regional distribution have been described. A typical 60 month dynamic population sequence resulting from this approach might look like the following charts for the Eastern and North Central regions:

Figure 14 *Typical simulated population sequences*





These charts (Figure 14) illustrate some salient features. The first is the obvious stability in the system. Low populations tend to stay low, and high populations may maintain that state for several periods. The second feature is the flat spots, where no change occurs. This rather crude representation of reality derives from the zero elements on the diagonal of Table 18 which prescribe no growth if the same population state is maintained. Note that growth rates change seasonally, whereas the data are monthly, implying that constant rises or falls can be observed in sets of four. A third point to note is that the population occasionally runs up against the maximum constraint – 200 000 million. This implies either that in reality regional populations do exceed this value, but are merely unobserved, or that the model is mis-specified. The latter is more likely, but the impact on the model results is relatively trivial, compared with the other uncertainties.

Desert Locust intra-regional distribution – Once regional populations are determined within the model, the allocation of locusts to degree squares within a region is obtained from monthly frequency data derived from the GIS, SWARMS, which documents distribution of locust infestation between 1940 and 1969. Two sets of maps were generated (see Annex 11), one for recession and upsurge years (all life-stages); the other for plague and decline years (swarms).

ELS uses the observed relative frequencies (see Annex 11) to distribute the Desert Locust population each month. The first step is to distribute a given monthly regional population between countries in the region. This is simply the sum of the frequencies in each country over the sum of the regional frequencies. Next, the same method is used to distribute the population in a country between cropped and non-cropped degree squares according to relative frequencies[5]. Locusts are assumed not to seek out particular localities. Specifically, they do not favour crops over non-cropped areas. They merely tend to go where they have gone in the past.

This is a complex part of the model, and a hypothetical example will illustrate the procedure. Consider a region with three countries as shown in Figure 15. The cropped area is shaded. The numerical values are the number of years in which there have been one or more reported observations of Desert Locust swarms in a degree square in a given month, e.g. January, during the 20 plague and decline years between 1940 and 1969. Some degree squares record the minimum, 0, whereas in one degree square in Country 1 swarms were observed in 15 out of a possible 20 years.

Figure 15 *Hypothetical example of frequency distribution*

Country 1 Country 2

0	0	1	4	2	1	0	0		
0	0	3	5	4	3	3	1		
0	1	6	9	4	7	5	1		
0	3	5	4	3	4	4	0		
2	4	10	10	13	4	7	2	Country 3	
0	3	5	10	15	1	5	2	0	0
3	7	3	7	8	3	7	3	1	1
0	6	5	2	3	3	5	4	3	0
4	4	5	2	2	2	0	0	2	0
6	7	4	4	0	4	2	0	1	1

Of the 300 frequency values over the years in the three countries, 150 or a half occurred in Country 1, of which 75 or 25 percent of the total were in the cropping areas. These data are tabulated in Table 20 for all three countries.

[5] . Data on cropped and non-cropped degree squares derived from the cvi-gis (see also Annex 8).

TABLE 20. ELS: **Distribution of a given regional population between countries and between cropped and non-cropped areas – hypothetical example**

	Sum of frequencies	Sum of frequencies in cropped areas	Proportion of regional population in country	Proportion of regional population in cropped degree squares
Country 1	150	75	0.50	0.25
Country 2	100	30	0.33	0.10
Country 3	50	15	0.17	0.05
Region	300	120	1.00	0.40

From such an analysis, ten percent of a given regional plague population is allocated to the cropped areas of Country 2 in the month of January. Similar calculations follow for February through December.

Population can be presented algebraically as follows:

$$P_{rt} = P_r(_{t-1}) (1+g_{rt}) (1- k_{rt}) + m_{rt}, \qquad 10^7 < P_{rt} < 2x10^{11} \qquad (1)$$

where

P_{rt} = Desert Locust population in region *r* in period *t*
g_{rt} = growth rate of population in region *r* in period *t*
k_{rt} = proportion of Desert Locusts killed by control methods in region *r* in period *t*
m_{rt} = net migration into region *r* in period *t*.

(t-1) refers to the previous period.

The growth rate g_{rt} depends on the transition probabilities associated with particular population states regions less outward migration. Outward migration is determined as a percentage of current population states (Table 17). Net migration mrt to any region is the sum of migration from the three other regions less outward migration. Outward migration is determined as a percentage of current population given that the population exceeds a certain threshold, and that the current month is May or November. The chosen percentage is an evenly distributed random variable between the designated lower and upper bounds. The determinants of control, which influences the number killed, k_{rt}, are described next.

Control

The first module of the ELS model determines populations and their spatial distribution across regions and across degree squares within regions. The second component concerns control. Control parameters are given in Tables 21 and 22. These are the same across all four regions. Control occurs initially when regional populations exceed 50 million. Below this, locusts are unlikely to be detected or are so dispersed as to be difficult or expensive to kill.

Fixed cost estimates are based on several case studies of the Western and North Central Regions, as noted in the main report. Although there are reasons to suppose that other regions may experience different fixed costs levels, there is insufficient empirical evidence on which to base an estimate. Hence, all regions are assumed to have the same fixed costs. In a similar vein, variable costs are also assumed to be the same across all regions and campaigns.

Discount rates are used to weigh cost and benefits occurring in different periods. Costs or benefits deferred into the future are of less significance than current values. A real rate (after adjustment for inflation) of seven percent *per annum* is fairly standard in project analysis where donor funds are used. As the time horizon is only five years, and the benefits from control accrue relatively soon after the expenditure is incurred, the choice of discount factor is not particularly significant.

TABLE 21. **Regional control parameters**

Control threshold	Million	50
Fixed costs	US$ million	6
Variable costs	US$ million/ha	19
Discount rate	Annual %	7
	Monthly %	0.58

The effectiveness of control is an important variable. The number of locusts killed from control measures varies because many locusts may be located in areas that are inaccessible, at least at certain times of the years. In arid or sparsely populated areas, many may not be detected. Finally, even under good conditions, not all treated locusts will succumb. Judgements have been made about these factors, about which there is little more than anecdotal evidence. Locusts not detected are not counted, and it only becomes apparent at a later date and perhaps another location that a portion of the regional population was not detected. Nonetheless, the relevant factors are assembled into two scenarios, combining ranges of these variables. Even in the more favourable circumstances little over half the existing locusts will be killed.

TABLE 22. **Effectiveness scenarios**

Variable	**Favourable scenario**	**Less favourable scenario**
	%	**%**
Proportion of months or infested area in which control possible	90	80
Detection rate (proportion of regional population treated)	75	50
Mortality (proportion of treated population killed)	80	70

Mathematically, the proportion of locusts killed k_{rt} in region *r* in period *t* depends on treatable area TA_{rt} times the rate of detection D_{rt} times the effectiveness E_{rt}:

$$k_{rt} = TA_{rt}\ D_{rt}\ E_{rt} \quad (2)$$

The right hand side variables are all determined exogenously. Given the population is over a certain threshold, and that control is undertaken, k_{rt} gives the proportion of the regional population killed by control activities.

Costs associated with control are simply fixed costs plus variable costs times the area treated (population/density):

$$C_{rt} = FC_{rt} + c_{rt}\ P_{rt}\ /Den_{rt} \quad (3)$$

where
FC_{rt} = fixed costs per region per month
c_{rt} = variable costs per area treated
Den_{rt} = locusts per ha, determined by regional population (see Table 15).

Here, variable costs are treated as a linear function of area treated. The ELS model is programmed to allow for increasing or decreasing cost per hectare as the area treated is increased. Generally, it is reasonable to expect decreasing costs, but the data to confirm this are not yet available.

Damage

If locusts escape effective detection and treatment, they may migrate into a cropped area, whereupon damage may occur. The actual damage that occurs is some proportion of the maximum possible loss. As noted in the main report, most reports of damage are minimal or small, with significant or substantial damage resulting only occasionally. Total damage is quite rare.

For damage to result locusts must exist in the region in a particular month, locate in a particular degree square with growing crops, alight in the cropped area and impose damage according to historically observed probabilities. Crops can only be infested if the population reaches a degree square during that crop's growing season (refer to Annex 8 for method). If infestation does occur then the maximum amount of crop damage that can accrue, if there is a total loss, is the area of locust reaching the crop times the yield of the crop in that degree square (t/ha). ELS takes into account the possibility of multiple damage. Since damage is recalculated monthly the same crop can be damaged several times during the growing season. These calculations are quite complex. An important component is the beta distribution, which determines how much damage is done once locusts land in a crop.

The beta distribution – The cumulative beta probability density function (henceforth referred to as the beta distribution) is well suited to determine the distribution of a variable that lies between 0 (no damage) and 100 percent (total damage). The formula for the cumulative beta probability density function is:

$$F(y) = \int_0^y t^{\alpha-1}(1-t)^{\beta-1} / B(\alpha, \beta)\, dt, \quad \alpha, \beta > 0;\ 0 \le y \le 1 \qquad (4)$$

where

$$B(\alpha,\beta) = y^{\alpha-1}(1-y)^{\beta-1}\, dy = \Gamma(\alpha)\,\Gamma(\beta)/\Gamma(\alpha,\beta)$$

$F(y)$ gives the area under the cumulative probability function between 0 and y, where y is a proportion of damage bounded by 0 and 1. This equation gives the probability, for example, that less than half of the crop will be destroyed in a given month. See Mendenhall, Scheaffer, and Wackerly (1981, p147) for a more detailed exposition.

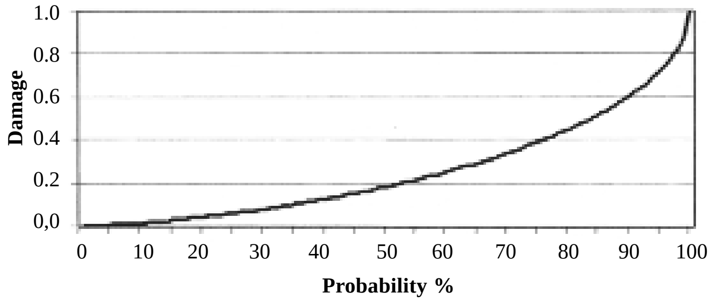
The skewness of the distribution is determined by the parameters alpha and beta, which must both be positive. Values of 1 for alpha and beta would lead to a straight line, implying an even and symmetric distribution with all levels of damage reported equally frequently. Such a distribution would have a mean of 0.5 and 0 skewness, and be represented by a straight, diagonal line in Figure 16. In this application to Desert Locust damage there are many more reports of minor damage than major losses (see Annex 5 and Annex 7). To accommodate this, the alpha and beta parameters are set at 1.5 and 0.5 respectively (Table 23) so that the probability distribution is positively skewed. The third moment, a measure of skewness, is just over one. Most of the observations are below the mean.

TABLE 23. **Beta distribution parameters for all regions and crops**

Alpha	1.5
Beta	0.5

These beta distribution parameter values produce a mean of 0.25 rather than 0.50 in an unskewed distribution. The following figure illustrates that less than the mean level of damage would occur 60 percent of the time and that less than 50 percent of damage would result from 84 percent of reported infestations. Recall that these levels of damage are predicted once it known that that infestation has occurred.

Figure 16 *Beta cumulative probability distribution alpha = 1.5 beta = 0.5*



Predicting damage – To illustrate the potential damage and the use of the of the beta distribution consider a further hypothetical example using the data in Table 24. Suppose there are crops in four degree squares within a country. Earlier it was shown how locusts are allocated to these areas depending on the relative frequencies relevant to the particular month. Given production and yield data, it is straightforward to determine the proportion of the degree square under crop (column 4). The next column records the probability of locusts landing in a particular degree square given that they do infest crops in the country. These are based on relative frequencies specified for Country 2 in Figure 15 shown earlier.

The probability of a crop in any one degree square being infested is simply the product of that degree square's relative frequency and its proportion in crop (the fourth column in Table 24). For example, for the first degree square, the proportion under crop (0.04) times the relative frequency (0.13) gives a probability of crop damage of 0.005, that is half of one percent.

Suppose this unlikely (for this month at least) event occurs, what will be the likely damage? Locusts are assumed to swarm together – either the entire population reaches the cropped areas or none of it does. Assuming a population large enough to cover 10 000 ha, the expected production losses would amount to the tonnage given in the final column of simply the area infested times the yield times the beta distribution mean of 25 percent. These losses are 'expected' in a statistical sense – the sum of all possible losses weighted by their probabilities. Losses may range from none to the maximum possible, four times the figures given in the final column. Note that all areas would not be destroyed simultaneously in the same month as the table suggests. However, the same crop could be damaged in later months in the same season.

Table 24 **Predicting damage: hypothetical example[a]**

Degree square	Area (ha)	Yield (t/ha)	Proportion of degree square under crop[b]	Relative frequency	Probability crop infested	Expected damage if infested (tonnes)
1	40 000	1.25	0.04	0.13	0.005	3 125
2	80 000	1.21	0.08	0.10	0.008	3 025
3	20 000	1.75	0.02	0.33	0.007	4 375
4	20 000	1.00	0.02	0.43	0.009	2 500
Total				1.00		

[a] Assumes Desert Locust population covers 10 000 ha.
[b] Area of crop/area of degree square (approximately one million ha).

Damage equation – The damage equation used by ELS for each cell is as follows (time subscripts are dispensed with here).

D	= AI . CP . PDp . MDp . β	if Pr > 10 000 million	(5)
	= AI . CP . PDu . MDu . β	if Pr < 10 000 million	

where

D	= damage (tonnes)
AI	= area infested (ha)
CP	= a dummy variable taking the value 1 if crop present, 0 otherwise
PDp	= relative probability of damage in a plague
MDp	= maximum damage in a plague
PDu	= probability of damage in a recession/upsurge
MDu	= maximum damage in a recession/upsurge
β	= beta distribution between 0 and 1 with alpha = 1.5 and beta = 0.5
Pr	= regional locust population.

An example will illustrate. Consider estimates of June losses of millet or sorghum in Ethiopia, a regional locust population covering 100 000 ha (AI) and default parameters and values. Millet or sorghum are present in Ethiopia in June, so CP is 1, implying some positive damage is possible. If the regional population is in plague proportions, as is likely to be the case with a population of this size, the probability of damage is 0.041064 and 18 164 tonnes is the maximum possible loss. If damage occurs at all, losses may range from 0 to over 18 000 tonnes, with a most likely value of around 4 540 tonnes (that is, 18 164*.25). If the locust population arrived in what was technically a recession period, the probability of damage would be 0.065987 and 6 750 tonnes the maximum possible loss. Note that the probability of damage is a relative figure, and relates to the other observed frequencies in a particular month. The higher probability for Ethiopia in June in a recession than in a plague does not mean damage is more likely to occur in a recession, because the area infested is much less. Given that damage occurs, the expected loss would be (6 750*.25=) 1 687 tonnes. The beta distribution is assumed to have the same parameters for both recessions and plagues, even though the probability of damage occurring differs.

Suppose that national policy makers in Ethiopia know that a swarm covering 100 000 ha exists but are not aware of any damage having occurred yet. From this perspective, what is the expected crop loss of millet and sorghum in June? This is the probability of damage (0.041064) times the expected loss if damage occurs (4 540), which amounts to a tolerable 186 tonnes. Mindful of a potential catastrophe, the policy maker could have calculated the probability of losing more than half the maximum possible 18 164 tonnes at (0.041064*0.182=) 0.0075, less than one percent. And the probability of losing three quarters or more of these crops in the area infested is 0.0023, less than a quarter of one percent. However, this applies for only one month and for only small grains. Consideration must be given to the damage that might occur in other months and for other crops in season.

Distribution and damage during recession and upsurge years – Reports of Desert Locust populations are fewer and less widespread during recessions or upsurges. The more limited distribution is reflected in the frequency maps. Thus, if the regional population is below a standard threshold value (set at 10^9 locusts or 2 000 ha of medium density swarms) ELS uses a slightly amended method, in order to reduce the influence of reporting biases within this relatively sparse data. Instead of comparing the relative frequency values of swarms between countries and within countries, ELS compares the relative number of degree squares with ANY reported incidence of Desert Locusts (that is, frequencies greater than zero). Once within the cropped area, ELS treats all degree squares with reported incidence of Desert Locust during the ten recession and upsurge years between 1940 and 1969 as having an equal chance of receiving populations. The way in which production data are utilised is as described previously.

National aggregation – The above examples illustrate damage calculated at degree square level. In order to simplify the total number of calculations undertaken by the model, the relative frequencies are weighted according to the proportion of total national production produced by each degree square, and the yields are weighted by area. This allows the damage calculations to be undertaken at a more aggregated country level whilst retaining the influence of the degree square level data on predicted outcomes. By this means, ELS estimates plague damage for 30 countries and two groups of countries by month, for each of eight different crop aggregations. Regional and crop aggregations are shown in Tables 25 and 26.

TABLE 25. **ELS: regional aggregations**

Region	**Western**	**North Central**	**South Central**	**Eastern**
Country	Algeria	Djibouti	Ethiopia	Afghanistan
	Benin	Eritrea	Kenya	Bangladesh
	Burkina Faso	Iraq	Somalia	India
	Cameroon	Saudi Arabia	Tanzania	Iran
	Chad	Sudan	Uganda	Pakistan
	Guinea	United Arab Emirates	OTHER**	
	Mali	Yemen		
	Mauritania			
	Morocco			
	Niger			
	Nigeria			
	Senegal			
	Tunisia			
	OTHER*			

* Includes Central African Republic, Ghana, Guinea-Bissau, Ivory Coast, Liberia, the Gambia, Togo and Sierra Leone; ** Includes Burundi and Rwanda.

TABLE 26. **ELS: crop aggregations**

Aggregation	**Crops**
Millet and sorghum	millet, sorghum
Wheat and barley	wheat, barley
Maize	maize
Rice	rice
Fruit and nuts	citrus, dates, fruits, almonds, figs, grapes, olives
Other fruit and vegetables	legumes, potato, tomato
Pulses and oilseeds	common bean, groundnut, pulses
Cotton	cotton

Valuation of damage

The extent of crop damage depends, in part, on crop yields. The value of the damage depends, among other things, on the value of the crops lost. In order to assess the financial impact of simulated physical production losses on a comparable basis, an adjustment is made to take account of the differences in yields and prices of different crops. This was achieved by calculating an equivalent ‘value of production’ for each crop. This is the average value of production per hectare in terms of wheat equivalent.

$$Vpj = Pj/Pw*Yj/Yw \quad (6)$$

where
VPj = value of production of commodity *j*
Pj = price of commodity *j*
Pw = price of wheat
Yj = yield of commodity *j*
Yw = yield of wheat.

Using equation 6, in Table 27 a hectare of rice is worth 32 percent more than a hectare of wheat. In fact wheat and rice have a similar yield, and the higher value of production can be attributed to the higher price for rice current at the time (1994).

TABLE 27. **Relative prices and relative value of production**[a]

Crop[b]	Price US$/tonne	Value of production
Millet and sorghum	125	0.89
Wheat and barley	137	0.98
Maize	121	0.86
Rice	185	1.32
Fruit and nuts	433	3.09
Other fruit and vegetables	193	1.38
Pulses and oilseeds	395	2.82
Cotton	742	5.30
Wheat reference price	140	-

[a] Values are relative to wheat.
[b] See Table 26 for crop aggregations.

The calculation uses prices received by farmers (FAO, 1998). Crop aggregations (Table 26) use a simple average of ‘value of production’ for individual crops. The values used by ELS are shown in Table 27 along with prices calculated against a wheat reference price of US$140/t.

The value of damage is not simply the value of the lost production. As explained in the main report, if damage is sufficiently large prices will rise in response, to the benefit of producers with products to sell, and to the detriment of consumers. If damage is insufficient to affect prices, the burden falls primarily on the affected producer. In many cases, of course, producers are also consumers, to a lesser or greater extent.

Responsiveness to price changes – At the heart of any economic analysis is the response of producers and consumers to changes in prices. How far will prices rise following locust damage to crops? How will producers respond to rising prices? Likewise, to what extent will consumer purchases fall in response? If producers are able to respond by replanting their crop, planting a substitute crop, taking better care of their remaining crops, drawing down stocks, etc, the effects are likely to be less significant than otherwise. Similarly, if prices rise sharply but consumers can readily switch to another commodity, the welfare effects will be minimal.

In this analysis, producers are assumed not to respond to price rises induced by locust damage. Supply elasticities are zero. This reflects the difficulties in making such an estimate, and to some extent results in an overestimation of the effects of the damage. Likewise, neither producers nor consumers respond to changes in the prices of substitute or complementary commodities. Such estimates are available but tend to be quite small, and their omission reflects expedience and the desire for simplicity.

The relationships between prices and quantities consumed, known as demand elasticities, can be seen in Table 28. These estimates are taken from FAO's World Food Model where available and apply at a national level. (See FAO, 1993 for model description. Data are available on request from FAO).

The first point from Table 28 to note is that, with the exception of Mauritanian millet and sorghum, all elasticities are negative, implying that consumers purchase less as price rise. This is usually but need not necessarily be the case, particularly when dealing with staples that comprise a high proportion of total expenditure. The second observation is that all estimates are less than (the absolute value of) -1. This means that a given change in price leads to a less than proportionate change in quantity. This is a characteristic of essential items such as food, and fertiliser. It implies that consumers are reasonably unresponsive to price changes, and continue to buy when prices rise. This has important implications, in that as national production is reduced, producers with products to sell are more than compensated by the rise in prices. Total sales increase as a result of a small decrease in production. Locust damage has a similar effect as production quotas or other supply controls used in many developed countries to support producer incomes.

TABLE 28. **Demand elasticities for selected countries**

Country	Crops	Elasticity	Country	Crops	Elasticity
Mali	Maize and sorghum	-0.20	**Sudan**	Maize and sorghum	-0.30
	Wheat and barley	-0.45		Wheat and barley	-0.60
	Maize	-0.26		Maize	-0.50
	Rice	-0.25		Rice	-0.90
	Fruit and nuts	-0.50		Fruit and nuts	-0.50
	Other fruit and nuts	-0.50		Other fruit and nuts	-0.50
	Pulses and oilseeds	-0.50		Pulses and oilseeds	-0.50
	Cotton	-0.50		Cotton	-0.50
Mauritania	Maize and sorghum	0.00	**India**	Maize and sorghum	-0.50
	Wheat and barley	-0.60		Wheat and barley	-0.25
	Maize	-0.49		Maize	-0.60
	Rice	-0.38		Rice	-0.40
	Fruit and nuts	-0.50		Fruit and nuts	-0.50
	Other fruit and nuts	-0.50		Other fruit and nuts	-0.50
	Pulses and oilseeds	-0.50		Pulses and oilseeds	-0.50
	Cotton	-0.50		Cotton	-0.30
Eritrea	Maize and sorghum	-0.20	**Pakistan**	Maize and sorghum	-0.30
	Wheat and barley	-0.45		Wheat and barley	-0.50
	Maize	-0.20		Maize	-0.20
	Rice	-0.20		Rice	-0.20
	Fruit and nuts	-0.50		Fruit and nuts	-0.50
	Other fruit and nuts	-0.50		Other fruit and nuts	-0.50
	Pulses and oilseeds	-0.50		Pulses and oilseeds	-0.50
	Cotton	-0.50		Cotton	-0.50

Source: FAO World Food Model (FAO, 1993) for food grains; for other commodities values are best judgements. See Table 26 for crop aggregations.

Export markets – These elasticities apply to the domestic market. Producers selling to international markets usually have little scope to influence prices. In such cases, locust damage losses will have little or no effect on prices, pushing the burden of the losses on to the individual producers affected. However, domestic and international markets are usually not fully integrated, with transport costs and other impediments implying that production shifts have some effect on local prices. In this analysis export volumes are assumed not to change, implying the burden of adjustment falls on the domestic (national) market. To the extent that producers cater for export market, this assumption underestimates the losses to these producers. However, while there are notable exceptions, most production in the locust-affected areas is domestically consumed.

Income effects – A rise in prices of a good on which household expenditure is a sizeable component has an income effect in that the consumer's ability to buy all goods is reduced. ELS calculates national producer and consumer gains and losses by estimating the income effects of price changes caused by Desert Locust damage. This requires estimates of how consumption of a good increases as income increases, so called income elasticities. These are obtained from the World Food Model (FAO, 1996) where available, and apply at the national level. There is no differentiation between different income groups. Typically, income elasticities for food are less than 1, and tend to become smaller as food takes a lesser share of total expenditure. Poor people spend most of any additional income on food, whereas more affluent consumers are more likely to spend any extra income on nonfood items.

A second necessary variable is the proportion of expenditure allocated to food or the particular staple of interest. It is assumed here that 70 percent of income is spent on food. Expenditure shares for each of the eight crop aggregations are derived from this. Using information on demand and income elasticities and expenditure shares and price changes, welfare effects of a negative production shock can be calculated. The procedure used in equation 8 involves calculating the 'equivalent variation', a measure which takes into account the income effect of price changes. This is thought to be particularly relevant given the low incomes of many producers who are affected by locust damage.

Formally:

$$CL_j = CON'_j * (P_j - P'_j) - 0.5*(P_j - P'_j)*(S'_j - S_j) \quad (7)$$

$$CS_j = CL_j + (\eta_j * (CL_j / (CON'_j * P_j / \sigma_j)))* CL_j \quad (8)$$

where

CL_j = consumer losses to consumers of commodity *j*
CS_j = consumer surplus to consumers of commodity *j*
CON'_j = base consumption of commodity *j*
P'_j = base price of commodity *j*
P_j = price of commodity *j*
S'_j = base production of commodity *j*
S_{jj} = production of commodity *j*
σ_j = expenditure share of commodity *j*
η_j = income elasticity of consumers of commodity *j*

Consumer losses are the base consumption level times the rise in price less half the product of the change in price times the change in quantity. The second term in equation 7 is merely a small triangle bounded by the price and quantity changes. Equation 8 takes into account the income effect of a price rise and simply measures a small shift or pivoting of the demand curve.

In the absence of any producer response to price changes, producer losses are simply:

$$PL_j = (S'_j - S_j) P_j. \quad (9)$$

However, producers gain from the rising prices:

$PG_j \quad = (S'_j)\ (P'_j - P_j)$ (10)

where

PL_j = production losses

PG_j = producer gains.

Net losses are:

$NL_j \quad = CL_j + PL_j - PG_j.$

Producer gains will outweigh producer losses if prices rise sufficiently, but these net producer gains are likely to be outweighed in turn by consumer losses, resulting in a net welfare loss overall from the locust damage.

Welfare loss estimates – At present ELS does not automate the estimation of welfare impacts. In order to evaluate the welfare effects for Morocco and Ethiopia discussed in the main text, ELS was set to output potential losses for these countries in a single peak year (worst year of each five year simulation run). The impacts were then evaluated exogenously in this case. Impacts were also calculated for several additional countries assuming a one percent production loss for each crop aggregation. The results are set out Table 29. For example, a one percent loss in Mali's millet and sorghum crop valued at US$125/t amounts to US$2 633 631. With an elasticity of 0.2, prices rise by five percent (the reciprocal of the elasticity). These higher prices are received by the producers of the remaining 99 percent of the crop, providing them with a gain of US$13 036 473. Consumers pay an extra US$13 175 907 in higher prices, although they consume less than in the absence of locust damage. Net losses amount to US$2 699 472, but the most significant effect is a large transfer from consumers to producers.

For each additional unit of income in Mali, it is estimated that 20 percent is spent on millet and sorghum. Using this information, plus the assumption that 70 percent of household expenditure goes on food items, it is possible to calculate the wealth-reducing effect of a price rise (not shown in Table 29). Instead of US$13 102 314, the equivalent variation of consumer losses for millet and sorghum consumers in Mali is US$13 266 577. The valuation of net losses rise from US$2 699 472 to US$2 863 735. Such calculations can be made for all crops in each country, but of course their validity depends on the assumptions concerning price and income elasticities and expenditure shares. Affected groups may have values for these parameters quite different from the estimated national average.

Note that while one percent loss of a particular commodity would not be uncommon, it is very unlikely that all crops would simultaneously be damaged to this extent – it would be misleading to add up the damage across crops within one or more countries.

Some final comments

There is scope for refining some of the assumptions and parameter values underlying ELS. It makes sense to focus on the variables that have the greatest influence on the outcome, particularly those about which there is uncertainty as to their value. The key variables in this analysis include:

- population growth rates;
- relative frequencies;
- detection rates and effectiveness;
- control costs.

Choosing a different historical period (wetter or drier) as an empirical basis for the population growth probabilities may give different results. A different base period would also affect the relative frequencies.

The model allows the user to specify detection rates and control costs, and also the rates at which these change. While substantial effort has gone into estimating control costs, little is known about detection rates or effectiveness of control activities.

The model provides a useful framework for a preliminary analysis and for possible further development. The quality of the data would seem not to justify a more sophisticated approach, but suggests instead that improved monitoring of population, detection, effectiveness and damage assessment might prove rewarding. Many parameters assumed common to all regions may well differ from region to region, from country to country, or from crop to crop. For example, the beta distribution may vary on this basis.

The economic analysis appears relatively robust. It could be improved by including export demand elasticities for crops that are internationally traded. Including positive supply responses in the model may be a useful refinement, but this would require knowledge of how farmers cope with losses. Lack of data on the distributional effects of locust damage limits analysis of its social impacts.

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TABLE 29. **Economic impact of a one percent loss of production in selected countries**

	Crops	Production loss tonnes	Base price $/t	Value of lost production $	Demand elasticity	Price change $/t	Producer gains $	Consumer losses $	Net losses $
Mali									
	M&S	21 030	125	2 633 631	-0.20	6.3	13 036 473	13 175 907	-2 699 472
	W&B	0	137	0	-0.45	0.0	0	0	0
	Maize	5 980	121	723 570	-0.26	4.7	2 755 132	2 772 448	-737 485
	Rice	8 020	185	1 482 350	-0.25	7.4	5 870 104	5 925 026	-1 511 996
	F&N	0	433	0	-0.50	0.0	0	0	0
	Oth. F&N	1 290	193	248 918	-0.50	3.9	492 858	495 654	-251 407
	P & O	3 320	395	1 310 418	-0.50	7.9	2 594 627	2 611 894	-1 323 522
	Cotton	7 300	742	5 419 697	-0.50	14.8	10 731 000	10 823 048	-5 473 894
Mauritania									
	M&S	3 430	125	429 546	0.00	0.0	0	0	-429 546
	W&B	0	137	0	-0.60	0.0	0	0	0
	Maize	410	121	49 609	-0.49	2.5	100 231	100 806	-50 116
	Rice	900	185	166 348	-0.38	4.9	433 381	436 981	-168 537
	F&N	0	433	0	-0.50	0.0	0	0	0
	Oth. F&N	100	193	19 296	-0.50	3.9	38 206	38 413	-19 489
	P & O	3 760	395	1 484 088	-0.50	7.9	2 938 493	2 992 807	-1 498 928
	Cotton	570	742	423 182	-0.50	14.8	837 900	843 838	-427 414
Eritrea									
	M&S	5 090	125	637 431	-0.2	6.3	3 155 285	3 845 648	-653 367
	W&B	1 740	137	238 455	-0.45	3.0	524 602	546 417	-241 105
	Maize	980	121	118 578	-0.2	6.0	586 963	620 122	-121 543
	Rice	1 230	185	227 343	-0.2	9.2	1 125 347	1 131 031	-233 026
	F&N	0	433	0	-0.5	0.0	0	0	0
	Oth. F&N	1 330	193	256 637	-0.5	3.9	508 140	511 132	-259 203
	P & O	590	395	232 875	-0.5	7.9	461 093	463 765	-235 204
	Cotton	1 042	742	773 794	-0.5	14.8	1 532 113	1 540 857	-781 532
Sudan									
	M&S	20 020	125	2 507 146	-0.3	3.9	7 870 419	7 756 484	-2 546 321
	W&B	2 720	137	372 758	-0.6	2.3	618 586	615 050	-375 864
	Maize	9 820	121	1 188 203	-0.5	2.4	2 371 643	2 352 643	-1 200 085
	Rice	3 150	185	582 220	-0.9	2.1	643 676	640 442	-585 454
	F&N	0	433	0	-0.5	0.0	0	0	0
	Oth. F&N	8 120	193	1 566 833	-0.5	3.9	3 118 095	3 102 330	-1 582 502
	P & O	6 560	395	2 589 259	-0.5	7.9	5 157 807	5 126 733	-2 615 152
	Cotton	15 040	742	11 166 061	-0.5	14.8	22 271 689	22 108 801	-11 277 722
India									
	M&S	238 570	125	29 876 620	-0.5	2.5	59 155 708	59 472 831	-30 175 386
	W&B	1 229 750	137	168 528 956	-0.25	5.5	667 374 666	676 082 809	-171 899 535
	Maize	116 820	121	14 135 023	-0.6	2.0	23 322 788	23 442 057	-14 252 815
	Rice	1 672 920	185	309 208 495	-0.4	4.6	765 291 025	772 486 700	-313 073 601
	F&N	127 120	433	55 006 364	-0.5	8.7	108 912 601	109 507 686	-55 556 428
	Oth. F&N	312 640	193	60 326 945	-0.5	3.9	119 447 351	120 172 056	-60 930 214
	P & O	108 660	395	42 888 552	-0.5	7.9	84 919 332	85 378 223	-43 317 437
	Cotton	20 020	125	2 507 146	-0.3	3.9	7 870 419	7 756 484	-2 546 321
Pakistan									
	M&S	9 970	125	1 248 564	-0.3	4.2	4 120 261	4 141 202	-1 269 373
	W&B	772 480	137	105 863 182	-0.5	2.7	209 609 100	211 288 920	-106 921 814
	Maize	33 890	121	4 100 633	-0.2	6.0	20 298 133	20 400 649	-4 203 149
	Rice	268 210	185	49 573 686	-0.2	9.2	245 389 745	247 575 952	-50 813 028
	F&N	130 340	433	56 399 697	-0.5	8.7	111 671 400	112 291 237	-56 963 694
	Oth. F&N	36 050	193	6 956 200	-0.5	3.9	13 773 276	13 844 743	-7 025 762
	P & O	9 400	395	3 710 219	-0.5	7.9	7 346 233	7 383 601	-3 747 321
	Cotton	53 420	742	39 660 304	-0.5	14.8	78 527 402	78 940 099	-40 056 907

The measure of consumer welfare used here, known as equivalent variation, takes into account the impact of price changes on real purchasing power.

Costs and financing of Desert Locust management – case studies

Data

Eight countries were commissioned to provide evaluation reports of campaigns carried out between 1987 and 1996, including details of expenditure incurred in maintaining their permanent locust control capacity. The countries and campaigns were selected as being representative of a range of different circumstances affecting locust-affected countries. The reports provided are listed at the end of the annex under country campaign evaluations.

In addition, donor agencies were requested to provide details of expenditure on Desert Locust control, including research and development. FAO provided details of its own projects from records.

There is some difficulty in separating aid and expenditure on Desert Locust from that on other grasshopper pests, since some projects covered both. Projects specifying 'locust and grasshopper' or 'antiacridienne' are totalled separately. They amount to 3.2 percent of the total expenditure in nominal terms and 3.6 percent in terms of 1990 US$.

The analysis gets closer to a complete picture of the costs of Desert Locust management than has previously been available, but is still not comprehensive. There are gaps in the external financing data. Reports from individual countries also show that there were a large number of emergency donations, some by non-governmental organizations and some by other countries in the region which are not accounted for.

Country campaign evaluations

Algeria – Information on international assistance and expenditure was included in this study but the full report analysing campaigns arrived too late for inclusion.

Eritrea – Eritrea is a newly independent country. As a result, there are no figures on long term fixed costs. These have therefore been estimated from the durability of capital equipment, the recurrent government budget and the contribution to the Desert Locust Control Organization for Eastern Africa (DLCO-EA). Variable costs are taken to be the government emergency budget and the donor contributions to operations. The report states that pesticides for the campaigns were taken from stock or supplied through DLCO-EA and so costs were estimated by applying a standard cost per hectare treated (US$5.5).

Mali – Mali gives detailed costs in local currency for the 1987/88 and 1996 campaigns. The fixed costs consisted of government recurrent staff costs and recorded expenditure on vehicles and equipment written off over ten and five years respectively. Since details of capital purchases are not given for other years, it must be assumed that this is an underestimate.

Mauritania – Mauritania gave detailed expenditure in local currency from 1986 to 1996 (11 years). It also gave areas treated for each season. Pesticide costs were calculated by summing the purchase of pesticide (1990 US$) over ten years and allocating them to each season in proportion to the area treated. The mean cost/ha was US$4.53. A discrepancy between stocks at the beginning and end of this period would create an error.

Morocco – Detailed budgets and international assistance are given in local currency over the ten year period. Fixed costs are calculated as recurrent government expenditure plus average capital expenditure from all sources. Total pesticide costs (1990 US$65 203 537) are given, but cannot be attributed by year, since total quantities used are not given for each year. Instead, pesticide costs are estimated by a standard rate (US$5.5) per hectare treated.

Saudi Arabia – Saudi Arabia maintains a substantial budget allocation for locust control. The data used here are as reported verbally to FAO consultant Laury McCulloch. It is assumed that these expenditures are primarily towards fixed costs, and that supplementary allocations have been made in seasons during which campaigns have been carried out.

The Sudan – The report gives expenditure and international assistance over the period of the study. Details are given of the campaign on the Red Sea coast in the winter of 1993. Analysis is made complicated by the fact that a further campaign was carried out in the summer of the same year in central and western Sudan, but no costs are given for it. This creates problems in allocating fixed costs to the campaign. The report gives a priced inventory of equipment with estimates of durability. It is not clear how much of this equipment was used in both campaigns, or what proportion of the government's recurrent expenditure should be allocated to each. The compromise that has been adopted is to attribute to the winter campaign the entire annual depreciation of the equipment actually used in it and half the recurrent government expenditure for the year.

Yemen – The total quantity of pesticide used is given, but is not broken down by type. The report gives an average cost of US$8/kg-litre and the total cost is estimated from these figures. The report gives fixed costs for the campaign year using estimated depreciation of capital equipment. The area treated is not broken down by method or life-cycle stage. In order to complete the analysis and calculate a cost in terms of swarm equivalent, a guess has been made of the breakdown, using information on flying hours and comparing with other countries.

Pricing

Prices are in 1990 US$. These are calculated from local currency using the real exchange rate and the US gross domestic product (GDP) deflator for each year (IMF 1997). Where original prices are given in dollars, these are used and deflated. Some countries have presented all expenditure in local currency and since the exchange rate used for dollar purchases is not known, this may be a source of error. During the period of the study, most countries went through severe devaluation of their currencies and so changes in local costs may reflect this rather than true economic values.

Costs

Calculating fixed costs – Fixed costs are the depreciation costs of capital equipment such as vehicles, application equipment and aircraft (where purchased specifically for locust control) plus the recurrent costs of maintaining the establishment, such as staff salaries, services and recurrent purchases. There is some variation between reports in coverage and methodology. Where necessary fixed costs have been inferred from the available information, in one of two ways.

- Where there is a priced inventory of equipment for one year, with an estimated durability, its annual depreciation can be calculated.

- Where annual expenditure on capital equipment is given for each year of the study, this can be averaged over the full period.

Countries differ in how completely they provide recurrent establishment expenditure. Staff costs are usually given as salaries, which do not capture the full cost of employing permanent staff. Some countries give details of expenditure on services, others give none. Where the only information is the national annual budget allocation, this is used.

Where countries contribute to regional organizations or trust funds, this is included in fixed costs. Eritrea's contribution to DLCO-EA is the major item of its fixed costs. Although the Sudan is a member, it has not made any contributions for many years.

Calculating variable costs – Variable costs include all expenditure incurred above fixed costs by field operations (survey and control). They include vehicle running costs (fuel and repair), hire of aircraft, subsistence, medical and travel costs for staff in the field, casual or seasonal labour and pesticides. In this analysis, the pesticide costs are separated from the other operational costs, as there are a number of problems in estimating them.

- Figures for expenditure refer to purchase, not use, since stocks may remain in store for many years.

- Figures for quantities used seldom specify type and price.

- Prices of the insecticides commonly used against Desert Locust have declined in real terms and really need their own deflator figure. A further distortion occurs if the original purchase price is given for the year in which the chemical is used. This is the cause of the most extreme inconsistencies in the costs that have been calculated.

Maintaining large pesticide stocks creates other costs which have not been captured in this analysis.

- Opportunity cost of the capital locked up in stocks.

- Physical deterioration and loss of the material (including disposal of obsolete stocks).

A best estimate of pesticide costs is made for each country, using the data available. However, because of inconsistencies between countries, a figure is also given which estimates pesticide costs by multiplying the area treated by a standard cost/ha. (US$5.5) based on those prices that have been given. It is, however, only a rough approximation and this is an aspect on which more work needs to be done.

Calculating unit costs – The number of locusts killed by a hectare of spraying will vary with many factors, the most important of which are the method of application and the life-cycle stage of the insects. Symmons (1992) estimates that block spraying of hoppers bands kills only four percent as many locusts as the equivalent area of adult swarm, whereas target spraying hopper bands from the ground kills the equivalent of twice the area of adults. These estimates are rated as ‘plausible’.

Unit costs have been calculated here in terms of ‘swarm equivalent hectares’. In the analysis it is assumed that aerial spraying of hopper bands is block spraying and ground spraying is target spraying. Whereas one hectare of target-sprayed hopper band represents two hectares of adult swarm, twenty-five hectares of block spraying represent one hectare of adult swarm. Clearly, the proportion of bands that were sprayed from the air rather than from the ground has a strong influence on unit cost.

There are other factors, such as the density of the insects and the efficiency of the application, that will bear on the reduction of population achieved, but there are no data on individual campaigns. During a large campaign, it might be expected that variations in insect density will be averaged out, but this may be an important source of error in small campaigns of a few thousands of hectares.

The swarm equivalent is therefore calculated by adding the area of adult swarms actually treated, twice the area of hopper bands treated from the ground and four percent of the area of hopper bands treated from the air.

Factors driving fixed costs – Morocco has the highest fixed costs. This is partly attributable to the fact that the Ministries of Interior, Defence and Health, as well as Agriculture, all have recurrent locust control budgets and that the Ministry of Defence has purchased aircraft for this purpose.

Table 30 shows each country's fixed costs against a number of indicators. The human development index (HDI) is calculated from life expectancy, level of education and income (UNDP 1995). Crop vulnerability index (CVI) is a measure of relative vulnerability to crop losses over a long period, calculated from historical frequencies of infestation and the area, yield and value of susceptible crops. Fixed costs show some correlation with GDP/capita (1993).

TABLE 30. **Total and fixed costs of Desert Locust control for selected countries versus economic indicators**

Country	Ten year total US$	Fixed cost US$	Area km^2	Crop vulnerability index	UN human development index	GDP/ head US$	Agriculture as % GDP
Algeria	104 774 731	1 830 019 *	2 381 741	2 427	0.732	4 870	13
Morocco	128 680 960	2 773 387 *	446 550	16 061	0.554	3 270	14
Mauritania	30 643 793 ††	778 652 **	1 030 700	186	0.359	1 610	28
Saudi Arabia	no data	25 734 611 †	2 240 000	136 978	0.762	9 880	38
Sudan	8 149 718	366 183	2 505 813	19 098	0.379	1 350	34
Mali	no data	255 572	1 240 000	345	0.222	530	42
Yemen	3 194 747	187 521 *	536 869	2 437	0.424	1 600	21
Eritrea	no data	156 715	121 144	10 818	0.227	420	60

* 10 year average; ** 9 year average; † government annual budget; †† 9 years corrected to 10.

Factors driving variable costs – A large component of variable costs, notably pesticide cost and aircraft hire, have international prices. The only source of variation ought to be the efficiency with which they used and the need for aircraft survey. However, there are a number of difficulties with pesticide costs, which have been discussed above.

The financial cost of running vehicles is sensitive to fuel costs. Where labour-intensive ground operations are used, labour costs will also be an important variable. Ground and aerial spraying operations will have distinct cost functions. However, in nearly all the campaigns studied, both methods were used and the operating costs attributable to each were not disaggregated. Because of the difference in "swarm equivalence" between ground and aerial treatment of hopper bands, the proportion in which these two methods were used is the most important factor in determining unit cost. However, it should be emphasised that although target spraying of bands is efficient in terms of cost and pesticide used, it is extremely inefficient in terms of the proportion of the infestation likely to be controlled (Symmons 1992).

The analysis of eleven campaigns from six countries is shown in Table 31. There are no apparent economies of scale in the variable component of unit costs, though clearly there is an effect on total unit cost as fixed costs are 'diluted'.

TABLE 31. **Costs of selected Desert Locust control campaigns (1990 US$)**

Country	Year	Ha treated	Swarm equivalence	Costs fixed	non-chemical	chemical	Total
Eritrea	1993	27 378	18 888	156 715	481 984	150 579	789 278
	1995	51 897	53 657	156 715	201 404	285 434	643 552
Mali	1988	503 098	205 046	255 572	3 634 894	2 998 500	6 888 966
	1996	1 600	2 122	227 297	83 615	4 667	315 579
Mauritania	1992	12 575	24 950	695 470	127 590	65 714	888 774
	1994	834 400	854 400	695 470	2 696 409	4 360 370	7 752 248
	1996	12 857	20 128	695 470	195 297	67 188	957 954
Morocco	1988	2 855 905	2 909 145	3 559 771	38 910 532	21 419 288	63 889 591
	1995	139 106	137 134	3 157 614	2 588 473	1 043 295	6 789 383
Sudan	1993	86 083	89 947	366 183	282 792	441 571	1 090 549
Yemen	1993	192 405	292 405	194 301	561 051	888 271	1 643 624

TABLE 32. **Unit costs of selected campaigns calculated from standardised pesticide costs**

				Pesticide cost given		Pesticide US$5.5/ha treated	
Country	**Year**	**Ha treated**	**Swarm equivalence ha**	**$/ha swarm equivalence**	**$/ha swarm equivalence variable**	**$/ha swarm equivalence**	**$/ha swarm equivalence variable**
Eritrea	1993	27 378	18 888	no data	no data	41.74	33.49
	1995	51 897	53 657	no data	no data	11.99	9.07
Mali	1988	503 098	205 046	33.60	32.35	32.47	31.22
	1996	1 600	2 122	148.72	41.60	150.67	45.55
Mauritania	1992	12 575	24 950	35.62	7.75	35.76	7.89
	1994	834 400	854 400	9.07	8.26	9.34	8.53
	1996	12 857	20 128	47.59	13.04	47.77	13.22
Morocco	1988	2 855 905	2 909 145	no data	no data	20.00	18.77
	1995	139 106	137 134	no data	no data	47.48	24.45
Sudan	1993	86 083	89 947	12.12	8.05	13.14	8.69
Yemen	1993	192 405	292 405	5.62	4.96	6.20	5.54

Total expenditure – Table 30 includes total expenditure on Desert Locust control for each country (as given in the reports) from all sources. The following possible errors exist.

- The estimate takes no account of the inventory of capital and consumable items held at the beginning and end of the study period.
- Some countries, notably Mauritania, received bilateral assistance from others, such as Morocco and Saudi Arabia. Algeria both received assistance from Saudi Arabia and gave it to Mauritania. There may therefore be some double accounting, if these sums appear in the budgets of both the donor and the recipient.
- For Mali and Eritrea, there are no overall costs covering the ten year period.

There are discrepancies between expenditure as reported by the countries and the aid contributions as reported by the donors and FAO.

TABLE 33. **Estimates of total expenditure, 1990 US$ – self financing and external assistance**

Country	Domestic	Aid	Total
Algeria	92 578 844	13 345 483	105 924 327
Eritrea	no data	2 094 201	2 094 201
Mali	no data	6 941 128	6 941 128
Mauritania	5 059 776	37 161 958	42 221 734
Morocco	101 362 974	5 573 860	106 936 834
Saudi Arabia	25 734 611	0	25 734 611
Sudan	2 994 679	9 041 961	12 036 640
Yemen	1 047 740	3 583 771	4 631 511
Other countries	no data	5 087 740	5 087 740
Regional	no data	44 230 290	44 230 290
Unattributed	no data	20 226 928	20 226 928
Total	228 778 624	147 287 320	376 065 945

Table 33 shows all known expenditure from donors and from national budgets for which information is available. For example, it includes assistance to Mali and Eritrea even though it has not been possible to calculate the ten year totals for those countries. There are therefore some discrepancies between Tables 1 and 33

Economic costs – This analysis uses financial costs converted to dollars (when necessary) at the real exchange rate (IMF 1997) and deflated to 1990 values by the US GDP deflator. There are areas where this may lead to some divergence from true economic costs.

- Local fuel prices may contain a high element of tax or subsidy, which needs to be removed from the cost.

- Many countries had overvalued currencies, during the early part of the study that were devalued towards the end. The result is a distortion of the cost of non-tradable goods, such as manpower, services and accommodation, that should be corrected by an appropriate conversion factor.

- Staff costs, where given, include only salary costs. The full cost should include pension and social security and should also be corrected for income tax.

- The price of pesticide has remained remarkably stable in nominal terms over the period of the study, which means that it has declined in real terms. Since this is a major cost component, a special conversion factor should be calculated for it.

- The analysis contains no element for the cost of capital committed as equipment and pesticide stocks.

Campaign effectiveness

Campaign effectiveness is the proportion of the population killed by the operations. This can only be properly evaluated on the basis of information collected daily during a campaign. As a crude approximation, for the campaigns reported here, the gross infested area was estimated by counting the number of degree squares in which the population was thought to be present, reckoning each degree square to be one million hectares and assuming a level of infestation of one percent. The swarm equivalent area treated during campaigns was multiplied by a factor for mortality (0.8) and expressed as a percentage of the gross infested area. This gives results ranging from 1.5 to 180 percent.

Conclusions

This study represents an initial attempt to establish actual costs of locust control operations in the eight countries of the study. The total figure for the ten year period, 1987-1996 is US$376 million (1990 US$). This includes a relatively small amount of regional aid that benefited other countries and US$13.9 million (1990 values) of aid that was intended for both locust and grasshopper control.

The study reveals striking differences in costs between countries and between campaigns. It also reveals important areas of uncertainty and data shortages. There is a widespread lack of verifiable data for levels of infestation, detection rates and mortality from spraying; as well as actual pesticide costs that require more detailed investigation.

References

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Nurein, M.O.M 1995. *Study on the economic significance of Desert Locust*. Khartoum, Arab Organization for Agricultural Development. (Unpublished report)

Symmons, P. 1992. Strategies to combat the Desert Locust. *Crop Prot.*, 11: 206-212.

UNDP. 1995. *Human development report*. New York, Oxford University Press.

Country Campaign Evaluations

Abdalla A. A. 1997. *Campaign evaluation report season 1992/1993: Sudan*. Rome, FAO. (Unpublished report)

Ba-Angood, S. & Mughni, A.A.A. 1997. *EMPRES Central Region Desert Locust campaign 1992/93 evaluation report: Yemen case study*. Rome, FAO. (Unpublished report)

[Ghaout, S.] 1997. *Evaluation des campagnes de lutte contre le criquet pèlerin au Maroc*. Rome, FAO. (Unpublished report)

Gruys, P. 1996. *Desert Locust campaign evaluation in four countries in the Western Region. Consultancy report, FAO EMPRES*. Rome, FAO. (Unpublished report)

McCulloch, L. 1996. *EMPRES Central Region campaign evaluation case studies: supplementary guidance notes for authors*. Rome, FAO. (Unpublished report)

McCulloch, L. 1996. *Campaign evaluation mission to Eritrea, Saudi Arabia, Sudan and Yemen. Consultancy report, FAO EMPRES*. Rome, FAO. (Unpublished report)

Soumaré, L. 1997. *Evaluation des campagnes de surveillance/lutte contre le criquet pèlerin au Mali en 1988 et 1996*. Rome, FAO. (Unpublished report)

Ould Babah, M. A. 1997. *Evaluation des campagnes anti-acridiennes récentes en Mauritanie*. Rome, FAO. (Unpublished report)

Woldu T. 1997. *EMPRES Central Region Desert Locust campaign evaluation: Eritrea case study*. Rome, FAO. (Unpublished report)

Selected case studies of Desert Locust damage

1. Morocco 1954/55

Sources of information
Original source of information for the invasion of the Souss Valley and damage levels appears to be an unattributed report in Le Figaro (18 November 1954). Other information for this case study has been taken from the following publications (the quality of the information is unknown):

- Vayssière P. 1954. Le problème acridien sur le continent africain. Rev. Étud. Calam., **XIV**: 23-36.
- Bouhelier R. 1955. L'invasion acridienne au Maroc d'octobre 1954 à mars 1955. *Terre maroc.*, **304**: 1-11.
- Rainey R.C. 1963. Meteorology and the migration of Desert Locusts. *Anti-Locust Mem.* No. 7: 115pp.
- FAO. 1965 Final Report of the Operational Research Team of the United Nations Special Fund Desert Locust Project. Volume 1. *Project report* no. UNSF/DL/OP/5. Rome.
- Pedgley, D. (ed.). 1981. *Desert Locust forecasting manual.* Vols I & II. London, HMSO.

Locust situation and reported damage
Swarm invasions of Morocco are a normal occurrence between late September and the beginning of November, following earlier summer breeding in the Sahel and the first swarm was reported in Morocco on 16 October on the west coast at 31°N. This swarm was part of an extensive north/north-westward displacement by swarms which led to the invasion of the Canary Islands on 14 October (and locusts reaching the British Isles between 17 October and 2 November). Extensive swarm movements into Morocco continued until January with swarms moving north through Morocco and further invasions from the east and from southern Algeria, although the peak of swarm redistribution ended in November. By the end of February 1955, control had been carried out over 4 610 km^2 in Morocco.

The Souss Valley, which opens to the sea at ~30°N and is bordered by mountains 2 500 to 4 000 m high, was reached by swarms in late October. Some of these swarms appear to have remained continuously within the valley until they matured and bred from the end of January 1955. This relatively static situation can be attributed to local winds (sea breezes and anabatic winds) confining swarm movements to local displacements within the valley and to low temperatures inhibiting flight activity. The swarms, which were estimated to cover 2 500 km^2 caused US$13 million of damage to market gardens and orchards in the Souss Valley. Nearly a quarter of the damage was caused during the first two weeks of the invasion.

2. Ethiopia 1958

Sources of information
Data for this study have been taken from four sources:

- Joyce, RJV. 1962. Crop losses in Eastern Africa. *In Report of the Desert Locust Survey 1st June, 1955 to 31st May, 1961.* p. 86-90. Nairobi, East African Common Services Organization.

- FAO. 1965. Final Report of the Operational Research Team of the United Nations Special Fund Desert Locust Project. Volume 1. *Project report no*. UNSF/DL/OP/5. Rome.

- Bullen, F.T. 1969. The distribution of the damage potential of the Desert Locust *(Schistocerca gregaria Forsk)*. AntiLocust Mem. No. 10.

- Pedgley, D. (ed.) 1981. *Desert Locust forecasting manual*. Vols I & II. London, HMSO.

Most of the information on the locust situation and control operations is derived from experienced survey and control officers in the Desert Locust Survey. The damage estimates are derived from both visual estimates and losses calculated by the Eritrean Department of Agriculture.

Locust situation in summer 1958

Swarms from Saudi Arabia invaded Eritrea (then part of Ethiopia) in June and July 1958 and breeding resulted in large-scale hopper infestations that extended into the Sudan. Numerous immature swarms were produced in early September onwards, covering an area that stretched across the Sudan, Ethiopia and Eritrea in an east-west belt north of 10°N. A smaller area of swarms was reported in the south of Yemen at the same time. Fledging continued into October in parts of the Sudan, Eritrea, Ethiopia and southern Yemen, with the last reported fledging swarm in southern Yemen on 30 October. From the end of September to the end of October, swarms started to migrate from the breeding areas. They moved to the south of 10°N in Ethiopia; northwards to Egypt and southern Sinai, and eastwards to the Red Sea coast of the Sudan and the Arabian Peninsula

Control

From 22 to 25 August, 1331 gallons of insecticide (mainly 20% dieldrin) was applied from aircraft in Eritrea. From 21 September to 8 October, 4 430 gallons of insecticide (mainly 15% gamma BHC) was used against 14 swarms (~15 °N 36 °E). An estimated 41 km^2 of swarms were killed, but this was only a very small proportion (< four percent) of the total swarm area.

Locust populations and reported damage

Heavy damage to the predominant subsistence crop in Eritrea (~125 500 tonnes of mixed grains) occurred over a ten day period when the locusts were late instar hoppers (Joyce 1962; Bullen 1966, 1969) and fledglings. The swarms in Eritrea were estimated to cover 1 036 km^2. Together with damage in Tigré and Harar Provinces, the total value of the crops lost was US$12 million and a further US$400 000 was spent distributing food aid. Taxation was also remitted in the affected areas.

In Eritrea, production estimates based on mean July rainfall, altitude and mean yield from five agricultural divisions where crops are grown on the summer rains (i.e. excluding the Red Sea coastal plains were compared with actual production figures and visual estimates of damage.

Crop	Calculated % reduction due to locusts*	Estimated % reduction
Sorghum	70	90
Millet	50	90
Barley	0	10
Wheat	18	50
Maize	37	30

* ± 20% error

3. The Sudan 1988

Sources of information

The data for this analysis have been taken from a report (15 December 1988) by CARE (Britain) entitled – *Report on the use of Karate 40 ULV donated by ODA*. Much of the information on degree of damage and levels of locust infestation is anecdotal and/or based on visual estimates from rapid surveys. Additional locust data were derived from the FAO Desert Locust Bulletins for the period May to October 1988 (see also Bullen F.T. 1996. Cost effectiveness of control measures. Preliminary Analysis. Unpublished Report).

Agriculture in Kordofan

The main subsistence crops grown in Kordofan are millet and sorghum, 68 percent of which is produced in South Kordofan. The bulk of the millet (82 percent) is produced in northern and central Kordofan (Zones 1 and 2, see below) and most of the sorghum (91 percent) is grown in southern Kordofan (Zone 3, see below). In 1988, rainfall began in May and was prolonged and heavy. This resulted in crop losses due to flooding in South Kordofan, but greater productivity of millet, groundnut and sesame in central Kordofan (due to farmers planting a wider variety of crops over larger areas) (Zone 2, see below).

Locust situation in summer 1988

From mid-May to mid-July 1988, several mature swarms were reported in the Sudan across an east-west belt between 12 and 18°N and summer breeding was underway. Further major large scale swarm invasions occurred from the east from mid-July onwards. Summer rainfall was good and widespread breeding occurred across the Sahel, resulting in largescale hopper band formation in August and further laying by mature swarms. By late August and early September, new first generation swarms were being produced. It appears that swarm maturation was rapid in the favourable conditions throughout the Sahel and a second generation of breeding began in mid-September. Breeding and swarm formation continued for the next few months, with swarms starting to move towards the Red Sea coast in late September and continuing eastwards to the Arabian Peninsula over the next few months.

Locust populations and reported damage

Kordofan was divided into three zones according to level of locust infestation and damage:

Zone	~ latitude	Locust situation	Damage levels	% normal total food production
Zone 1	~north of 13°N	widespread swarm invasion and breeding zone	damage to food crops ~ 50%	~7
Zone 2	~12-13°N	some swarm invasion	damage ~5%	35
Zone 3	~south of 12°N	very restricted swarm invasion	no damage	58

In detail within Zones 1 and 2, the following information is available at District Council level:

Zone 1

District	Locust months	Locust population	Crop growth stage	Crop	Crop area affected	% damage
Bara	July>	hoppers, swarms (breeding)		millet	45%	5-50
Sodiri	August>	hoppers, swarms		millet pasture		30-40 10-60

Zone 2

District	Locust months	Locust population	Crop growth stage	Crop	Crop area affected	% damage
El-Obi	September (last week)	2 swarms (overnight)	mature	millet		1-2
Umm Ruwaba	October (few hours each swarm)	swarms	mature?/ harvest	millet sorghum		10
Umm Ruwaba	1 October	1 swarm		cotton millet/sorghum/ sesame	1.18 km^2	100 0
Umm Ruwaba	post 1October			millet/sorghum/ sesame millet/sorghum/ sesame	0.38 km^2	100 7.5
Umm Ruwaba	October (overnight)	swarm(s)		sorghum millet sesame		20 20 15
Umm Ruwaba	October	1 swarm				~0
Umm Ruwaba	October	>2 successive swarms		millet	10 km^2	75
En Nahud	September (few hours) September (overnight) September (overnight)	1 swarm 1 swarm 1 swarm		millet? sesame/ groundnut		0 5 0
En Nahud	3-5 October	2 swarms	green/ not mature	sorghum/ millet groundnuts/ pasture/trees	1.18 km^2	100 0
En Nahud	6 October	1 swarm		grain groundnuts		5 0
En Nahud	7 October (6 hours)	1 swarm				~0
En Nahud	7-9 October	2 swarms		sorghum/millet water melon groundnuts	30%	80 50 ~0
En Nahud	1st week October	swarms (not settled)				0

Population dynamics parameters

Roffey and Magor prepared a paper that summarises information on parameters required to build population models. It is based on an unpublished report by Roffey (1991) and incorporates many amendments suggested by colleagues to whom it was circulated. Those developing models, to evaluate the economics of Desert Locust impacts or to testing strategies and tactics of control interventions, will quickly realise that some parameters are better documented than others. For example, sufficient quantitative data exist for swarm migration and egg and hopper development to be well understood and models of these processes already exist (Reus and Symmons, 1992; Meteo Consult, 1994). Where information is unavailable or insufficient, the authors have suggested values that may be used. They have cited data sources so that modellers can evaluate and modify values.

The Desert Locust upsurge 19921994: a controlfree simulation

Magor developed a model using population parameters from Roffey and Magor (in preparation). Likely timing of breeding was linked to widespread falls of rain and its duration was estimated from maps of incubation and hopper development periods (Symmons *et al.*, 1973). Population growth was estimated from a relationship between rainfall and multiplication rates. Swarms appeared with little warning on the Red Sea Coasts of Eritrea, southern Sudan and Saudi Arabia in November 1992. The study established that the model simulated these appearances with reasonable accuracy. The simulations suggest that although some locusts had gregarized locally, most arrived from spring and summer breeding in northwestern Somalia and the adjacent parts of Ethiopia, and from summer breeding in the Sudan. The upsurge continued to develop within the Central Region and spread to the Eastern and Western Regions in the summer of 1993. These later events were simulated without control.

Preliminary results indicate that without control a major plague may have developed. Model simulations begin to produce markedly larger populations in the Central and Eastern Regions, than those reported, from the spring of 1993. The model suggests that about 50 swarms (2×10^{10} locusts) with a total area of 450 km^2 would have invaded India and Pakistan. Above average rainfall suggests further population growth to around 5×10^{10} locusts, approximately 1 000 km^2 of swarms, during the first summer generation. Half of this population was assumed to migrate westward. Part invaded western Pakistan, Iran and northeastern Arabia, and the rest moved to southern Arabia and to northern Somalia. Monsoon rains continued in part of the Indo-Pakistan breeding area and would have allowed further population increase during the second summer generation. The model indicates that a very large plague population could have resulted, 2×10^{11} locusts occupying over 3 000 km^2. A quarter was assumed to move south and eastward and to die without breeding. Half of the remaining population was assumed to move north and remain within India and Pakistan without breeding until the following spring. The final quarter moved westward to western Pakistan, Iran and Arabia.

The movement of swarms into Somalia in October simulated a spread of the plague into Eastern Africa. Assuming normal rainfall, populations totalling 2×10^{10} locusts (425 km^2 of swarms) could have entered Kenya after Short Rains breeding early in 1994.

The simulated swarming and non-swarming locusts that invaded Mauritania and Senegal in the summer of 1993 would have led to a modest but larger invasion of Northwest Africa than actually occurred. Currently, the impact of breeding during the spring of 1994 is being simulated.

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Historical Desert Locust damage database

Note. Only selected sections of the full documentation on this database have been included here. Those omitted are: database structure, data aggregation and standardisation, adjusting multi-species financial damage estimates and a full list of references.

Introduction

Information on damage by Desert Locusts is sparse, usually subjective and not in a standardised form. Inspite of these limitations, however, this is the only primary data source on losses due to Desert Locusts. Before any preliminary estimation of the scale and distribution of economic returns to Desert Locust management can be carried out, these damage data needs to be collated as a basis for comparing damage, population size and control efficacy.

DLDAMGE3 (Desert Locust Damage Database Version 3) has been developed in order to investigate recorded instances of Desert Locust damage. The database was created in Microsoft Access® forWindows™ Version 2 and requires 1 081 344 bytes of disk space. The database contains nearly 650 damage records from 63 of the references cited in the COPR Locust and Grasshopper Agricultural Manual (COPR, 1982) and in a bibliography on the economic importance of Desert Locusts (Groenewold, 1995). The records, held at NRI, contain Desert Locust damage events from the early 1900s to 1994. Most records are from three plague periods: 19251934, 19401948 and 19491963 and the main sources of data were:

- questionnaires sent to affected countries by locust coordinating committees in 1936 and 1953 (repeated 1957); and

- published and unpublished literature describing observations by survey teams and citing questionnaire results.

A quarter of the records contain financial estimates of the damage, others contain quantitative estimates of yield losses, but most have only qualitative descriptions of crop loss. Other references cited by COPR (1982) and Groenewold (1995) were scanned, but not included in the database since they did not contain any additional financial estimates of damage. Individual locust reports archived at NRI (1929-1978) and FAO (post-1978) were not scanned for crop loss data, since they rarely include quantitative damage information (Bullen, 1969).

About the locust data

Defining Desert Locust damage – Crop damage is a function of locust numbers, their feeding behaviour and the length of time they remain in a crop. Only one paper (Joyce, 1962) described the method used to assess crop loss. This is a serious omission because yield loss from defoliation, the most common form of locust damage, depends on when the crop is defoliated. In cereals, loss may be complete at the seedling stage, although some economic compensation by farmers will usually be feasible. Losses become high again if the plant is damaged after the ear emerges. Yield may be unaffected during the intervening vegetative period. Bullen (1969) summarized likely effects on frequently damaged crops: wheat, barley, maize, sorghum, pennisetum, rice, sugarcane, citrus, coffee and cotton.

It is clear from the documents used in the database, that qualitative losses were normally assessed at the time of observation and so may not be an accurate reflection of yield loss at harvest. Where monetary values have been given, the methods by which these values were derived are rarely provided. It is assumed that the value is based on loss of gross income/production, but this would result in an overestimate of losses if the crop was not near harvest. Financial estimates of damage may also differ between reports for a multi-reported event, particularly when different currencies were used.

About the financial estimates

Standardising financial estimates from different countries and time periods – Two main approaches may be used to standardise data for intercountry comparisons: first, choosing a set of reference prices (expressed in a common currency unit) for different commodities and aggregating values for different countries by repricing the output of different commodities at the reference prices; and secondly, choosing conversion rates that can be used to convert aggregates into a common currency unit – generally referred to as the purchasing power parity approach.

Reference price– The data available are the major determinant for the choice of approach. If physical loss data of individual commodities are available, it is possible to express physical losses in any common currency unit, e.g. present day US$, wheat relatives or calorific units. Using this approach, historical damage expressed in, for example, tonnes would be given a present day value by multiplying this loss by a present day price. Thus, 43 000 tonnes of sorghum estimated to have been lost in Eritrea in 1958, would represent present day losses of US$4 300 000, assuming a present day price of US$100/tonne.

If physical loss data are available, the choice of price is the next major consideration. A farm-gate price would be most appropriate in terms of actual loss to the farmer. The determination of such prices would take a considerable amount of time in view of the number of countries and crops involved. Alternatively, a market price (e.g. in the country's capital) could be used if it was applied consistently and this would reflect a wider loss to the economy.

A major advantage of this approach is that it is relatively straightforward to apply if the physical loss data are available. However, although physical losses may have been estimated at the time of the original report, usually only a gross income figure is actually documented. In addition, the losses are usually aggregated and not reported as individual commodities. Thus, the reference price approach is not feasible with the data available.

Purchasing power parity – There are a number of alternative measures of purchasing power parity, but the most popular for conversion of value aggregates (in national currencies) is a common currency unit. The US$ is usually the base currency. There are a number of problems involved in this approach:

- fluctuations in exchange rate (due to, for example, political factors or capital movements) may result in change in output values with no change in agricultural output levels;
- official exchange rates reflect relative price levels of only those commodities freely traded internationally;
- official exchange rates may be fixed by government and not reflect the actual supply and demand situation.

In practical terms, exchange rates are the most viable means for converting historical losses to present day values. There are two options:

1. Historical values in original currency converted to present day values in original currencies and then converted to US$ using present day exchange rates. This method of analysis retains consistency in terms of the country where the damage occurred, the currency of valuation and the price index. The international financial statistics (IFS) yearbook produced by the IMF contains a number of indices indicating changes in domestic prices. The most appropriate index is the producer price index (PPI) which should reflect farm-gate prices for the agricultural sector and ex-factory prices for the industrial sector. The wholesale price index (WPI) covers a mixture of prices of agricultural and industrial goods at various stages of production and distribution, inclusive of imports and import duties. Unfortunately, these indices are not available for the majority of countries affected by Desert Locusts. In fact, for many Desert Locust-affected countries, a consumer price index (reflecting changes in the cost of acquiring a fixed basket of goods and services by the average consumer) is not readily available.

In the example given below, original losses are reported in rupees and this figure is converted to present day values using a wholesale price index (WPI) for India. The 1990 value is then converted to US$ using the 1990 exchange rate.

Losses(Rs) (1950 prices)	Losses(Rs) (1975 prices)	Losses(Rs) (1990 prices)	Losses(US$) (1990 prices)
27 024 000	94 821 053	265 605 190	15 177 439

Notes:
1 Rupees converted to US$ at 1990 exchange rate of US$1 = Rs 17.5
2 Losses converted to 1975 prices using WPI for India 1950 = 28.5
3 Losses converted to 1990 prices using WPI for India 1975 = 35.7

2. Historical values converted to US$ using historical exchange rates and then inflated to present day US$ values. The Grilli and Yang commodity price index (GYCPI) is a US$ index of prices of twenty four internationally traded non-fuel commodities, beginning in 1900. The original index was base weighted with 1977-1979 values of world exports of each commodity used as weights. This index includes agricultural commodities and metals (Grilli and Yang, 1988). There are several modified versions of this index (Grilli and Yang, 1988). To account specifically for developing countries, the weights of the GYCPI are the value share of developing countries' traded non-fuel exports (instead of world exports). Other indices include food commodities only (GYCPIF) or nonfood agricultural raw materials only (GYCPINF).

Countries affected by Desert Locusts may be generally termed developing counties and losses are essentially of agricultural goods. None of the GYCPIs meet both these criteria, but the GYCPI, which is weighted according to the value share of developing countries' exports, is probably the most appropriate and this was used to convert historical damage to present day values. The previous example is reworked below.

Losses(Rs) (1950 prices)	Losses(US$) (1950 prices)	Losses(US$) (1990 prices)
27 024 000	5 630 000	14 815 789

1 Rupees converted to US$ at 1950 exchange rate of US$1 = Rs 4.8
2 Losses converted to 1990 prices using GYCPI[1] for 1950 = 38

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The crop vulnerability index

The crop vulnerability index (CVI) comparative risk model, originally developed at the Anti Locust Research Centre, London (Bullen 1966, 1969, 1970), has been updated and modernised (Rutter and Bullen, 1997). An operational geographical information system (GIS) was developed at NRI, containing historical data on Desert Locust incidence and agricultural systems in affected countries. The CVI GIS was developed on a UNIX workstation using ARC/INFO GIS software in order to be fully compatible with and complementary to existing systems used by FAO for forecasting and information services, e.g. the Schistocerca WARning and Management System (SWARMS) GIS.

The CVI is based on the comparative risk of a crop area to attack by an 'average' Desert Locust swarming population in any month of the year, based on data concerning the frequency of occurrence of such populations over long (e.g. 30 year) periods. Formally it is a mathematical combination of the relative frequency of Desert Locust infestations over defined time periods and the area or production value of all major crops grown in the same area. The model has spatial resolution of 1° latitude and longitude grid cells (c.10 000 km^2), with a temporal resolution of a month.

As a relative indicator of vulnerability to production losses, it is anticipated that the CVI-GIS will be valuable as an aid to planning and resource allocation. It has been designed with in-built flexibility to accommodate future improvements in data and analytical approaches. For example, this might include information on the relative size of locust populations in relation to frequencies of occurrence and improved data on crop yield responses to attack. There may also be potential to include losses of pasture and natural vegetation biomass and livestock production and value.

Cropping data included in the CVI-GIS

Cropping data for the African countries in the Desert Locust invasion area were obtained in digital format from the draft version of the AGDAT Global Food Production Database, produced by the Agrometeorology Group at FAO. Non-digital data for the non-African countries in the Desert Locust invasion area were obtained from the annual statistical abstracts of the countries themselves, using one sample year between 1991 and 1993. Cropping data obtained in this way were very variable in the number and type of crops given for each country. There were no data available on crop production in Bahrain, Egypt and Libya.

<u>Crop harvest calendars</u> – The vulnerable growing season for each crop was defined as the period of time between sowing and harvesting. A vulnerability table was constructed for each crop, using data from the World Crop Harvest Calendar (FAO, 1958); these initial versions of the vulnerability tables were then supplemented by data from Crop Calendars (FAO, 1978). As a final check on these data, crop growing and harvesting periods were obtained for the countries of the IGADD2 region through the Crop Production System Zones of the IGADD Sub-Region database (van Velthuizen and Verelst, 1995). The crop harvest tables were then checked against these data and no significant differences were found.

<u>Market prices of crops</u> – In order to assess the economic impact of crop losses on a mutually comparable basis, an adjustment was made to take account of the variability of the yield per unit area and the variability of the cash value per unit of weight among different crops. This was achieved by calculating a ‘yield factor’ for each crop giving its average cash value of production per unit area in terms of equivalent wheat grain. Data on prices received by farmers for different crops worldwide, published by the FAO (1995), were used. These calculations were completed as follows:

Yield factor relative to wheat = ***C / C(Wheat)***

where **C** = Value of yield per hectare in metric tonnes wheat equivalent (A x B)
and **A** = Cash value per unit weight relative to wheat
B = Average yield (metric tonnes per hectare)

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Review of known environmental impacts of Desert Locusts

Note. This annex was abstracted from a paper that is being prepared for publication: Environmental economics and the Desert Locust by Mohammad Belhaj, Finn R. Førsund, Åsa Lundberg and Staffan Wiktelius.

Introduction

Proper ecotoxicological studies related to locust control started only during the last decade. There are at present ongoing studies in a few African countries. The most detailed study is carried out in Senegal where a Netherlands funded project, LOCUSTOX, run by FAO has been operational since 1991. In a recent review, Everts and Ba (1997) use the following general scheme for defining environmental effects.

i) Human exposure:
- handling personnel;
- exposed persons;
- consumers of sprayed products.

ii) Animal husbandry:
- exposed animals;
- animals feeding on sprayed vegetation.

iii) Wildlife:
- aquatic fauna in temporary pools, perennial standing water, running water:
  - fish;
  - dormant stage of toads, tortoises, lungfish;
  - crustaceans and insects;
- birds:
  - direct intoxication;
  - food deprivation;
- reptiles and amphibians;
  - direct intoxication
  - contaminated food
- mammals:
  - rodents;
- terrestrial invertebrates and nontarget insects:
  - pollinators (bees);
  - locust natural enemies;
  - insects essential for soil functions.

Results from this project and other studies in Africa have demonstrated or indicated the following side effects:

Human health

Blood samples have shown that spray personnel were frequently exposed to dangerous levels of pesticides. More than 1 000 persons were removed from spray operations temporarily or permanently in Morocco during the 1986-1989 campaigns (Showler, 1996). However, no deaths have been reported from locust campaigns. A potential danger for the public is newly sprayed crops and killed locusts collected for consumption. This can be avoided through adequate warnings and information via radio and other media.

Domestic animals

Tunisian Crop Protection Service reported that 30 sheep died after grazing in contaminated pastures. The pesticide involved is unknown (Potter and Showler, 1991).

There is anecdotal evidence of abortion in camels due to pesticide poisoning (Everts and Ba, 1997).
Contamination of pastures and fodder can potentially have adverse effects and may give rise to waiting periods of over two weeks (Gadji, 1993).

Fish
Most of the pesticides used are toxic to fish. Fish kills (certain species and juvenile stages) are reported from Senegal.

Non-target invertebrates
Bees and other pollinators – There are several reports of bee kills from operations (Potter and Showler, 1991; Gruys, 1991). There is also experimental evidence that bees and other pollinators can be reduced due to pesticide applications (Keith, 1992; Van der Valk, 1990).

Aquatic invertebrates – Rather dramatic effects in temporary ponds have been shown in experiments. An almost complete eradication of several species of macrocrustaceans was reported. For some species a recovery could be seen only after one year. Zooplankton and aquatic insects were also affected but for a shorter period of time (2-4 weeks) (Lahr, 1990; Lahr and Diallo, 1993; Lahr *et al.*, 1995).

Terrestrial invertebrates – There are several reports on short term effects on non-target insects (Van der Valk, 1990; Ottesen and Sømme, 1990; Johannessen, 1991; Fiskvatn, 1993). Anecdotal evidence of upsurges of secondary pests is reported (Gruys, 1991; Showler, 1993; Johannessen, 1991). Secondary pest upsurge has been shown experimentally after spraying against grasshoppers in millet (Van der Valk and Kamara, 1993; Kamara and Van der Valk, 1995).

Phytotoxicity
Most of the pesticides used for Desert Locust control have little phytotoxic effect in recommended dosages. However fenitrothion is reported to cause phytotoxicity in sorghum (TAMS, 1989).

Higher fauna
Birds – There are several anecdotal reports of bird kills (TAMS, 1989; Gruys, 1991; Ritchie and Dobson, 1995). There is experimental evidence of effects on birds. A decline in sprayed areas was due more to birds emigrating in reaction to a reduction in their arthropod food than to bird mortality (Mullié and Keith, 1993).

Mammals – Several reports of gazelle mortality were noted in Tunisia during the 1988 campaign (Potter and Showler, 1991).

Reptiles and amphibians – Although there are few reports on actual kills of reptiles or amphibians due to pesticides they are potentially regarded as vulnerable mainly through contaminated food items (insects) (Lambert, 1997).

Rare or specialised species
There is some speculation of the effect on, what is believed to be sensitive areas, e.g. wetlands, oases or other isolated ‘refuges’ with a unique fauna but experimental evidence is lacking (USAID, 1991; Potter and Showler, 1991; Everts and Ba, 1997).

Pesticide waste
There are at present more than 15 000 tonnes of obsolete pesticides in Africa. The majority of these stocks are in very poor condition posing environmental as well as health problems (FAO, 1995; Showler, 1996). A pesticide store in Somalia bombed and looted in 1988, subsequently led to the contamination of large areas and confirms the potential danger of these stores (Lambert, 1997).

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Agricultural policy: programme response to Desert Locust risk

Agriculture is risky, especially so in the marginal semi-arid environments favoured by the Desert Locust. There are several options open to governments and donors to counter food sector instability in general which would reduce the adverse impacts of any localized production shortfalls caused by these pests. Instability in production creates food insecurity only if it destabilizes or reduces people's real (subsistence or cash) incomes and access to food: variations in local production need not destabilize food availability and prices if trade, processing, or storage can be used to integrate markets geographically, across products, or over time (USAID, 1993). In the Sahel, as in other parts of Africa, the lack of such integration is frequently caused by high trading costs, itself associated with poor infrastructure and market information flows, weak regulatory and financial institutions and restrictive government policies.

In broad terms, Anderson and Dillon (1992) point out that *ipso facto* productivity growth has the benefit of providing insurance against risk. Thus a commitment to accelerate the agricultural growth rate in affected semi-arid countries, allied to broad-based rural productivity growth will reduce the real and perceived importance of locusts. More specifically, a continued commitment to the gradual and phased, liberalization of food and input marketing at all levels will be a key stabilizing measure. Investments in rural roads, market information systems, and appropriate grades and standards, will serve to reduce marketing costs. Identification and support for diverse farm level risk-mitigation institutions, ranging from informal reciprocal arrangements to explicit contractual arrangements, and generally, the development of freely functioning rural financial markets, also has a significant role in helping farmers to meet risks (Anderson and Dillon, 1992). A more contentious issue is the role that food aid can have. Efficient use of food aid can help to stabilize supplies and prices (USAID, 1993). In the context of a localized shortfall caused by locusts, the targeted support necessary would have high administration costs; however there is some potential for support through labour intensive food-for-work schemes managed by local non-governmental organizations.

Improved response to and preparedness for Desert Locust invasions could be developed under the umbrella of a National Disaster Prevention and Preparedness Strategy (DPPS) such as that developed by Ethiopia following famine periods in the 1980s (Webb *et al.*, 1992). The principal components of the Ethiopia DPPS are commitments toward (1) emergency legislation designed to delegate responsibilities and speed up responses to crises; (2) institution building to strengthen the planning and response capacities of relevant government organizations; (3) investment in enhanced information systems (to guide the appropriate crisis response) and; (4) preparation of interventions to enhance institutional readiness for action.

Given the inherently unpredictable nature of locust impacts and the low overall probability of an individual farmer or village being affected, crop insurance is an obvious means, in principle, to mitigate the risks (Hazell *et al.*, 1986). In practice, high operating costs and premiums would render formal public or private insurance schemes impractical in the context of locusts threatening semi-arid farming systems (Anderson and Dillon, 1992), where assistance towards community level, informal risk mitigation measures has better potential. This is not necessarily the case in the countries where high-value agriculture (citrus plantations, almonds, dates, olives, vegetables, grapevines, irrigated cotton and sugarcane) is threatened[6]. The potential for insurance schemes has been under-explored. Public funded

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[6] . A number of examples of insurance schemes are identified by Gudger (1991) in areas which may be affected by locusts (including Red Locust and Migratory Locust); Kenya (tea, export flowers, tree crops, vegetables); Zambia (maize); South Africa (30 crops); the Sudan and Egypt (cotton); Morocco and Tunisia (unspecified); Israel (unspecified); Jordan (vegetables); Pakistan (livestock); Turkey (grains and vegetables); Mauritius, while it does not have a locust problem, apparently has a ‘model scheme’ for insuring its sugar crop.

schemes rarely operate without subsidy; private/informal schemes may have more potential but in many countries would require parallel policy changes.

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Frequency maps, 1940-1969

The two sets of monthly frequency maps used in the analysis have values for each one degree square grid cell. The values range from 0 to 18 for the 20 plague and upsurge years and from 0 to 7 for the 10 recession and upsurge years between 1940 and 1969. The complete range of values was difficult to distinguish when prepared for black and white reproduction and so they were aggregated to provide a clear display.