reports

EVALUATION STUDY EV621

December 1998

DDT Impact Assessment Project Zimbabwe

by M E S Flint and M J S Harrison

DFID EVALUATION DEPARTMENT

DEPARTMENT FOR INTERNATIONAL DEVELOPMENT

EVALUATION REPORT EV: 621

DDT IMPACT ASSESSMENT PROJECT ZIMBABWE

by

M E S Flint
M J S Harrison

EVALUATION DEPARTMENT
DEPARTMENT FOR INTERNATIONAL DEVELOPMENT
94 VICTORIA STREET
LONDON
SW1E 5JL

In May 1997 the Overseas Development Administration (ODA) was replaced by the Department For International Development (DFID). References in this report to the ODA apply to events and actions prior to this change.

TABLE OF CONTENTS

ANNEXES

PREFACE

Each year the Department For International Development (DFID) commissions a number of ex post evaluation studies. The purpose of the DFID's evaluation programme is to examine rigorously the implementation and impact of selected past projects and to generate the lessons learned from them so that these can be applied to current and future projects.

The DFID's Evaluation Department is independent of DFID's spending divisions and reports direct to the DFID's Director General (Resources).

Evaluation teams consist of an appropriate blend of specialist skills and are normally made up of a mixture of in-house staff, who are fully conversant with DFID's procedures, and independent external consultants, who bring a fresh perspective to the subject-matter.

For this evaluation the team consisted of the following:
Mr Michael Flint, Economist and Team Leader; and Dr Michael Harrison, Ecologist.

The evaluation involved the following stages:-

- initial desk study of all relevant papers;

- consultations with individuals and organisations concerned with the project, including a field mission to collect data and interview those involved;

- preparation of a draft report which was circulated for comment to the individuals and organisations most closely concerned;

- submission of the draft report to the DFID Director General (Resources) to note the main conclusions and lessons to be learned from the study on the basis of the draft report.

This process is designed to ensure the production of a high quality report and summary sheet (EVSUM) which draw out all the lessons.

This study is one of a series of evaluations of projects in the natural resources sector. A synthesis study which draws out the conclusions and lessons from all these evaluations will be available from Evaluation Department next year.

C P Raleigh
Head, Evaluation Department
August 1998

ACKNOWLEDGEMENTS

The evaluators are grateful to the staff of TTCB for their cooperation and contribution to this evaluation; to the five scientific reviewers; to BDDCA and BHC staff for their support and assistance; to NRI staff for their advice and comments; to David Duthie for extensive background research; and to Elizabeth Wade-Brown, Marianne Clark-Hattingh and William Klusey for the project history.

GLOSSARY AND ABBREVIATIONS

ADI	Acceptable Daily Intake
BDDCA	British Development Division in Central Africa
BDDSA	British Development Divsion in Southern Africa (later BDDCA)
BHC	British High Commission
CSAD	Central and Southern Africa Department, ODA
DDD & DDE	metabolites of DDT
DDT	Dichlor-diphenyl-trichloroethane
DDTIA	DDT Impact Assessment (Project)
DNPWLM	Department of National Parks and Wildlife Management
DRSS	Department of Research and Specialist Services
DVS	Department of Veterinary Services
EC/EEC	European Commission
EU	European Union
Goal	The higher-order programme or sector objective to which the project contributes.
GoZ	Government of Zimbabwe
MIS	Management Information System
MNR	Ministry of Natural Resources
MRL	Maximum Residue Limit
NGO	Non Governmental Organisation
NRI	Natural Resources Institute
ODA	Overseas Development Administration
Purpose	The desired impact on the target group or institution which the project is expected to achieve if completed successfully. Formerly known as the 'immediate objective'.
RTTCP	Regional Tsetse and Trypanosomiasis Control Project
SEMG	Scientific Environmental Monitoring Group
TCO	Technical Cooperation Officer
TDRI	Tropical Development Research Institute
TTCB	Tsetse and Trypanosomiasis Control Branch
UNEP	United Nations Environment Programme
WHO	World Health Organisation

EVALUATION SUMMARY

THE PROJECT

1. Dichlor-diphenyl-trichloroethane (DDT) had been widely and successfully used to control tsetse fly in Zimbabwe in the late 1960s and 1970s. By the 1980s the use of DDT had become highly controversial in Zimbabwe, partly because of the effects of DDT residues on non-target wildlife and partly because of its persistence in temperate climates where it had already been banned.

2. The general objective of the DDT Impact Assessment Project (DDTIA) project was to produce a better understanding of the environmental costs of using DDT, or alternative insecticides, for ground spraying against tsetse, and to provide evidence which contributes to a rational evaluation of this technique's role. The project was implemented between 1987 and 1992 by a team of three TCOs (ornithologist, terrestrial ecologist, and fish biologist) assisted by short-term consultancy inputs from NRI. The project's total cost is estimated by the evaluators at £ 866,000.

THE EVALUATION

3. The evaluation was undertaken by an ecologist and economist, and involved a short visit to Zimbabwe. Reviews were commissioned from five scientists in Zimbabwe and Europe. The findings and lessons learned will be included in a forthcoming synthesis of natural resources research projects (1.7-9).

OVERALL SUCCESS RATING

4. The project is rated as **partially successful** overall. It is judged to have been successful in terms of the immediate scientific objectives set, but not to have achieved developmental benefits commensurate with its costs. Despite the excellent scientific research, the project is unlikely to have a significant impact on tsetse control policy and practice.

EVALUATION FINDINGS

Identification, design and appraisal

5. The project was identified by the Tsetse and Trypanosomiasis Control Branch (TTCB) in Zimbabwe as a follow on to a six-month NRI study (2.2-5). It provides a good example of genuinely demand-led research (2.8). The design, however, focused too narrowly on the TTCB as the main end-user. Higher level policy-makers (eg. Ministry of Natural Resources) and policy-influencers (eg. environmental NGOs) were not directly or sufficiently involved (2.31).

6. The scientific design of the research was excellent (2.16), but clarity on precisely how the research would contribute to policy was lacking. In particular, the risks that DDT would be phased out anyway, and that the research might not succeed in influencing policy, were overlooked (2.25 & 6 & 2.28-30). ODA advisers were aware of these risks, but were under pressure to provide work for TDRI for internal institutional reasons (2.27). Limited consideration was given to wider environmental impacts; alternative insecticides; the constraints on the potential conclusiveness of the study; and potential human health impacts (2.32 & 35).

7. During design and appraisal, insufficient use was made of the extensive literature available on DDT impacts in temperate zones and on how this had led to its disuse in Europe and North America. The ecological parallels, the likelihood of inconsistent species responses, the risks of inconclusive research, and the understanding of the wider issues crucial to the policy debate, were not explicitly considered (2.17&18, 2.28).

Implementation

8. In general, the project's administration and management went smoothly, and the team was well supported by TTCB and BDDSA. With the exception of the delays in the DDT residue analysis, most problems occurred in the first year (3.13-15). Recruitment of two of the TCOs was slow, and resulted in the loss of one wet season's study (3.3). There was only one counterpart and training benefits were limited (3.4-7).

9. A limited study of the impact of an alternative insecticide - deltamethrin - was added late in the project (3.11 & 12). The project was restricted to monitoring, rather than experimenting with, insecticide use and so limited the extent to which the project could be redirected from DDT to the use of alternative insecticides (2.32).

10. The project is estimated to have cost 75% more than the initial approved estimate of £498,557. Financial monitoring was unsatisfactory (3.18-20).

11. Significant reporting delays were due to a number of factors. Analysis and reporting took much longer than had been expected, and the NRI publication process was very slow. The main report was not distributed until 1995, four years after the completion of fieldwork and five years after the discontinuance of ground-spraying with DDT (3.22 & 23).

Results

12. The methodologies used in the research were excellent but could not, in all cases, overcome the difficulties inherent in dealing with a diverse and variable tropical environment within the project's resources and its relatively brief time span. (4.7&8).

13. The project produced substantial new scientific knowledge on the extent and nature of DDT's environmental impacts in the tropics (4.10). The results, however, are not conclusive in a number of areas. Significant uncertainties still remain, over the impacts of DDT on less common species, over the high natural variability inherent in the tropical environment which may mask DDT impacts, and over the long-term global future of DDT. Nor is it possible for research to prove conclusively that DDT has no environmental impact (4.11-13).

Scientific and policy impact

14. The presentation and dissemination of project results to the scientific community have been good. Numerous excellent scientific publications have been produced in refereed journals, although these have been biased more towards some sections of the project than to others (3.21&2).

15. The presentation and dissemination of project results to policy-makers and NGOs have been poor. Although the final report is very well produced, it was late, mistargeted (aimed predominantly at a scientific rather than a lay readership), and the conclusions and policy recommendations are limited and unclear. The report contains 170 pages on detailed scientific results, but only 1 page on policy conclusions (4.21-23). Fundamentally different conclusions have been drawn from the research , depending on the point of view of the stakeholder concerned (4.19&20). Most people have read the report as suggesting that the use of DDT is acceptable in certain circumstances, but, with the exception of TTCB, most do not believe this conclusion is justified (4.21).

16. DDTIA represents the most comprehensive study of its kind to have been undertaken in the tropics. Insufficient attention was, however, given to other policy-significant areas : economic assessment, alternative insecticides, the long-term future of DDT, wider land use issues, and human health aspects. With hindsight, the latter can be seen to be a ‘killer assumption’ : a key external factor which was not adequately addressed within or outside the project (4.14&15).

17. The evaluators conclude that the project results have led to the intended *purpose* being substantially achieved : there is now a better understanding of the environmental impacts of DDT used in ground-spraying against tsetse fly in Zimbabwe (4.25). This may not, however, be a sufficient understanding. Because of the uncertainties and omissions, the report is less conclusive than implied and, because of its poor policy analysis and presentation of conclusions, the report has been interpreted in radically different ways both in Zimbabwe and elsewhere : TTCB concludes that continued or reintroduced use of DDT is acceptable but the wider scientific community and environmental NGOs conclude that the use of DDT is unacceptable (4.38).

18. The project’s assumed *goal* was to contribute to improved and/or better informed tsetse control policy (4.28). To date, the findings of DDTIA have not significantly influenced policy decisions on whether DDT should or should not be used. DDT was phased out in 1990, two years before the project was completed. Although it is possible that early results that showed serious deleterious impacts on some bird species may have brought forward TTCB’s decision to phase out the use of DDT, the evaluators conclude that external pressures had already made phasing out inevitable. The suggested contribution of DDTIA to the phasing out of DDT also sits oddly with TTCB’s current view that the findings support DDT’s reintroduction in certain circumstances (4.30-32).

19. It can be argued that the project findings could still contribute to a reassessment and possible resumption of ground-spraying with DDT in the future. TTCB insists that this remains an option (4.33). The evaluators, however, conclude that such an option is no longer conceivable or defensible, particularly if donors and environmental NGOs are involved (4.35&6).

Sustainability

20. If DDT use were ever to be reconsidered, DDTIA would be an important source of information. However, its uncertainties and omissions, its unclear policy presentation, and its lack of impact to date on public and donor attitudes, all suggest that DDTIA is unlikely to have any future policy impact (4.47&8).

Conclusions

21. The overall conclusion of the evaluation is that, despite the excellence of the scientific research, the project has been of little policy value, and is unlikely to produce developmental benefits commensurate with its considerable cost. The main reason for this is that the project was simply too late to influence decisions on DDT use within Zimbabwe, and might never have been able to do so because of the public prejudice against DDT. This risk was clearly identifiable by the time the project was approved in 1987 (4.48-50).

LESSONS LEARNED *(cross-references are to Summary paragraph numbers)*

General

22. All research involves risk. Research into controversial subjects, or which runs counter to accepted policy and opinion, is especially risky. Particularly critical appraisal is required before aid funds are committed to such research. (6.,13.)

Policy research projects

23. Research that is intended to influence policy must involve careful appraisal of the existing policy context and trends, and be explicit about the ways in which research can influence policy. (6.)

24. Before becoming committed to long-term and expensive applied research projects, existing knowledge must be critically examined to assess what new policy-relevant information might be expected and whether this will add significantly to understanding and policy. This needs to be compared with the “no-project” scenario. (7.)

25. Research which is demand-led by one particular stakeholder still needs to be designed with the participation of all stakeholders. Appraisal needs to ascertain that there is a wider demand and constituency for the research, and that it is likely to meet all the major stakeholders’ requirements. (5.)

26. The importance of factors peripheral to the main field of enquiry (eg. health impacts in the natural resources sector) needs to be assessed by appropriate specialists as part of project design. If deemed important, adequate and specialist provision should be made within the project, or within a separate project, if they are not to become ‘killer assumptions’. (6.;16.)

27. Conclusions and recommendations derived from the research need to be clear, accessible, and balanced if they are to influence policy. Adequate time and funds for the presentation and dissemination of project findings must be built into the design of long-term research projects (11, 15).

Environmental policy research

28. Policy decisions on sensitive environmental issues are political and are rarely determined solely or even largely by economic and scientific arguments. The likelihood of scientific research being able to counter strong public perceptions and the risk that decisions will be made before the research is completed, need to be critically assessed. (6.;16;19.)

29. Environmental impact studies which do not or cannot address a wide range of major related policy concerns cannot be conclusive and may be of limited value to policy development in isolation. Project designers need to ensure or verify that all the major issues can be and are adequately addressed. If this is neither possible nor likely, the justification for more limited research should be reconsidered. (6.;13.)

30. Research into sensitive environmental issues often cannot be undertaken quickly, especially ecological studies that aim to elucidate complex, variable and dynamic tropical environments. (12)

31. Single research studies into complex and sensitive environmental issues cannot expect to prove a negative (i.e. no environmental impact), especially in relatively unknown and naturally variable and dynamic tropical environments, or in cases where the precautionary principle might apply. (13.)

EVALUATION SUCCESS RATINGS

The Overall Success Rating for a project is allocated on a scale from A+ to D according to the following rating system:-

Highly Successful (A+): *objectives completely achieved or exceeded, very significant overall benefits in relation to costs*

Successful (A): *objectives largely achieved, significant overall benefits in relation to costs*

Partially Successful (B): *some objectives achieved, some significant overall benefits in relation to costs*

Largely Unsuccessful (C): *very limited achievement of objectives, few significant benefits in relation to costs*

Unsuccessful (D): *objectives unrealised, no significant benefits in relation to costs, project abandoned*

The judgement on the Overall Success Rating is informed by a tabulated series of judgements on individual aspects of performance, including the project's contribution to achievement of ODA's **priority objectives** (listed in the upper section of the table). First an assessment is made of the relative importance in the project of each criterion or objective, which may be **Principal** or **Significant**; or, if not applicable, it is marked " - " . Where no specific objective was established at appraisal, the importance assessment is given in **brackets**. Each performance criterion is then awarded a rating, based only on the underlined sections of the five-point scale above.

Project Performance Criteria	Relative Importance	Success Rating
Economic Liberalisation	-	-
Enhancing Productive Capacity	-	-
Good Governance	-	-
Poverty Impact	-	-
Human Resources: Education	-	-
Human Resources: Health	(Significant)	D
Human Resources: Children by Choice	-	-
Environmental Impact	Principal	C
Impact upon Women	-	-
Social Impact	-	-
Institutional Impact	-	-
Technical Success	Principal	A
Time Management within Schedule	(Significant)	B
Cost Management within Budget	(Significant)	D
Adherence to Project Conditions	-	-
Cost-Effectiveness	-	-
Financial Rate of Return	-	-
Economic Rate of Return	-	-
Financial Sustainability	-	-
Institutional Sustainability	-	-
Overall Sustainability	-	-
OVERALL SUCCESS RATING		B

1

BACKGROUND

1.1 The control of the tsetse fly has been a major activity in Zimbabwe since 1933. Tsetse fly is the carrier of trypanosomiasis, a parasitic disease potentially fatal to humans and cattle, and a constraint to livestock keeping in two-thirds of the country.

1.2 Since the 1960s, the Tsetse and Trypanosomiasis Control Branch (TTCB) of the Department of Veterinary Services (DVS) has been running a campaign aimed at eradicating tsetse in Zimbabwe. Ground spraying with DDT has, in the past, been the most effective means of eradicating tsetse, and some 50,000 km2 have been cleared of the fly since 1967. During the civil war in the 1970s much of the cleared land was reinvaded. After independence in 1980 TTCB used aerial spraying with endosulphan in order to recover much of the reinvaded land. In western Zimbabwe this was complemented by ground spraying over 7,000 km2 with DDT to eliminate fly pockets not reached by aerial spraying.

1.3 By the 1980s the use of DDT had become highly controversial in Zimbabwe, partly because of the effects of DDT residues on non-target wildlife, and partly because of its persistence in temperate climates where it had already been banned (Annex D2.1-8). Although there was little existing information on its environmental impact under tropical conditions, by the 1980s the agricultural use of DDT in Zimbabwe had been banned for most crops. In 1985 DDT was declared a Group 1 Hazardous Substance. This restricted its use to “research purposes”, which included its use for malaria and tsetse control. DDT ceased to be used for malaria control in Zimbabwe in 1991, largely due to concerns over the possible contamination of tobacco exports.

1.4 A third method of tsetse control, involving pesticide impregnated targets, was developed in the 1970s and 1980s, and is now the main technique used in Zimbabwe and the region. In the mid-1980s, however, TTCB considered that ground spraying with DDT was the most reliable and cost-effective method of tsetse control. Aerial spraying was more expensive and less effective in wooded or broken terrain. Targets were still unproven and also more expensive. Total elimination of ground spraying was therefore expected to add greatly to the cost of tsetse control. TTCB sought to respond to external criticism by investigating the environmental impacts of DDT use and by developing alternative and safer control technologies.

THE PROJECT

1.5 The project's main objective was to produce a better understanding of the environmental costs of DDT and other insecticides used in ground spraying against tsetse fly (Annex C1). The project was implemented between 1987 and 1992 by a team comprising three TCOs (ornithologist, terrestrial ecologist, and fish biologist) assisted by short-term consultancy inputs from NRI. Field studies were carried out around Siabuwa in north-western Zimbabwe (see Map 1). Impacts on species populations (bats, birds, lizards, fish and invertebrates) and ecological processes were assessed by comparing parameters in sprayed and unsprayed areas, and by monitoring changes in relation to on-going operations. Residual DDT levels in study samples were measured, to provide circumstantial evidence of cause and effect and an assessment of dissipation rates.

1.6 The total ODA project expenditure is estimated by the evaluators at £866,000, against an initial commitment of £489,000.

THE EVALUATION

1.7 The evaluation's terms of reference are contained in Annex A. The objectives were :

a) to assess the project's immediate impact, in particular, its scientific and policy impact;

b) to evaluate project design and implementation;

c) to derive lessons relevant to projects which aim to inform environmental policy and to research projects in general.

1.8 The project's final report was only published in 1994 and distributed in 1995 (NRI, 1994). However, although this means that it is premature to attempt to assess the project's full impact, sufficient policy and scientific impacts are now identifiable and further delay to the evaluation would not have been justified.

1.9 The evaluation was carried out by an ecologist and an economist, and involved a ten day visit to Zimbabwe in August 1995. Discussions were held with representatives from TTCB, the Wildlife Department, and with a wide range of individuals and organisations. A list of the people consulted is contained at Annex B. An additional UK researcher was employed to assess the wider scientific contribution of the project, and reviews of the project report were commissioned from five scientists in Zimbabwe and Europe.

2

IDENTIFICATION, DESIGN AND APPRAISAL

Identification

2.1 A number of studies in the 1960s and 1970s in Zimbabwe had shown significant DDT residue accumulations in wildlife. Much of this was said to be in areas of intensive agriculture where DDT was used, although some areas where contaminated fish were found had been repeatedly sprayed with DDT for tsetse control (Matthiessen, 1984[1]). A Department of National Parks and Wildlife Management (DNPWM) report on DDT residues in a very large sample of birds eggs[2] confirmed the widespread nature of DDT contamination in Zimbabwe. The study also demonstrated eggshell thinning, correlated with DDT residues, in fish eagles from Lake Kariba. This had strong parallels with the eggshell thinning, linked to organochlorine pesticide residues, that had led to reproductive failures in American and European eagles during the previous decade, and was the first indication of possible environmental impacts resulting from DDT use in Zimbabwe. The author predicted decimation or extinction of raptor populations in Zimbabwe, as had occurred with some American and European raptors, unless action was taken *before* obvious signs of reproductive failure were seen.

2.2 This evidence from Zimbabwe, and the controversy that had led to the disuse of DDT in temperate countries, instigated the first ODA-funded DDT contamination study in Zimbabwe (Matthiessen, 1984). This 6-month study in 1982-83 aimed to measure DDT insecticide residues in a wider range of environmental components, to determine the contribution of tsetse fly control compared with mosquito and crop-pest control, to assess the persistence and accumulation of residues in wildlife, and to assess possible biological impacts.

2.3 The conclusions of Matthiessen's study were as follows :

a. tsetse control operations were almost certainly the main source of contamination, as DDT use had largely been phased out of commercial farming;

1 P.Matthissen (1984) Environmental contamination with DDT in western Zimbabwe in relation to tsetse fly control operations. Final report of the DDT Monitoring Project, ODA.

2 R W Thompson (1979) DDT contamination in Zimbabwe-Rhodesia. Unpublished, DNPWLM.

b. DDT residues did not persist in the physical environment;

c. DDT residues (including DDT metabolites DDE and DDD) accumulate in insectivorous birds and bats, and although not toxic at levels found then may affect their reproduction and behaviour, as well as causing reproductive damage to their avian predators;

d. fish and mussels along shorelines draining from sprayed areas were significantly contaminated;

e. fish fry in seasonal rivers might also be at risk;

f. the levels of contamination in fish were sufficient to explain contamination and eggshell thinning in the Lake Kariba fish eagles but insufficient, according to internationally recognised standards, to be harmful to human consumers.

2.4 Matthiessen drew two recommendations from this study. On the one hand the report stated that the levels of residue contamination and potential biological impact were sufficiently great to justify a more detailed follow-up study of the biological consequences of this contamination, concentrating on predatory birds, river-breeding migratory fish and important terrestrial insects (op.cit. p76-77). On the other hand, he did not believe the existing evidence was serious enough to warrant discontinuing the use of DDT on conservation or human safety grounds, without this further evidence of biological impact (op.cit.p81). In other words, the risks were sufficient to justify further research but not sufficiently serious to justify preventative action. DDT was innocent until proven guilty, not *vice versa*.

2.5 The recommendation for further study into the biological impacts of DDT contamination before deciding on discontinuing the use of DDT was supported by two contentions (op.cit. p81). First, DDT was being phased out anyway (presumably under pressure from a strong environmental and health lobby and a history of environmental damage in Europe and America), both in commercial agricultural use, and in tsetse control where it was being replaced by endosulfan and new control techniques. The recommendation thus implicitly assumes that this phasing out may not have been justified. Secondly, DDT residues are relatively non-persistent in the non-living environment under tropical conditions, implicitly assuming that DDT may be a safe option for tsetse control in the tropics.

Design

2.6 Although Matthiesson's research had concluded that there was insufficient evidence to recommend discontinuance of the use of DDT, TTCB was under considerable pressure to abandon ground spraying with DDT on environmental grounds. TTCB believed that target technology was not yet adequately proven, and intended to continue to use DDT. The Matthiesson report had recommended an extension to a second phase to examine in more detail the biological impact of DDT and other pesticides. TTCB believed that this extension was necessary to confirm the view that residue levels in wildlife did not warrant discontinuance of the use of DDT.

2.7 TDRI had drafted a follow-up research proposal in 1984. This had been shelved pending the formation of a EEC-funded scientific consortium that would assess environmental impacts as part of the proposed Regional Tsetse and Trypanosomiasis Control Project (RTTCP). Opposition, however, from UK environmentalists to the use of DDT in the proposed EEC project led to DDT's specific exclusion from RTTCP. GoZ therefore decided in 1985 to approach ODA for funds to support a revised TDRI proposal.

2.8 In the main, the design process involved TDRI, ODA (BDDSA) and TTCB in appropriate roles : TTCB requested the research and set broad TORs; TDRI drove the detailed design; and ODA asked critical questions during the process. The project represents a good example of demand-led research. TTCB clearly wanted the research and hoped that it would support its case for using DDT.

2.9 In 1985 TDRI was asked by TTCB to design a reduced project for Z$400,000 (£182,000). The rationale for this figure is not known. As this was enough only to cover a small part of the Matthiessen recommended studies, TDRI responded with a draft proposal including only one 3-year TCO Ecologist and a part-time entomologist, giving preference to the study on birds of prey and selected invertebrates and dropping the fish study from Matthiessen's original recommendations. The case for this preference was made on the basis of the advantages of the bird study (good indicators, most susceptible to decline from DDT, easily studied), and the considerable difficulties of undertaking research on fish (problems of measuring survival of fish fry in seasonal rivers, and relating this to levels of DDT as opposed to other environmental variables). The cost of this revised proposal was nevertheless higher at £245,127.

2.10 ODA was concerned that TDRI had designed the project to fit an arbitrary figure. In particular, ODA questioned the wisdom of dropping the fish studies, as DDT from soil run-off appeared to be persistent in the water-borne food-chain. It was agreed that TTCB should draw up TORs and TDRI should then design the study. The revised proposal prepared by TDRI, following TORs developed by TTCB, included a full time terrestrial ecologist and fish biologist over 3 years, and short-term inputs on soils and ornithology. This was costed at £387,750.

2.11 Over the next 5 months (October 1985 to March 1986), there was considerable discussion between ODA, TDRI and TTCB as to the wide ranging nature of the TORs for the TCOs, and whether the project could be phased, using the first season to identify the most promising lines of enquiry. TDRI argued that three years was the minimum time span required to distinguish seasonal and climatic effects from those of DDT, leading to greater confidence in results. ODA advisers suggested limiting the scope of the TORs for the fisheries biologist and TDRI suggested shortening this input to 2 years.

2.12 TORs were finally agreed for a more limited fisheries study. The ODA Fisheries Adviser's proposal for a lake-wide study of the populations of *Hydrocynus* and *Limnothrissa*[3] to assess potential effect on the human population, was dropped. The agreed TORs, to determine whether DDT residues were affecting the aquatic fauna, and particularly the breeding success of *Hydrocynus* and *Clarias*[4] in seasonal rivers flowing into Lake Kariba, was included in the final project approved by ODA. Costings now included provision for report writing in the 3rd year (total cost £411,850), a 2 years input from the fisheries TCO, and a study on bats which TDRI agreed to include at no additional cost.

2.13 The long debate on the merits and TORs of the fish study turned out to have limited value, as this study developed its own wider-ranging TORs and was not limited to the proposed species. As no tigerfish were found in the sampled rivers and flash flooding was a problem in the study site, work was extended to the main lake, and covered whatever species were caught in the gill-nets. The main value of the debate was that it ensured the inclusion of the fish study.

Design rationale

2.14 The scientific rationale for the design was the investigation of the impacts of DDT residues on vertebrate populations on a landscape scale, including key taxonomic groups at different trophic levels: birds, bats, nocturnal mammals, lizards, fish. Some limited work on invertebrates and soil processes was also proposed, to assess direct impacts of DDT on productivity, with follow-on consequences for vertebrate predators further along the food chain. In other words, the study aimed to assess direct and indirect impacts of DDT on non-target fauna. Although the selected fauna were chosen principally as ecological indicators, the TORs also included investigation of commercially important fish species, which would focus attention on potential human health impacts.

3 *Hydrocynus forskahlii* (tigerfish, which migrates up rivers to breed) and its main prey *Limnothrissa miodon* ('kapenta' sardines, the mainstay of the lake's economic fisheries).

4 *Clarias gariepinus* (a predatory catfish, which lives in both rivers and the lake).

2.15 The design's major axis was the comparison of animal populations in sprayed and unsprayed areas, and the monitoring of changes following spraying. There would be major methodological difficulties to overcome, including lack of baseline data on DDT impacts on tropical wildlife, lack of data on animal communities and ecological parameters in Zimbabwe, and lack of experimental control over natural populations. The only way to reduce non-DDT environmental variables would be to sample adjacent sprayed and unsprayed sites in ecologically similar areas, and interpret differences in populations on the basis of DDT residues detected. No laboratory work was envisaged, to look at physiological mechanisms for DDT impacts on animal population.

2.16 The methodological design of the component scientific studies was excellent. The studies focused on key ecological indicators at different trophic levels, namely soil processes, woodland invertebrates, woodland birds and insectivorous mammals, and aquatic fauna including fish and their predators. One weakness was the focus on immediate and secondary impacts of DDT (killing of non-target species, and secondary mortality of species higher up the food chain). The longer-term and more distant persistence of DDT as a global pollutant was ignored, and would have required a major redesign of the project. The design was also unlikely ever to overcome the environmental "noise" threshold for this kind of landscape. Koeman et al (1980) recommended a minimum of three years pre-spray monitoring to provide an adequate baseline for separating out "noise" from spray effects.

2.17 The design process may also be criticised for an insufficiently thorough background survey of knowledge of DDT development and use, which would have placed the study in its wider context (see Annex D, for a summary of the very extensive knowledge of the environmental impacts of DDT up to 1985). Much was known from temperate regions, and much of this is applicable as general rules to the tropics, such as DDT dispersal routes, mechanisms for mortality and reproductive failure and susceptibility of different taxonomic groups. There are two objections to this criticism. First, findings from temperate zones cannot simply be applied to the tropical situation. Second, the big problem with DDT environmental research, and with trying to predict the effects of different doses, is the highly varied nature of responses by different species to DDT contamination, even by species that are at the same trophic level or very closely related. Because of this, there was undoubtedly a sense of ignorance about the specific ecological impacts of DDT in Zimbabwe, but equally there may have been greater cause to reflect on just how much less ignorant TTCB would be at the end of this single study, as regards definitive policy recommendations on DDT use or disuse. If there was such wide specific variation in response to DDT, it did not make sense to design a study based on detailed knowledge of selected indicator species. This overall design weakness remains at the heart of continuing scepticism about the value of this research amongst environmental groups in Zimbabwe (see 4.11). On the other hand, given such a complex and diverse environment, without making some basic assumptions about the indicators no research could have proceeded.

2.18 NRI did complete a literature review at the start of the project, and believes that the information from temperate climates was thoroughly reviewed. However, NRI's view is that the temperate literature is less relevant than the evaluators suggest. While this may be true in narrow scientific terms, the lessons of the wider policy debate in temperate zones (including the limitations of DDT research) are arguably very relevant. The likelihood of inconsistent species responses, the risks of inconclusive research, and the importance of non-scientific influences on policy, are all crucial.

Final project design and costs

2.19 The final project objectives as contained in the Project Memorandum are set out in Annex C. These have been interpreted by the evaluators in the form of a (reconstructed) Logical Framework. The assumed *Goal* and *Purpose*[5] of the project - against which project impacts will be assessed - are given below.

GOAL	Tsetse control policy informed and improved
PURPOSE	Better understanding achieved of the environmental costs of using DDT, or alternative insecticides, for ground spraying against tsetse

2.20 The reconstruction of the original project objectives in this way is clearly not without problems. The importance, however, of reaching a judgement on the extent to which the objectives were met at the *Output, Purpose* and *Goal* levels requires this type of reformulation. The critical question in this case is whether the project's *Purpose* was to achieve improved knowledge or to contribute to improved tsetse policy through the <u>use</u> of that knowledge (ie. with improved understanding as the main *Output*). While logic suggests that it should have been the latter, the evaluators accept the argument that the project was designed and implemented with the former (less demanding) *Purpose* in mind. The objective of improved tsetse policy is therefore treated as the *Goal* in this evaluation.

2.21 From an initial proposal costing £245,127, the final costing of the project had escalated to £489,557, once all additional studies, prices, contingencies, allowances, project administration, equipment, analyses and other costs had been agreed.

5 See Glossary for current definitions.

APPRAISAL

2.22 The justification for the project centred around the lack of reliable information on the environmental impacts of DDT, upon which to base policy decisions about its continued use in tsetse fly control. DDT, which had proved relatively safe (low operator hazard), robust, cheap and effective since its first use in the 1940s, led to its common use in developing countries. Adverse effects had been demonstrated, however, in temperate regions (see Annex D2-8)), derived predominantly from its persistence in the environment and accumulation in food chains, leading to reproductive failure in higher predators, notably through eggshell thinning in birds of prey, and ultimately in marine mammals distant from sources of use, through the global atmospheric transportation and polar accumulation of DDT residues.

2.23 Outright rejection of DDT before alternative chemicals and techniques had been developed, and before full environmental assessment in Zimbabwe had been undertaken, would have jeopardised the successful large-scale aerial spraying operations against tsetse fly. It would also have doubled the cost of tsetse fly control, as aerial spraying and targets cost twice as much as ground-spraying. TTCB intended to continue to use DDT until alternative methods were proven, and to cease using DDT only if serious environmental hazards were clearly demonstrated. Even if aerial spraying succeeded, there would still be a need for ground-spraying in isolated remnant pockets. In addition, RTTCP was trying to develop more acceptable alternatives, including new target methods, but targets were as yet unproven, and the costs and benefits of alternatives had not been compared.

2.24 Recognising the potential adverse non-target impacts of DDT in ground-spraying, and yet accepting the practical reasons for TTCB's continued use of DDT, it was considered essential to investigate thoroughly the effects of DDT on the environment in Zimbabwe so that scientifically based decisions about its continued use could be made. There was some evidence that DDT breaks down more rapidly in the tropics but otherwise the actual amount of reliable information on the residual and other effects of DDT in the tropics was very limited. ODA advisers wanted to ensure that decisions on the use of DDT were made in as rational and informed a manner as possible.

2.25 Clarity on precisely how the research would link to policy was, however, lacking. There was an implicit assumption that science would inform policy. It was also implicitly assumed that TTCB would be the most important end-user, and that the aim was to improve sectoral tsetse control policy rather than national DDT policy. The validity of a sectoral rather than national policy focus was not challenged.

2.26 A key risk - known to both ODA and TDRI, but not highlighted - was that DDT was likely to be phased out anyway. For example, there is no mention in design or appraisal of the strong existing evidence of adverse effects of DDT in Zimbabwe, nor of the tide of opinion and policy already running strongly against DDT. In August 1985 the Minister of Natural Resources and Tourism announced at UNEP that GoZ would phase out the use of DDT in tsetse control over the next three years. Thomson's work on widespread DDT residue accumulation in Zimbabwean birds and eggshell thinning in raptors matched exactly the findings of American and European studies of DDT impacts in the 1960s and 1970s. There was also widespread public disquiet about DDT use, both from environmental NGOs in Zimbabwe, and from other donors. Already, almost all agricultural use of DDT had been phased out, through pressure from environmental and overseas trade lobbies, and within Zimbabwe there was a highly vociferous campaign through NGOs and the media against DDT. TTCB had adopted a siege mentality to this campaigning and relations with the media and environmental lobbies were very poor. The EC had already rejected the use and study of DDT, because of fears of adverse side-effects and the European environmental lobby.

2.27 An alternative view is that the limitations of the project were well known to ODA, but were ignored for internal institutional reasons. ODA scientific advisers repeatedly stated their concerns that the study would have little impact on policy and opinion. However, there was strong pressure within ODA to provide work for TDRI from bilateral development funds, and an instruction that ODA advisers should not second guess the professionalism of TDRI. According to a senior adviser at the time, there was little expectation that the project would have developmental impact.

2.28. ODA did recognise the possibility of an outcry from the environmental lobby should there be any hint of ODA being apologists for an insecticide already banned in the West. One condition of the project was that ODA funded staff would not be physically involved in the application of DDT, their sole responsibility being to monitor and assess the impact of routine operations. It was made clear that ODA did not support the use of persistent insecticides such as DDT except in localised, special circumstances.

2.29. More important than these public relations risks, however, was the risk, for two other reasons, that the research might not succeed in informing policy. First, DDT was a highly controversial issue where politics and public opinion in Zimbabwe - not science - might be expected to be the dominant influences on sectoral policy (see 4.48-51). Second, as Matthiesson had intimated, the research ran counter to existing scientific, public and political opinion, both in Zimbabwe and internationally. This was research which would need to reverse existing opinion if it was to have any major impact. Both factors increased the risk that the project would fail in its *goal*. In these circumstances, the wisdom of embarking on a three-year research project with a high risk of being only of academic interest must be questioned.

2.30. In addition to the possibility that DDT would be phased out anyway, there were other factors that might have prevented the research from having much or any policy impact but were not considered. These included the possibility that targets would prove effective and require no support from DDT and the possibility that the study would be inconclusive in its results and policy recommendations. Instead, the implicit assumptions were, first, that the facts about DDT could be established and, second, that these would lead to a rational decision being made. Both assumptions have proved mistaken. With hindsight, both the "no impact" and "no project" scenarios might have been considered. The latter would have involved acceptance of the general view that DDT should be phased out and the carrying out of research into the alternatives' relative merits.

2.31 The focus on TTCB as the key policy end-user is understandable but, with hindsight, over-narrow. A broader appreciation of who was making and influencing policy (and a focus on 'policy' rather than 'knowledge' in the *Purpose*) might have raised questions about the research's likely effectiveness in informing policy. TTCB is an implementing rather than a policy-making department. On DDT and other environmental issues, TTCB is perhaps better seen as a policy-taker rather than a policy-maker. Higher-level policy-makers (such as the Ministry of Natural Resources or the Ministry of Health), and such major policy-influencers as environmental pressure groups, were not directly or sufficiently involved in the design and appraisal of what was intended to be policy-relevant research. Greater involvement of these other stakeholders might have raised questions about the extent to which this research could inform national opinion and policy with respect to DDT, and/or directed the project at other policy-significant areas (eg. the long-term consequences of DDT; and the economics of DDT and alternatives).

2.32 Two other aspects of the design warrant mention. First, despite reference to 'alternative insecticides' in the objectives (see Annex C1), all the intended activities and outputs related to DDT. A specific objective relating to an alternative insecticide -

deltamethrin - was only added during project implementation. Given what was already known about DDT and deltamethrin, the low priority accorded to alternatives is perhaps questionable and, with hindsight, an experimental project which studied the environmental impact of alternative insecticides for ground-spraying would have been more useful. On the other hand, it can be argued with some justification that, in view of the wider work of the EC-funded Scientific Environmental Monitoring Group (SEMG), it was right for the ODA project to concentrate on DDT. The constraints imposed by ODA on the experimental use of insecticides (2.28) - and by TTCB - also ruled out a more comparative research approach. DDTIA was explicitly designed as a monitoring study rather than an experimental research project.

2.33 Second, the possible implications for human health were only included as a rider (see Annex C3). No specific financial provision was made for what might have needed to be a substantial health impact component. The rather incidental inclusion of the human health angle in the project objectives, and the very limited coverage of the issue by the project in practice, has proved to be a significant weakness as far as environmental NGOs are concerned (para 4.15(b) below). There is no record of ODA health advisers or the GoZ Ministry of Health having been consulted and involved.

2.34 The evidence was (and is) strong that DDT is one of the safest pesticides ever developed with respect to human health. The main evidence of potential risk to humans is a link between ingestion of DDT residues from contaminated breast milk of lactating mothers, and hyporeflexia in infants, although no long-term consequences of hyporeflexia have been demonstrated. Furthermore, the overall significance of tsetse spraying operations in this connection is arguably minor compared with its use in malaria control campaigns. There have been reports of associations between DDT and increased risk of cancer but the evidence is inconclusive. Given this background, the key questions are whether there should have been health impact component, and if so, what form it should have taken.

2.35 The main focus of historical concern had been on ecological impacts, and this was quite correctly the focus for the project design. However, assessments of the impact on human health must be part of any wider assessment of the environmental impact of any proposed intervention. Such health impact assessments need to be carried out thoroughly or not at all. The evaluators conclude that a more detailed investigation of health impacts would have required a large, separate project if NGO and public concerns were to be sufficiently addressed. However, such research would not have been justified given the rapidly declining use of DDT in Zimbabwe.

Economic justification

2.36 The project's economic justification was that as aerial spraying was twice as costly as DDT in financial terms, the full costs of DDT use needed to be known and balanced against the economic costs either of using alternative control methods or of allowing control to break down. The project was expected to show whether, in order to avoid environmental degradation, increased costs of using alternative chemicals or techniques would be necessary. Added justification was given by virtue of DDT's essential place in the wider armoury of the RTTCP's ambitious programme of tsetse eradication throughout Southern Africa, for use in mopping up surviving tsetse pockets in areas missed by aerial spraying or targets.

3

IMPLEMENTATION

3.1 Two key features of project implementation were the independent nature of the research and the good relationships which were built up and maintained with local institutions. DDTIA was originally located in the Department of Natural Resources (DNR) but remained independent even when physically relocated to TTCB. While there was inevitably some suspicion that the project was a means by which TTCB could legitimise the continued use of DDT, in general DDTIA scientists were highly respected within Zimbabwe and retained the confidence of, as well as good working relationships with, both TTCB and environmental groups. This was an important achievement, and was crucial for ensuring the findings' scientific credibility.

Staffing and training

3.2 The DDTIA team originally comprised a part-time (4 months p.a.) ornithologist/team leader and two TCOs : a terrestrial ecologist and a fish biologist. The ornithological input was later expanded and made full-time. Additional short-term inputs were also provided, from a second ornithologist, herpetologist, entomologist, and soil scientist.

3.3 The team leader, an NRI staff member already working in Zimbabwe as part of SEMG, was identified prior to the project's start and was in post in July 1986. Recruitment and arrival of the other two TCOs were delayed by slow administration in the UK and in Harare. Although suitable candidates had been identified by May 1986, the formal exchange of letters between GoZ and HMG did not take place until April 1987, by which time the fisheries candidate had withdrawn. Letters of appointment for the two TCOs were prepared in August 1987 and the TCO arrived in October 1987, having missed one wet season's study.

3.4 The TCOs'counterpart staff were to be provided by GoZ and/or other institutions within Zimbabwe. With the exception of the fisheries counterpart, who joined the project in March 1988 five months after the TCO's arrival, this ambition was not realised. A freeze on civil service recruitment in Zimbabwe, coupled with staff resignations, restricted the availability of qualified counterpart staff in entomology and pesticide dynamics.

3.5 TTCB provided the project with four full-time assistants, together with extra assistants as required. Local villagers were engaged as guides, guards, and building labourers.

3.6 The project was designed to have a training element but difficulties in finding suitable counterparts hindered progress. Counterpart training, with the prospect of British Council scholarships at the project's end were offered to several departments but were not taken up.

3.7 The main training element was in fisheries biology. The fisheries counterpart attended two in-country courses and was recommended for further training in the UK. He eventually received NORAD sponsorship to attend a MSc course at the University of Wales, Cardiff. MNR also sent three staff members to the UK for undergraduate courses at the project's instigation. Other training was given to the TTCB staff who assisted the terrestrial ecologist and who worked on the deltamethrin study. TTCB core staff, however, did not benefit to any great extent from the presence of the DDTIA team because of the limited need within TTCB for that type of expertise. It had been hoped to develop expertise at the Department of Research and Specialist Services (DRSS) laboratory, but unfortunately the breakdown of its gas chromatograph meant that DRSS could not undertake the sample analysis.

Fieldwork and analysis

3.8 The project was designed to be completed within three years, ie by March 1990. It was subsequently extended to March 1991 to allow the field studies to be completed (to make up for the season lost by their delayed arrival), and again to 1994 for the completion of reports. TCO contracts were extended accordingly.

3.9 Drought conditions preceding the project affected fish and bat populations in the study area. Bat and fisheries sample collection was also hindered by delays and equipment failures. Although some damage had been anticipated, damage by crocodiles and hippopotami to the gill nets used to collect fish samples was unexpectedly severe.

3.10 The main fieldwork site was near Siabuwa, south of Lake Kariba in north-western Zimbabwe (see map). This was the only site in the Zambezi valley with adjacent unsprayed and heavily sprayed areas, and with access to a wide range of sample sites. A subsidiary camp had to be set up at Tashinga on the shore of Lake Kariba for the fish biologist when the original study area yielded insufficient samples. The logistical difficulties involved in working at these rugged and remote research sites were very significant. Vehicle breakdowns caused delays in, or prevented the completion of, the work of some of the short-term consultants. The poor maintenance of TTCB-supplied vehicles contributed to this problem.

3.11 The study of deltamethrin was a limited and late addition to the project. In 1989 TTCB conducted an efficacy trial over 600 sq.km, using this insecticide. The trial was repeated over 200 sq.km in 1990. The main reason for the limited scale of the study - and for the use of areas sprayed with DDT in 1988 and 1989 - was cost : TTCB could not afford to spray a new area.

3.12 The objective of the deltamethrin monitoring study was to monitor the short-term impact of deltamethrin, used as a residual ground-spray against tsetse fly, on selected non-target organisms in order to evaluate the probable side-effects of this insecticide used as a substitute for DDT. The study commenced in 1989 with a local biology graduate, financed from contingency funds. In 1989 extra staff time was commissioned to extend this study, following a recommendation of the Third DDTIA Review Mission. Trap theft and tampering by animals affected the quantity of samples collected in the initial deltamethrin study. This study was also affected by vehicle breakdowns and by delays in species identification at the Bulawayo museum and subsequent sample analysis.

3.13 Original plans for DDT residue analysis were thwarted. The gas chromatograph at DRSS broke down and the UK laboratory at Monks Wood in the UK was severely damaged by fire. This resulted in a backlog of samples at the end of the first season. Alternative commercial laboratories had to be used to reduce this backlog. By 1989, NRI Agrochemicals Section had relocated to Chatham and was able to take on the work. Progress was further slowed by a combination of the complicated manual analysis required, a lack of communication between the project and NRI, staff shortages, and other NRI commitments. In 1990, a commercial laboratory was identified in Zimbabwe which was able to undertake the analysis for 16% of the NRI price, and in 1991 the Tobacco Research Board facilities were used, with NRI undertaking some cross-checks. This helped to recoup previous overexpenditure on residue analysis.

Administration

3.14 Independence had brought an influx of aid projects to Zimbabwe, and by 1987 the British High Commission (BHC) lacked the resources to administer them all.

Consequently, it advised that NRI be engaged as independent contractors. NRI was therefore made directly responsible for the project's management. Administrative matters, accounts and logistical matters were handled directly by NRI and by the team leader in Zimbabwe. BHC assisted by facilitating the customs clearance of equipment. Local administration, however, still took up so much of the team leader's time that a part-time administrative assistant was engaged locally. The cost of this assistant, and those of other locally engaged staff and consultants, were set against contingencies.

3.15 In general, the project's administration and management went smoothly and implementation support from TTCB and BDDSA was also good. With the exception of the residue analysis (see above), the majority of problems were encountered in the first year. Lack of consultation with the team leader at the outset gave rise to initial administrative and logistical difficulties. For example, overspending on the equipment budget resulted from the shipment of goods by air rather than by sea as budgeted. A provisional fisheries equipment list approved by the team leader in May 1986 was not taken into consideration. As a result, by December 1987, half of the overall equipment budget for that financial year had been spent on fisheries equipment, much of which was unsuitable for the study area.

3.16 Inadequate administrative support in Harare meant that up to 25% of the contract time allocated to field work for short-term consultants was spent on administrative matters in Harare (clearance, provisions, formalities, etc.). The same was true for the TCOs, who spent considerable amounts of their leave time on administrative matters.

Monitoring

3.17 Project monitoring was largely an internal process, carried out by the team leader. Overall project supervision was the responsibility of the Head of the Pesticide and Vector Management Division at NRI. Annual review missions were carried out comprising representatives from NRI, BDDSA, and ODA London. These lasted at the most four days, with very short field visits. The review teams therefore relied largely on reports from, and interviews with, the project staff, together with annual progress reports and staff visit reports.

3.18 The project was not reassessed or overhauled even when it became increasingly evident that the original objectives were becoming less and less relevant to Zimababwe's needs (paras 4.30-32 below). The 1990 Review Mission recognised that DDT could no longer be considered an acceptable option for long-term tsetse control, but did not recommend closing the project at this stage. The potential value of the methodologies being developed for assessing the environmental impact of pesticides in hot dry tropical areas, and the recognition that ground spraying could be required to wipe out residual populations of tsetse in cleared areas while targets prevent reinvasion, were considerations. It is also likely that NRI would have strongly resisted any attempt to close the project.

3.19 Financial accounting arrangements were unsatisfactory for a number of reasons. The project started before the ODA Management Information System (MIS) was in operation, and there is reason to doubt the validity of some of the early MACSTATS data. Initial administrative errors in Harare then meant that financial monitoring through the MIS was virtually impossible for the first year. Local DDTIA costs were aggregated with those of all agricultural projects in Zimbabwe. More recently, it was not possible to distinguish between different TC projects within the Veterinary Department. The fact that NRI used different MIS codes did not help. Separate spending by the ODA Central and Southern Africa Department (CSAD)/Crown Agents, ODA East Kilbride, NRI, and the project team in Harare further complicated matters. Routine copying of NRI procurement costs to the project team later improved budgetary control.

3.20 These complications account for the significant differences between the total project cost as estimated in the Project Completion Report (£612,000), that recorded on MACSTATS (£932,000), and that estimated by the evaluators (£866,000)[6] . Details of these estimates are contained in Annex H. It may also explain why the costs of the project almost doubled the original commitment of £489,557. Increases to £675,000 were formally approved. While some of the increase in costs is explicable (eg. by the need to add the deltamethrin study and to increase the writing-up time), the original cost estimation and the subsequent cost monitoring were both unsatisfactory. The changes which occurred in ODA financial systems were a compounding factor.

Reporting and dissemination

3.21 The research findings have been disseminated in 4 ways :

- through workshops held in Zimbabwe during and at the end of the research;
- through scientific conferences worldwide;
- through scientific papers published in international, refereed journals;
- through the publication of a final report entitled “DDT in the Tropics : the impact on wildlife in Zimbabwe of ground-spraying for tsetse fly control” (NRI, 1994, pp.195, £ 20).

6 The BDDSA adviser is of the opinion that the PCR figure most closely reflects project costs.

3.22 A list of the scientific papers and conferences is included at Annex G. An assessment of the quality of the reported work is given in Chapter 4. The key point in the immediate context is that, although now mostly complete, reporting and publication were very significantly delayed. Some of the scientific papers arising from the fish and bat work had not been produced by 1995. The final report itself was only distributed in 1995, more than two years after it had been written.

3.23 A number of factors have contributed to the four years' delay in producing the main research report, after completion of the research. A major factor was the dispersal of project investigators and their involvement in other work, relatively soon after fieldwork completion. The time and funding necessary for analysis and writing-up was underestimated, as is frequently the case. Contributory factors include: the finishing of the three TCOs' contracts at different times; the backlog of residue analysis (3.13); the slow pace at which some of the authors produced papers, in part because of new jobs and commitments; the need for peer review; and NRI publications section were slow to produce the main report once it had been submitted to them. Distribution within Zimbabwe had to be limited because of the report's high cost.

4

IMPACT AND SUSTAINABILITY

A. *RESULTS*

4.1 Table 1 below summarises the results intended and achieved by the project. A full summary of results is contained in Annex F. An assessment of the Output-to-Purpose and Purpose-to-Goal impacts follows in sections B and C of this Chapter.

General conclusions and policy recommendation

4.2 The general conclusions drawn from these results, as presented in the main report (NRI,1994), were that:

- while there is a notable impact on some species, there is reasonable evidence that limited applications of DDT in ground-spraying against tsetse fly do not give rise to any irreversible damage to the biota and biological processes that were investigated;

- the effects of DDT on wildlife, when discriminately sprayed for tsetse control, are much less severe in the tropics than in temperate regions and are probably reversible in vertebrates over 10-20 years;

- the effects of DDT on wildlife are trivial compared to the greater long-term environmental threats to wildlife from habitat destruction in Zimbabwe.

4.3 The policy recommendation from this was that adverse impacts of DDT on wildlife can be mitigated by alternative control techniques, or by substituting the less persistent insecticide deltamethrin for DDT. If, however, deltamethrin costs are higher, wildlife conservation would benefit more if DDT continued to be used, with the cost savings invested in a compensatory project to manage wildlife habitat. Habitat loss rather than pesticide pollution is the greater threat to wildlife in the Zambezi valley (NRI,1994,p.24) .

TABLE 1

PROJECT OUTPUT	RESEARCH ASSESSMENT
1. Impact of TTCB ground spraying on aquatic fauna monitored and assessed	Fish accumulate significant levels of DDT residues from ground-spray run-off, but populations of common fish species do not decline in sprayed areas • Effects on the majority of rarer species remain unknown, and cannot be ruled out • The long-term fate of DDT after dissipation from the local environment, e.g. in the Lake Kariba ecosystem, remains unknown
2. Impact of TTCB ground spraying on terrestrial fauna monitored and assessed	Invertebrates accumulate high levels of DDT residues, notably in some insectivore food species, demonstrating key links in the food chain • Impact on invertebrate diversity and abundance is inconsistent, some taxa show a significant species or population decline in sprayed areas, others do not • DDT affects populations of at least 4 bird and 1 lizard species, in some cases showing up to 90% population decline • Population decline is reversible within 10-20 years • Negative impacts of DDT may also be implicated in lower populations of several other bird species • DDT residue concentrations in at least 5 bat species pose a significant risk to survival during drought • Effects on the majority of rarer vertebrate species remain unknown, and cannot be ruled out
3. Effects of DDT on reproductive performance of Fish Eagles established	DDT causes eggshell thinning and resulting low hatching rates in fish eagles, but at this rate does not cause population decline
4. Effects of DDT on nutrient cycling and soil productivity in treated woodland established	DDT has no significant effects on soil processes (although impacts on macro-invertebrates may have longer-term impacts on soil processes) • DDT dissipates at high rates in the tropics, with a half-life of 2-9 months compared to 3-10 years in the temperate zone
5. Environmental impact of deltamethrin evaluated	Deltamethrin dissipates rapidly: 80-90% dissipates within 2 months • A wide range of tree trunk invertebrate species are killed by deltamethrin spraying, but their long-term fate is unknown • The impact on vertebrates remains unknown, as the study was compromised by prior DDT spraying
Optional: health impacts arising from consumption of contaminated fish assessed.	Effects on human health were not investigated due to relatively low DDT residue levels found in fish[7]. DDT use in mosquito control may present a greater threat to human health than its use in tsetse ground-spraying

7 The report concluded (pp. 182-183) that neither the ADI nor MRL were exceeded. In fact, the FAO/WHO ERL in the fat of meat was considerably exceeded. However, it is arguable whether residue limits in meat are relevant for fish (P.Nagel, personal communication).

B. *OUTPUT-TO-PURPOSE IMPACT*

4.4 This section asks one question : did the results of the project (the *Outputs*) contribute to an improved understanding of the environmental impact of using DDT, or alternative insecticides, in ground spraying operations against tsetse fly (the *Purpose*)? The evaluation used the following criteria to develop indicators to assess this. Are the results :

- new?
- methodologically sound?
- conclusive?
- comprehensive?
- well presented?
- adequately disseminated?

New scientific knowledge

4.5 This was an excellent study, and constitutes one of the most thorough investigations of the environmental impacts of DDT in the tropics. The approach was wide-ranging, and covered many important effects of DDT on terrestrial and aquatic processes and organisms in Zimbabwe that were previously unknown. More emphasis, however, could have been placed on the aquatic environment as Lake Kariba and its fisheries are the major environmental, economic and food resource in the region. The study represents a rare insight into the impacts of a widely distributed poison on natural community ecology. It makes a substantial and high quality contribution to science, and in some taxa greatly improves our detailed understanding of the impacts on wildlife of using DDT in ground spraying operations against tsetse fly.

4.6 The new contributions to scientific knowledge added to Matthiessen's study are set out in Table 2 below. In particular, significant areas of detailed knowledge of particular species and processes have been acquired.

Methodology

4.7 The study chose to investigate a number of indicator taxa from a range of representative points in the food chain, and successfully overcame a number of major methodological difficulties in dealing with a variable and diverse tropical environment, isolating as far as possible the causal effects of DDT ground-spraying on a range of species in different taxonomic groups. The methodologies were excellent, some were path-breaking, while others were standard or adapted from standard techniques already developed by NRI and others before.

TABLE 2

Matthiessen's conclusions	Additional project contribution	Uncertainties remaining
• that tsetse control operations were almost certainly the main source of contamination, as DDT use had largely been phased out of commercial farming	• confirmed	
• that DDT residues did not persist in the physical environment	• confirmed	
• that DDT residues did accumulate in insectivorous birds and bats, and although not toxic may be affecting their reproduction and behaviour, as well as causing reproductive damage to their avian predators	• bio-accumulation confirmed, but this shown to be toxic to certain woodland birds. • specific detail on 4 common bird species, showing significant but reversible population impact. • specific detail on other vertebrates (1 lizard, 5 bat species), showing actual or potential population decline. • detailed knowledge of food chain leading to effects on susceptible birds and lizards. • indications of some adverse impacts on relative abundance of epigeal and soil invertebrates. • some evidence of changes in species composition of invertebrates. • in general, natural variation outweighed any adverse impacts of DDT on invertebrates.	• long-term consequences for less common species still unknown
• that fish and mussels along shorelines draining from sprayed areas were significantly contaminated	• contamination of fish confirmed, but no significant population impacts shown	• long-term consequences for less common species still unknown • longer-term prospects for studied waterbirds uncertain
• that fish fry in seasonal rivers might also be at risk	• confirmed. DDT contamination is reducing hatching success on Lake Kariba, but does not appear to be limiting population size (NRI, p.173)	• no further detail
• that the levels of contamination in fish were sufficient to explain contamination and eggshell thinning in the Lake Kariba fish eagles	• confirmed	• no further detail
• that levels of contamination in fish were insufficient according to internationally recognised standards to be harmful to human consumers	• effects of discriminatory ground-spraying of DDT on wildlife are as toxic to some species in the tropics as they are in temperate regions, but are less severe in the long-term as they are probably reversible in 10-20 years' (assuming no further applicationsat the same site).	• the long-term consequences for less common species remains unknown • population predictions are difficult in the context of poor understanding of population ecology of many species in Zimbabwe • no evidence is presented on the long-term fate of DDT after dissipation from the local environment
	• deltamethrin knocks out a wide range of invertebrate species from sprayed trees but dissipates rapidly from the environment and does not bioaccumulate • only 20% of trees are sprayed, and reinvasion of invertebrates highly likely	• the study of deltamethrin impacts on vertebrates was compromised by prior DDT spraying • long-term impacts from deltamethrin ground-spraying remain uncertain, although are likely to be limited

4.8 These methodologies could not, however, overcome all the inherent difficulties, both in dealing with a diverse and variable tropical environment, in a context where experimental manipulation of variables was not possible, and in working to understand processes and species whose ecology is still poorly known. Although the project took three years and cost over £800,000, these are relatively limited resources to deploy to the understanding of such ecological complexity and long-term population dynamics.

4.9 However, the contribution of the research to the policy debate remains questionable. There are still significant uncertainties about the studied fauna and, as suggested earlier (paras 2.32-4), key areas of policy-related research have been neglected (alternative insecticides, economics, human health impacts, and the global prospects for DDT). Understanding of human health impacts has not been increased at all.

Conclusiveness

4.10 Actual or potential deleterious impacts of using DDT in ground-spraying have been conclusively demonstrated in populations of a number of wildlife species. There are clear and sometimes severe side effects on the terrestrial fauna although none leading to local species extinction. There is also good evidence that DDT has no impact on a range of other species and ecological processes, that it dissipates more rapidly in the tropics than in temperate zones, and that deltamethrin dissipates even more rapidly.

4.11 There are also a number of areas where the effects of DDT remain inconsistent, uncertain or unknown, and where the research has not been conclusive. Many lesser known or rarer wildlife taxa remain unknown; some species show population decline which cannot conclusively be attributed to DDT but which remain of concern until this decline can be explained; population decline in vertebrate species is probably reversible over the 10-20 years following the cessation of DDT spraying but this is not conclusive; there are indications of negative side effects of DDT on fish populations, which although they are not major, may be important for this crucial resource; there are still large areas of ignorance about the distribution of DDT in the Lake Kariba aquatic environment and its potential effects on aquatic processes and organisms; and a possible risk to human health remains, given the evidence of some effects of DDT accumulations in human infants. Finally, the apparently less severe long-term population impacts of deltamethrin as an alternative insecticide were not conclusively shown, as studies were compromised by prior treatment of the area by DDT and aquatic fauna were not studied.

4.12 Overall, a cautious summary of the project's scientific conclusions would be that there is reasonable evidence that the use of DDT under controlled and limited-dose applications did not give rise to any irreversible damage to the biota and biological processes that were investigated.

4.13 The uncertainties implicit in the above scientific conclusions are one key to the project's weak policy impact. It is, however, in the nature of research into complex ecological processes and highly variable and dynamic tropical environments that uncertainties will always remain. This is especially the case when investigating "no impact". A negative is inherently difficult to prove. Proving a global negative is impossible.

Comprehensiveness

4.14 This study is the most comprehensive to have been undertaken on the environmental impacts of DDT in the tropics, within the context of the ecosystems being investigated, and the wide range of indicator taxa selected at many different trophic levels. The comprehensiveness of the research and its breadth of coverage in investigating population impacts of DDT on a landscape scale is a substantial achievement for a single integrated programme of research.

4.15 In the context, however, of informing the policy debate about DDT's continued use, there are a number of areas where the design of the study was not sufficiently exhaustive or extensive. The fact that the project was designed to improve sectoral rather than national policy explains why some aspects were insufficiently addressed.

(a) **Alternative insecticides** : Investigation of deltamethrin was added as an afterthought, halfway through the project and, as a consequence, its environmental impact was inadequately assessed. With limited resources, project staff commitments to other parts of the project, and limited control over the choice of sites for the deltamethrin trials, this could only be a study of limited scope. The result, however, is that the comparative evaluation of DDT is difficult, because there is inconclusive evidence about the impact of alternative insecticides.

(b) **Human health** : This has turned out to be a crucial determinant of DDT's acceptability. The fact that DDTIA did not significantly address this issue has significantly undermined the report's main conclusion that DDT could continue to be used in certain circumstances. Given both the uncertainty relating to child health and the availability of acceptable alternatives to ground-spraying with DDT, a recommendation that DDT should not be used for ground-spraying would be more defensible. This would be consistent with the recommendation in the main report (and post-1991 GoZ policy) relating to the use of DDT in malaria control. The evaluators are not suggesting that DDTIA should have had a more significant health component (2.35). Rather, the health issue has proved to be a 'killer assumption'[8] which, with the benefit of hindsight, should have been addressed during design and appraisal.

(c) **Global pollution** : It is known that DDT accumulates in the environment and is transported through water and air to cooler regions of the earth. The project concludes that DDT does not accumulate in the soil in sprayed sites but does accumulate in a range of species along the food-chain. There are, however, still large areas of ignorance about the distribution of DDT in the Lake Kariba aquatic environment and its potential effects on aquatic processes and organisms. Furthermore, little is known about the pathways of global transportation of DDT residues or the impact of total DDT accumulations globally and Zimbabwean DDT's contribution to this global stock. The continued use of DDT in Zimbabwe needs to be considered in the context of its uses elsewhere in the world (see Annex D3.7). Study of the global prospects for DDT was, however, clearly not within the scope of this project, even though it is highly relevant to any national or international policy debate.

(d) **Wider land-use** : The report refers to the much greater significance for Zimbabwean wildlife of other negative environmental impacts and land use changes, eg habitat loss from burning, agricultural clearance by migrant farmers, and elephant damage. These aspects of land use change and impact on wildlife have not, however, been addressed (nor were they within the scope of the project as designed). It has been argued that DDT was always something of a red-herring; that DDT was never the most important environmental issue; and that land use change after tsetse clearance is by far the major environmental issue. The project adds very little to this wider debate.

(e) **Economic assessment** : ODA commissioned an economic assessment in 1992, based on NRI's findings (Abelson,1992)(See Annex F11. 1-5). This was not part of the project. It concluded that the direct economic costs of DDT use were very low, except in important wildlife areas. There is, however, reason to believe that the costs of DDT use, as perceived by people in Zimbabwe and elsewhere, are much higher than suggested by Abelson (see annex F11, 1-5). The comparative cost-effectiveness of DDT and deltamethrin also requires further research. The possibility that costs of alternative insecticides will diminish in the future needs to be considered. Even if the apparent cost-effectiveness of DDT were to be confirmed, it is an open question whether any cost savings achieved by TTCB through using DDT rather than alternatives could simply be redirected to land use management as suggested in the NRI report (4.3). Finally, a complete economic and environmental analysis of all the different tsetse control options

8 A 'killer assumption' is an important external factor which is unlikely to be addressed by another project, and which cannot be addressed by a redesign of the project in question. From a technical point of view the project is not feasible.

(including the “no control” option) has not yet been made. The most thorough economic study to date (Barrett,1994) considered neither the environmental costs of different tsetse control methods nor the overall justification for tsetse control. The choice of insecticide for ground-spraying is at best only one of the aspects which needs to be considered. DDT needs to be evaluated against all other options, including alternative techniques, and not alternative insecticides only. It is not appropriate to conclude in isolation that DDT is or is not acceptable.

Presentation

4.16 In general, the background presentation and citation of relevant scientific literature is good, both from relevant work in Africa, and in temperate zones. Some key references did not, however, appear in the report[9] . There is limited contextual background on some relevant research work in the region (e.g. RTTCP, SEMG, Lake Kariba Research Institute, University of Zimbabwe, DNPWLM), on dissipation of DDT in tropics, on critical soil processes, on DDT in Lake Kariba fish and the lake ecosystem, on human health hazards of DDT, and on the overall background to the problems of chemical and non chemical control of tsetse fly in Africa. A wider readership than the scientific community (e.g. policy-makers) would benefit from such information. A reference to other large scale pest control schemes across Africa (mosquitos, ticks, bilharzia, locusts, quelea, rodents, etc) would also have helped to place the project’s work in a wider context for the purpose of policy debate.

4.17 In general, the results and scientific conclusions are clearly and well presented. The impacts of DDT spraying on certain wildlife taxa, both negative impacts and “no impacts”, are clearly presented. The summaries in the environmental statement are also well presented and clear.

4.18 Because, however, of the work’s extensive scale and depth, a great many results emerged. A clearer prioritisation of the importance of different results, key new insights and policy implications, and a stronger presentation of the main areas of continuing scientific uncertainty about DDT impacts, would have helped policy-makers to make balanced judgements.

9 Some key references to volatilisation and dissipation of DDT in the tropics; the global transport of DDT; other studies of the environmental impact of tsetse fly control; and the review by Allsop (1984) of control prospects did not appear in the NRI report. Some relevant references from other areas of Africa and Zimbabwe were also missing (D.Duthie and H.Berg, personal communication).

4.19 The report makes it clear that although some damage to the environment has been noted, this is, at least under the conditions and levels of spraying that were investigated, 'trivial' compared to other threats. The report's policy conclusion is that DDT is acceptable for use in ground-spraying against tsetse fly, based on the evidence available to date, the higher costs of alternative chemicals, and the much greater significance of these other negative environmental impacts and land use changes for Zimbabwean wildlife.

4.20 This view contrasts sharply with the strongly and widely held view, expressed by the scientific panel and in the numerous interviews conducted by the evaluation team in Zimbabwe, even on the basis of this report, that the continued use of DDT in ground spraying for tsetse control is not recommended. This view is based largely on the precautionary principle, and the existence of known, non-persistent alternative insecticides: DDT is persistent; it has negative side effects which are similar, if much less dramatic, to those found in temperate zones; it accumulates in the biotic environment, even though it dissipates much faster than in temperate zones; there are risks and uncertainties that remain unresolved even after this study; and its ultimate fate, probably transported to colder regions of the world, is still poorly understood.

4.21 The project memorandum did not specify the content of the final project report. In the event, the balance in the final report between the detailed scientific enquiry and the analysis of conclusions and policy recommendations was poor. Over 170 pages were given to scientific analysis and discussion, and only one to conclusions and policy recommendations. The wider policy issues, the economic arguments, the use of alternatives, the areas of continuing scientific uncertainty, and the precautionary principle, are all inadequately addressed. There is no balanced presentation of the arguments, and a lack of clarity in the overall conclusion. Many of those consulted during the evaluation conclude that the report is justifying (or at least not ruling out) the use of DDT in certain circumstances. Despite this, most recommend the permanent disuse of DDT. Some are highly critical of the report for suggesting otherwise[10] . The notable exception is TTCB, which holds the view that it will reserve the right to reintroduce DDT in future, if the circumstances are right, on the basis of this report. NRI on the other hand, is adamant that the report does not say DDT use is acceptable, except for one-off use in certain circumstances. The fact that such different conclusions can be drawn from the same report lends support to the view that the report is neither conclusive nor clear.

10 Pesticides and the Environment in Zimbabwe. C.H.D Magadza, University, Lake Kariba Research Station. Draft. 1996.
DDT in the tropics: a review of the NRI report on impacts of DDT in the Zambezi Valley, Zimbabwe. C.H.D. Magadza. Zambezi Society. 1996.

4.22 In all other aspects, the quality of the final project publication is of the highest standards, and has been widely admired for its graphics, illustrations, structure and referencing.

Dissemination

4.23 Dissemination has been poor, judged on whether results and conclusions are accessible, widely read, and timely. This report fails on most counts. The publications record for the bird, lizard and invertebrate studies (although not the fish studies) has been good, with many publications in refereed scientific journals. These sources, however, are not readily accessible to policy-makers. The main project report, aimed at a wider readership, was published very late, some 4 years after completion of the research; the policy conclusions and recommendations are only briefly and obliquely stated; many key policy issues are treated superficially (the context of tsetse control, other methods and chemicals, experience in other countries, economic assessment, wider land use issues); and distribution within Zimbabwe has been limited.

4.24 Nevertheless, earlier publication would not have influenced the decision to discontinue DDT, as this was taken regardless of this research. TTCB was aware of the research findings by the time the team left Zimbabwe in 1991. It is also true that, as DDT is not a major issue at present, late dissemination has made little difference. Clear, effective and accessible dissemination, however, will be more critical if DDT again becomes an issue.

Conclusion on scientific impact

4.25 The evaluators conclude that the project results have led to the intended *purpose* being substantially achieved; ie there is now a better understanding of the environmental impacts of using DDT in ground spraying operations against tsetse fly.

4.26 However, uncertainties remain about both DDT and alternative insecticides, key areas of policy debate have not been addressed and there are weaknesses in presentation and dissemination. These have major implications for the Purpose-to-Goal impact.

4.27 These conclusions are reinforced by the views of the five international reviewers consulted by the evaluators. Table 3 below gives a summary of their views.

TABLE 3 : Overall assessment score of reviewers, on a scale of 1 - 4

	Reviewers Assessment Scores					
	A	B	C	D	E	**Median score**
1. Scientific quality	2	1	1	1-2	1	1 - excellent
2. Presentation and interpretation of conclusions	3	2-3	3	3	2	3 - below average
3. Should DDT be used in ground spraying?	3	3	4	2	2	3 - negative

Note: 1 = excellent / very positive / strongly agree
2 = above average / positive / agree
3 = below average / negative / disagree
4 = poor / very negative / strongly disagree

C. *PURPOSE-TO-GOAL IMPACT*

4.28 The project's assumed goal was to contribute to improved and/or better informed tsetse control policy, based on a scientific evaluation of the role of DDT ground spraying, compared with alternative methods, in integrated campaigns for tsetse fly control. The test applied in this impact evaluation is : has the improved understanding produced by the project influenced TTCB, GoZ, NGO and donor policies towards ground-spraying with DDT, or is it likely to do so in the future? The test findings may be seen at the end of this section (4C), and in section D of this Chapter.

4.29 Two types of policy concerns can be distinguished. The first is about methods that should be deployed currently in the tsetse control programme. The second is about attitudes towards methods that are not currently deployed but might be considered in the future.

4.30 Views conflict about whether the findings of DDTIA have influenced decisions on whether DDT should or should not be used in the tsetse control programme. The decision to terminate the use of DDT was made by TTCB in 1990, two years before the DDTIA project was completed, and six years before the DDTIA report was published. The decision was contrary to the (albeit somewhat unclear) eventual project recommendations. NRI, on the other hand, believes that the early findings on birds in 1987, and an interim review of DDTIA results in 1989, led directly to, and brought forward, TTCB's announcement that DDT would be phased out. TTCB did not mention this to the evaluators. Furthermore, it is difficult to explain the contradiction between this version of history and TTCB's current view that the DDTIA findings support DDT's re-introduction, in certain circumstances.

4.31 In truth, a number of factors contributed to the decision to end ground-spraying with DDT in 1990. The early DDTIA results were possibly one of them. First, there was considerable NGO and public opposition to DDT use for tsetse control in the Zambezi valley. The decision to reduce and then phase out DDT was a direct response to this external pressure. Although more expensive than DDT, deltamethrin was an alternative, and arguably more effective, insecticide for ground spraying. Second, target technology had developed to a point where it represented an effective and less environmentally damaging alternative to ground-spraying. Third, RTTCP provided resources for the deployment and maintenance of targets, but was specifically forbidden to support the use of DDT. Around 35% of TTCB costs are currently financed by the RTTCP and Zimbabwe therefore had a strong financial incentive to adopt the target technology in preference to ground-spraying. Finally, while TTCB was not forbidden to use DDT on its own account, there was a concern that its continued use might jeopardise future EC support.

4.32 Historically, the real DDT crisis in Zimbabwe had come in the 1970s, with high rates and repeated applications of agricultural DDT. A decline in birds of prey with all the classic signs of egg shell thinning and poor breeding success was noted and there were many other signs of high DDT residues at that time (e.g. in fish, other birds and mammals). At the same time, the Ministry of Agriculture recommended expansion of cotton production, with DDT as the preferred pest control agent. Agricultural use of DDT stopped in 1985. Thus, by the time of the project, the real DDT crisis was effectively over, and residues were already dissipating so that rare species that had suffered were already building up again (e.g. Taita falcons & peregrines). After this, applications of DDT for tsetse control continued, but in small doses with few applications: conditions which the project has shown to produce relatively low impact. It can be said, therefore, that it was the 1970s crisis that fuelled public opinion and led to the eventual DDT ban.

4.33 Although DDTIA has probably not altered the course of policy (ie. DDT would have been phased out anyway), it can be argued that its findings have influenced TTCB's attitude towards DDT and that it could still contribute to a reassessment and resumption of DDT use in the future. TTCB is clear that it retains the option of returning to ground-spraying with DDT if necessary, an option that it sees as supported by the NRI study. The arguments given in favour of ground-spraying with DDT are (i) the ineffectiveness of targets in certain situations with certain species, and (ii) the cost advantages of DDT over deltamethrin (see Annex F11.4). TTCB argues that it is only able to afford to use the more expensive target technology because of EU support under RTTCP. Should Zimbabwe ever need to maintain its tsetse control programme without donor support, TTCB would have to use the most cost-effective method. TTCB believes that ground-spraying with DDT is both cost-effective and, according to DDTIA, environmentally acceptable. Thus, to the extent that DDTIA has lent support to TTCB's views on DDT, the project has informed and influenced TTCB policy regarding the control options available.

4.34 TTCB is, however, only one of the stakeholders in any decision regarding DDT use, and its views are open to challenge. Other groups, notably some other parts of the GoZ system, NGOs, the public, and donors, are major players. It is therefore important to consider the extent to which the attitudes of these groups have been, or might be, influenced by the DDTIA findings.

4.35 Table 4 below lists 13 possible conditions that would need to be met before the use of DDT for ground-spraying could be seriously reconsidered and assesses whether these conditions currently exist. The final five conditions only apply if donor assistance is required.

TABLE 4 : CONDITIONS FOR THE RESUMPTION OF GROUND-SPRAYING WITH DDT

	CONDITIONS	CURRENT ASSESSMENT
1.	GoZ accepts DDTIA scientific findings.	Yes
2.	GoZ accepts DDTIA conclusions and recommendations.	No
3.	GoZ considers risks to human health as acceptable.	No ?
4.	No better alternatives to ground spraying with DDT are available.	No
5.	TTCB has the capability to resume ground spraying.	Yes ?
6.	GoZ able to finance DDT spraying without external aid.	Yes ?
7.	Zimbabwe public/NGOs are convinced of 1 - 4.	No
8.	International pressures are negligible.	No ?
9.	Donors accept DDTIA scientific findings.	Yes
10.	Donors accept DDTIA conclusions and recommendations.	No
11.	Donors consider risks to human health as acceptable.	No
12.	Donors agree that no better alternatives exist.	No
13.	Public/NGOs in donor countries convinced of 9 - 12.	No

4.36 The overall conclusion of this assessment is that ground-spraying with DDT is no longer a defensible or likely option, particularly if donors are involved. The main reasons for this judgement are given below.

1. *Human health risks*

4.37 DDT is one of the safest pesticides ever developed. The World Health Organisation concluded that its human safety record has been "phenomenally good" (WHO,1979,1989). The significance of the DDT used in tsetse spraying operations, as opposed to its use in malaria control campaigns, may also be questioned. Nevertheless, as already discussed, significant uncertainties remain relating to DDT residues in breast milk and the possible effects on child health. The health aspects of the DDTIA final report are too slight to be of any value in allaying public concern about DDT use in ground-spraying, regardless of the fact that most DDT found in breast milk originates from malaria control or other uses. Unless and until this issue is better understood, the resumption of the use of DDT is likely to be opposed by the public and NGOs and avoided by GoZ and donors.

NGO and public attitudes towards DDT

4.38 A number of factors are likely to militate against acceptance by NGOs and the public, both in Zimbabwe and in donor countries. DDT has a uniquely bad name, which possibly no amount of science can counter. More substantively, the principal public concerns about DDT remain. First, there is an objection to the use of any persistent global pollutant which accumulates in the biotic environment. Second, concern over the effects of DDT levels in breast milk would be likely to figure prominently in any campaign, as it did in Zimbabwe in 1986. Third, while unlikely to challenge the scientific findings, NGOs may well challenge the conclusions and recommendations. DDT does have negative side effects which are similar, if much less dramatic, to those found in temperate zones. Conclusions about what is or is not a "trivial" or "acceptable" impact are value judgements. In addition, there still remains considerable uncertainty over DDT's impact on many lesser known or less common species. These objections are all the more strongly held because there are alternative control methods with fewer side-effects and uncertainties.

Alternatives to DDT and ground spraying

4.39 The major argument put forward for DDTIA in 1985 was that targets were not yet a proven alternative to ground spraying. This argument carries much less weight today : targets have proved to be an effective and less environmentally damaging technology. Deltamethrin also represents an effective and less persistent alternative to DDT for use in ground spraying.

4.40 It can nevertheless be argued, as TTCB does, that ground spraying with DDT may be necessary in some circumstances and may be preferable. Targets are costly, and appear to be less effective against one tsetse species (*G.morsitans*). Despite the success of targets, there may still be a need for ground spraying to clear pockets of flies which cannot be cleared with targets or aerial spraying[11] . It can also be argued that deltamethrin is not necessarily environmentally acceptable but merely that its impacts are different and less well-studied. Deltamethrin might also be more expensive than DDT. Both arguments can be challenged but the fact remains that the case against DDT and for alternatives is still not conclusive.

Donor attitudes

4.41 In 1987 a report by two Zimbabwean NGOs led to a written question in the European Parliament which asked amongst other things whether the Commission was prepared to make further aid to the tsetse control programme in Zimbabwe conditional on an undertaking by Zimbabwe that DDT use would cease. The Commission responded that the alternatives did not yet exist which could be used to persuade Zimbabwe not to use DDT.

4.42 In 1995 it can be argued that acceptable alternatives do now exist (4.39 & 40 above). This, with the fundamental environmental objections to DDT which remain, would arguably make it extremely difficult for a donor to support the reintroduction of DDT. It is the EC view that the use of DDT is neither socially nor politically acceptable. As far as EU support is concerned, there is definitely no possibility of a return to the use of DDT in ground-spraying. The DDTIA project has done nothing to change this view.

Ground-spraying capability

4.43 Ground-spraying requires considerable skill, management and logistics. TTCB has many of the key personnel but it is doubtful whether it could provide the scale of logistics required. EU support is currently essential to service targets and is unlikely to be provided to support the reintroduction of ground-spraying.

GoZ finances

4.44 RTTCP provides 35% of TTCB running expenses. EU would not finance ground-

11 Although less effective, the right trap and bait combination at the right density can still produce capture and kill rates sufficient to bring population decline to tolerable levels. This is acceptable where eradication is not the goal, which it sometimes is. This is why it is likely that TTCB will carry out a small ground-spraying operation using deltamethrin in the near future in an area where targets have been in use for about seven years, but where G.morsitans is still present in low numbers.

spraying with DDT. It would certainly be possible for GoZ to finance tsetse control from its own resources, given the high priority attached to this activity, but this is not a likely option.

Conclusion on policy impact

4.45 The reservations about the likelihood of DDT being reintroduced are necessarily speculative. They coincide however, with the widely and strongly held view expressed by the scientific panel and in numerous interviews conducted by the evaluators in Zimbabwe, that the use of DDT in ground spraying for tsetse control is not recommended. This contrasts with the obliquely given view expressed in the DDTIA report.

4.46 If most of the major interest groups outside TTCB now believe that DDT should not be used, despite the report's findings, what contribution has DDTIA made? DDTIA would appear neither to have informed the decision to phase out DDT, because it came too late, nor to have changed attitudes towards DDT. At best it may have brought forward TTCB's announcement that it intended to phase out DDT use. This is a disappointing record for a project which aimed to inform and improve policy. DDT was phased out, and is unlikely to be used again, with or without DDTIA. The uncomfortable implication is that DDTIA has had, and is likely to have, no policy impact. If this is the case, DDTIA cannot be said to have generated benefits commensurate with its costs.

4.47 This is not to deny the fact that, if DDT use were ever to be reconsidered, DDTIA would be an important source of information. Its scientific contribution may therefore be judged as sustainable. It might not be sufficient to win its reintroduction but it will make a significant contribution to the debate if and when it occurs. Nor is this a judgement on the scientific quality and value of the research. This is widely regarded to be of the highest order. Some of the scientific methodologies were path-breaking, and the information on DDT dissipation is relevant elsewhere in the tropics. This does not, however, detract from the judgement that the developmental value of this project to Zimbabwe has been, and is likely to remain, slight.

D. CONCLUSIONS

4.48 The overall conclusion of the evaluation is that, despite the excellent scientific research carried out under DDTIA and the volume of information generated, the project is unlikely to have a significant impact on policy and practice. There are two main explanations for this disappointing outcome. First, the project was simply too late to influence decisions on DDT within Zimbabwe. DDT was phased out before the project was completed. Second, the research could not counter the poor public image of DDT and the fundamental objections to DDT as a human and global pollutant. Any pollutant which accumulates is likely to fall foul of the precautionary principle : "if in doubt, don't". As has most recently been seen in the case of the Brent Spa oil platform, public perceptions are often more influential than scientific and economic arguments. And as also demonstrated by the BSE crisis, it is very difficult to prove a negative (whether or not this is the fact) within a reasonable political time frame.

4.49 Could these risks have been foreseen in the mid-1980s? It can be argued that the first was just bad luck : target technology was still in its infancy in 1985, alternative insecticides had not been tested, and DDT was still being used in malaria control. Ground-spraying with DDT was the only proven alternative to aerial spraying at that time.

4.50 The alternative view is that by the mid-1980s the tide was running very strongly against DDT in Zimbabwe. Environmental NGOs were campaigning against DDT use and in 1985 GoZ announced its intention to phase out its use in tsetse control. Alternative insecticides were available and target technology was showing promise. In the opinion of the evaluators, these factors mean that the decision to fund DDTIA was, by 1987, questionable. At the very least, the risk of DDT being phased out without the benefit of the DDTIA findings could have been identified at appraisal, and made explicit. Pressures within ODA to provide funding for TDRI led to these concerns being downplayed.

4.51 It is more difficult to argue that the second risk should have been foreseen. With the benefit of hindsight, and another ten years of environmental campaigning, the likelihood of such a sectoral research project answering all the questions on DDT to the satisfaction of an increasingly informed and aware public in Zimbabwe and the EU can now be seen to be slight. This must, however, be more a lesson for the future than a criticism of the past. The evaluators conclude that this particular risk could not reasonably have been foreseen at the time.

EVALUATION TERMS OF REFERENCE ANNEX A

DDT IMPACT ASSESSMENT PROJECT, ZIMBABWE

OBJECTIVES

- 1. The objectives of the evaluation are :

  i) to assess the immediate impact of the project, with particular reference to the scientific and policy impact;

  ii) to evaluate project design and management;

  iii) to derive lessons relevant to projects which aim to inform policy, and to natural resources research projects in general.

SPECIFIC TASKS

General

2. The Project Framework should be a central part of the evaluation. If this is lacking, or if different versions exist, the evaluators should agree a Project Framework as an integral part of the evaluation process, and use this as a basis for assessing the achievement of project objectives and outputs, and for analysing the risks and assumptions.

3. In addition to the specific issues detailed below, the evaluators should consider the significance of the following factors in determining the overall impact of the research project :

i) the timing of the research in relation to trends international and national policy towards DDT;

ii) the relationship between TC and NRED/NRI funding;

4. The evaluators will present and discuss their initial findings in a meeting involving the main stakeholders before leaving Zimbabwe. This is likely to involve TTCB, RTTCP/SEMG, Wildlife Department, and local NGOs.

5. An evaluation workshop will be held in the UK to discuss the findings of the study after the team have completed the overseas visits. The evaluators will present their interim findings, conclusions and lessons for discussion at the workshop.

Identification, Design and Appraisal

6. The evaluators will document the background and origins of the project;

7. The evaluators will assess the quality of the project design and appraisal process, with particular regard to :

    i) the objectives and scope of the research, and how this was agreed. Particular consideration should be given to the debate over the fisheries component, and the omission of any epidemiological studies of human populations;

    ii) the specification and timing of the research outputs;

    iii) the identification, participation and contribution of intended users and other stakeholders in the preparation of the project;

    iv) the relationship between the project and other parallel research projects (RTTCP/SEMG; NRI; TTCB; etc.);

    v) the absence of economic, financial, social, institutional and external scientific appraisal;

    vi) the type and timing of dissemination planned;

    vi) the arrangements for training and institutional collaboration;

Implementation and Management

8. The evaluators should analyse the main features of project implementation, and assess the quality of project management. In particular, the team should consider :

    i) if and how the objectives and activities of the project changed over time; how these were agreed; and the effect of these changes.

    ii) the TCO recruitment process;

    iii) administrative and procurement arrangements;

    iv) counterpart and training arrangements;

v) monitoring and review practices, and the role of different stakeholders;

vi) the extent of consultation and collaboration with intended users during project implementation;

vii) the cost-effectiveness of the research;

viii) the nature of any constraints on project implementation, and the effectiveness of the steps taken to remove these;

xi) the extent to which the project was adequately linked with, and/or influenced by, other research programmes;

x) arrangements for the production and dissemination of research findings.

Impact

9. The evaluation team will identify and analyse the immediate impacts of the project, and identify the extent to which further impacts may be forthcoming. Specific consideration should be given to the impact of the research on tsetse control policy within Zimbabwe; to the scientific impact of the research; and to the institutional benefits.

10. Particular attention should be given to the following :

i) the scientific achievement and outputs of the project;

ii) the dissemination to, and use of, the research outputs by different groups;

iii) the relative contribution of this project to the decision to phase out DDT use in Zimbabwe, or to other changes in tsetse control policy. The contribution of the previous NRI research project, other TTCB and SEMG research, and EC policy should also be considered;

iv) the institutional impact of the research for TTCB, NRI and other institutions;

11. To the extent possible, the evaluators will assess the economic costs and benefits of the project.

12. The evaluators will identify and analyse the major factors affecting the magnitude and distribution of actual or potential project impacts. These could include factors internal or external to the project.

13. The evaluators will assess the sustainability of the impacts of the research, and identify those factors internal or external to the projects which will affect this.

PERSONS CONSULTED — ANNEX B

R J Douthwaite	DDTIA	
H Berg	University of Stockholm	
D Buffin	The Pesticides Trust	
V Chadenga	TTCB	
P Chifamba	University Lake Kariba Research Station	
D Cumming	WWF	
M Dale	EC	
I Daniels	RTTCP	
E Dhlomo	University Lake Kariba Research Station	
J M Jewsbury	Environmental and Community Health	Consultant
I Grant	NRI	
J H Koeman	Agricultural University of Wageningen	
M D Laidler	EC Delegation, Harare	
D Lovemore	RTTCP	
C Machena	DNPWLM	
A Mangwiro	Ministry of Health	
B Marshall	University of Zimbabwe	
R Masendu	Blair Research Laboratory	
W Mhalanga	KFRI	
P Mundy	DNPWLM	
M Murphree	IUCN, Harare	
N Kautsky	Stockholm University	
P Nagel	Universitat des Saarlandes, Saarbrucken	
C F B Nhachi	Clinical Pharmacology, UZ	
D Peakhall	Editor, Ecotoxicolgy Journal	
J Perfect	NRI	
R J Phelps	RTTCP	
D Pitman	Zambezi Society	
C Plastow	BHC	
R Sanyanga	University Lake Kariba Research Station	
W Shereni	TTCB	
A Tainsh	BDDSA	
C C D Tingle	DDTIA	
J Trehy	EC Delegation, Harare	
G Vale	RTTCP	

C1. The objective of the project will be to produce a better understanding of the environmental costs of using DDT, or alternative insecticides, for ground spraying against tsetse and to provide evidence which will contribute to a rational evaluation of the role of this technique in integrated campaigns for tsetse fly control.

C2. The specific objectives will be :

(a) to determine whether residues from ground spraying lead to effects on the aquatic fauna of seasonal rivers flowing into Lake Kariba, with particular reference to breeding success of the commercially important fish species Clarias and Hydrocynus, and to assess whether these effects are likely to have long-term detrimental effects on the productivity of the lake ecosystem or pose a hazard to consumers.

(b) to investigate the effects of ground spraying on reproductive success and eggshell thinning of the Fish Eagle, selected because of its importance as a top carnivore in the aquatic ecosystem, its amenity and conservation value, and the known susceptibility of raptors to accumulation of persistent insecticides.

(c) to determine the effects of ground spraying on terrestrial fauna occupying the same habitat type as tsetse, including studies on abundance and diversity of selected groups occupying important positions in the food chain, insects having a key role as pollinators such as honey bees, and insectivores or carnivores particularly at risk. Bats and birds are likely to be the major groups in the latter category.

(d) to determine whether ground spraying affects the process of organic matter decomposition and mineralisation in such a way as to affect nutrient cycling and soil productivity in treated woodland.

C3. Should the studies under (a) indicate the possibility of significant accumulation of DDT or its residues in humans through consumption of contaminated fish, epidemiological studies of selected populations will be instituted through the GOZ Ministry of Health.

(Extract from project memorandum dated 14 April 1987)

D1. Discovery and early use

D1.1 2,2-bis-p-chlorophenyl)-1,1,1-trichoroethane, now better known as **DDT**, was first synthesised by Othmar Zeidler in the laboratory of Professor Adolf von Baeyer in 1874 (Zeidler, 1874). At this time, no mention was made of the molecule's insecticidal power, and it was not until September 25th, 1939 that Dr Paul Mueller, in the laboratory of J. R. Geigy A. R., recreated DDT as part of a research programme to find effective poisons against the clothes moth and carpet beetles. A Swiss patent of 1940 comments on "the strong action of DDT on a wide variety of arthropods"; in reality, DDT was so dramatically effective as an insecticide that Mueller was awarded the Nobel Prize for Chemistry in 1948.

D1.2 DDT's insecticidal properties had been discovered just as Europe entered World War II. Military medical researchers had grim memories of the significance of louse-borne typhus in the fortunes of the Central powers in the Balkans and the Eastern Front. WW2 was rapidly spreading into Greece, North Africa and (later) to the South Pacific where insect-borne diseases, notably malaria, were as great a threat as direct military conflict. A cheap, broad spectrum, persistent insecticide which could be applied to human bodies with no (immediate) side effects had obvious military significance. The first widespread use of DDT was in a campaign to eradicate malaria on Sardinia in the 1940s (Logan, 1953). The project succeeded in eliminating malaria but, in spite of a massive military scale operation, failed to eradicate the mosquito vector (*Anopheles labranchie*) and produced population increases in other mosquito species (*A.claviger* and *A. algeriensis*) (Aitken and Trapido, 1961). Even this early trial use of DDT brought reports of widespread mortality to bees, cattle and fish; these were disregarded as no direct causal link between DDT and mortality of non-target organisms could be proven (Logan, 1953).

D1.3 In the 1950s, the WHO proposed the Global Eradication of Malaria Plan, which proposed the use of DDT for residual house spraying twice a year for five years. By 1972, malaria was pronounced to have been eradicated in 37 countries (population 728 million) and under complete or partial control in another 80 countries (population 618 million). It is estimated that DDT "death control" saved millions of lives and billions of illnesses, helping to raise life expectancy in India from 32 years in 1948 to 52 years in 1970, and played a major role in the continuing rapid human "population explosion". But, by 1972 as the result of a combination of increased mosquito resistance to DDT and institutional weakness in many countries, the WHO Plan was declared ineffective and closed. Malaria is now present again in most of these countries, in some cases at levels exceeding the original situation (NAS, 1991). DDT continues to be used for malarial control in many tropical countries, mostly in Asia and Africa.

D1.4 In agriculture and forest pest control, DDT was also dramatically successful in the 1950s, and became the standard agricultural insecticide, at one time being registered for use on over 300 agricultural commodities in the US and being applied to most of the 400 million acres of agricultural land in the US at the time. DDT was also widely sprayed against the two great defoliators of American forests, the gypsy moth (*Lymantria dispar*) and the spruce budworm (*Choristoneura fumiferana*) (Rudd, 1964).

D1.5 DDT production rose from 30,000 metric tonnes in 1950 to a peak of almost 1000,000 metric tonnes around 1960, when it was being widely used throughout Europe and North America. Global production and use has declined since then to around 2,000 metric tonnes, with around 50% of global use now being concentrated in Asia, Central and South America and Africa (see Figure). The global distribution pattern of DDT recent use is clearly shown in results of surveys of atmospheric contamination by halogenated hydrocarbons (Bidleman, Wideqvist et al., 1987 Kurtz, 1990; Iwata, Tanabe et al., 1993; Tanabe, Iwata et al., 1994).

D1.6 Accurate estimates of total DDT use globally over the past 50 years are difficult to compile, but it is calculated that a minimum of 1,500,000 metric tonnes of DDT has been used; the true figure is more likely to be over 2,500,000 metric tonnes used between 1950 and 1993 (Voldner, 1995), although some earlier estimates claim that more than 3,000,000 metric tonnes of DDT were produced between 1940-1977 (WHO, 1979).

D2 The decline in DDT use in Europe and North America

D2.1 The physico-chemical properties of DDT which enable it to be an effective insecticide also make it well suited to be a global pollutant. DDT, and its immediate biodegradation products (e.g. DDE), have essentially the same physico-chemical properties, including low vapour pressure, low photo-oxidation decay, low water solubility but high solubility in lipid (fat).

D2.2 One consequence of the two last mentioned properties is that biological organisms are, in effect, “vacuum cleaners” for DDT in the environment, assimilating DDT whenever it is present, even very low concentrations and then only slowly losing it via excretion or metabolic (chemical) change.

D2.3 A further unexpected property of these compounds, not fully appreciated until the 1970s (see below), was that the physico-chemical properties of DDT and other organochlorine compounds predispose them to redistribution around the globe to sites where their persistence is the greatest, i.e. from the tropics to northern temperate/polar regions (Goldberg, 1975; Kurtz, 1990; Goldberg, 1991; Wania and Mackay, 1993; Wania and Mackay, 1995).

D2.4 Perhaps the first warning of the potential negative side-effects of DDT appeared in the Atlantic Monthly in 1945 in an article entitled: “DDT and the Balance of Nature” (Wigglesworth, 1945). As early as 1946 the US Fish and Wildlife Service was warning that DDT was a potential menace to mammals, bird, fishes and other wildlife and that special care should be taken to avoid DDT application to streams, lakes and coastal bays because of the sensitivity of fish and crabs (Cottam and Higgins, 1946). In 1949, an International Technical Conference on the Protection of Nature identified 5 types of side effect from using insecticides as: direct killing of non-target species; secondary mortality of animals eating poisoned insects; secondary mortality of insectivores due to lack of food; disruption of pollination; disruption of predator-prey relationships (Sheail, 1985); p.20).

D2.5 Since its first use as an insecticide, DDT has became the most intensively studied pollutant chemical ever; the environmental impacts of DDT are summarised in a number of reports and books (Mueller, 1955/9; Rudd, 1964; Moore, 1965; Pimentel, 1971; Edwards, 1973; Perring and Mellanby, 1977; Brown, 1978; WHO, 1989).

D2.6 In the early phase of concern over the negative impacts of DDT use, the persistence, and potential for residual toxic effect of the chemical in temperate regions was the major worry of both scientists and the general public. Following the publication of Rachel Carson's "Silent Spring" and a long and sometimes acrimonious debate in public, political and scientific circles (see Sheail, 1985; Mellanby, 1992 for historical reviews), use of DDT was restricted and consumption declined dramatically in the US and Europe.

D2.7 The history of the scientific, political and public debate which led to the restrictions or total bans on use of DDT in developed countries has been covered in several popular books e.g. (Busvine, 1989; Mellanby and Mueller, 1992) and will not be expounded here. Much of the confusion over the "rights and wrongs" of DDT arises from the attitudes taken by different advocates in this debate, which result from differences in the relative importance these attach to different facets of the "whole picture". Generally, those immediately involved in the agrochemical business, food production and public health were most influenced by the remarkably low toxicity of DDT to humans, whilst those charged with the protection of wildlife were more concerned about the threat of widespread ecological disruption which might follow increased use of DDT.

D2.8 The polarisation of attitudes over DDT use in the US and Europe in the late 1960s was not new. It was not restricted to this chemical alone, and it has not changed much since that time. As early as 1961, before the publication of Rachel Carson's Silent Spring, Hickey wrote:

"What appears to be lacking in the insect-control machinery of some states is an administrative realisation of the emotional impact of modern insecticides on the public mind, an alertness to all the questions that are puzzling conservation minded people, a willingness to admit that wildlife losses are taking place under certain conditions, and a sense of responsibility to show exactly how these losses are being kept to a minimum and why the losses are justified. When these are lacking, public fears of an entrenched bureaucracy are bound to mount." (Hickey, 1961, quoted in Peterle and Giles, 1964).

D3. The global use and effects of DDT

D3.1 Following the decline in use of DDT in Europe and the US, the continued use of DDT in developing countries for malaria control and agriculture led to a “southward tilt” in DDT use towards the tropics (Goldberg, 1975). As attention in developed countries turned towards the negative impacts of the “second generation” of organophosphate pesticides, the urgent need for cheap, effective insecticides in the tropics, coupled with low direct toxicity to humans and the apparently rapid degradation of DDT in tropical climates led to a reduction in concern about the wider negative impacts of DDT and little action was taken to reduce DDT use in the tropics by those countries which had banned or restricted its use within their own boundaries.

D3.2 Meanwhile, in the late 1960s, the “surprising” discovery had been made that DDT and other halogenated pesticides were distributed widely in the global atmosphere, and could be detected at sites thousands of kilometres from the nearest site of application (see Kurtz, 1990 for a review). In spite of the low vapour pressures of organochlorine compounds such as DDT, it was found that these chemicals could rapidly volatilise away from sites of application (Spencer and Cliath, 1972). At the time, the origins of this DDT were the countries which reduced or banned DDT use in the early 1970s, and little thought appears to have been given to the chance that DDT applied in the tropics would also redistribute itself more widely in the global environment.

D3.3 Interestingly, an early indication that the movement of pesticide residues from tropical environment might be global was provided by one of the principal investigators of impacts of insecticide use for tsetse fly control, who observed that residues of organochlorine pesticides were surprisingly low in wildlife in areas of Central Africa near Lake Chad and Lake Victoria in spite of extensive local use of pesticides in cotton production (Koeman and Penning, 1970). The researchers suggested that insecticide used in hot, arid countries must be lost to the atmosphere by evaporation and co-distillation.

D3.4 Field observations of rapid and extensive “loss” of DDT in tropical climates have been made by ODA researchers in Africa (Perfect, 1980), and in work completed in African countries with similar soils and climates to those of Zimbabwe (Sleicher and Hopcraft, 1984). These and other studies demonstrated that the half-life of DDT in tropical soils is of the order of 100 days, considerably less than that found in other habitats (see table). Sleicher and Hopcraft (1984) concluded that: “the results show that sublimation alone can account for the disappearance of pesticides of low volatility (such as DDT) even if they are strongly adsorbed on soils and that the uncontrolled use of DDT in Kenya may affect wildlife to a lesser extent than had been feared”.

D3.5 In parallel with the research that tracked DDT releases in the global environment, a detailed literature was developing which investigated the effect of soil type, temperature, etc. on rates of volatilisation of pesticides, including DDT (reviewed by (Spencer and Cliath, 1972). These technical data allow the calculation of rates of volatilisation over a wide range of environmental conditions. Whilst these calculations are not simple and would be subject to wide confidence limits, they provide a basis to predict long-term persistence and movement of pesticides applied at various rates in different climates. These technical data were used by Sleicher and Hopcraft to develop a model of rapid DDT sublimation in Kenya (Sleicher and Hopcraft, 1984).

D3.6 Once in the atmosphere, DDT could be transported over long distances and secondarily re-deposited in new sites where persistence times may be much longer than in the tropics. As early as 1969, Peterle calculated that up to 2.4 x 106 kg of DDT residues may have been deposited in Antarctic snow (Peterle and Keith, 1991). The indirect impacts of the "chemical fallout" of DDT thus represents a global pollution problem, not recognising international boundaries, with implications for organisms at the head of food chains, especially marine mammals, world-wide (Muir, Norstrom et al., 1988; Loganathan and Kannan, 1994; Norstrom and Muir, 1994; Tanabe, Iwata et al., 1994).

D3.7 Although the contributions to global pollutant usage made by individual users or separate countries are very small, the existence of global redistribution pathways, primarily from the tropics to the colder polar regions, where long persistence times and potential for bioaccumulation remain a problem, creates many additional complexities in the debate over the continued use of these chemicals. It was these broader issues, rather than narrow-focused cost-benefit analysis, which were important in the debate over restrictions on DDT use in the UK at the end of the 1960s, when UK use was less than 1% of global use and unilateral action would have had no immediate impact on global contamination (Moore, 1970; Tinker, 1970).

D3.8 The undesirable side-effects of DDT can be listed as follows:

- direct toxic effects on humans during manufacture and application;
- direct toxic effects on non-target organisms at the site of application;
- secondary toxic effects as the result either of persistence at the site of application, or transport and deposition at other sites;
- decreased long-term effectiveness as the result of the evolution of resistance in target species.

D4 Direct toxic and long-term chronic effects on humans during manufacture and application

D4.1 There is little doubt that, for a pesticide, DDT is relatively non-toxic to man. Short-term toxic effects on the central nervous system, notably hyperactivity and tremors, only arise from excessive doses which could not be encountered easily in the natural environment due to the low permeability of human skin to DDT.

D4.2 The WHO acceptable daily intake (a.d.i.) for DDT is 0.005mg/kg body weight; this is equivalent to about 0.35 mg/day for a 70kg man.; about 10 times the average DDT ingested in the US at the height of DDT use in 1965.

D4.3 DDT storage in human adipose (fat) tissue was discovered as early as 1948 (Howell, 1948), and it is likely that every human on Earth contains some residues of DDT or its derivatives (Kutz, Wood et al., 1991). The World Health Organisation reports a range of 2.3-21.3 ppm total DDT in adipose tissue of a wide range of subjects (WHO, 1976). In 1973, the average US citizen contained 2.3-4.0 ppm of DDT and 4.3-8.0 ppm of DDE in their body fat. In India, where use of DDT was higher, the average amounts were 16 ppm and 10 pmm respectively, whilst Eskimos, who did not use DDT, contained 0.8 ppm of DDT and 2.2. ppm of DDE (Metcalf, 1973).

D4.4 Despite this contamination, there is little evidence that DDT is responsible for any human illness or decreased longevity. DDT and its metabolites have a biological half-life of around six months in man, so a balance between intake and loss via excretion and metabolism can be reached at different levels of exposure. It appears that this "steady state" level occurs in man at levels which do not constitute a direct health risk.

jD4.5 Some US workers employed in the formulation of DDT insecticides were exposed for long periods of daily exposure to DDT levels of about 15-20mg/day over a number of years , yet no direct health impacts have been attributed to DDT over a 20 year monitoring period (Spindler, 1983). Volunteers have ingested up to 35mg of DDT per day (over 100 times the ADI and 500 times the average intake) for over 21 months and, despite accumulating DDT levels of up to 619 ppm in adipose tissue, showed no clinical evidence of harmful effects over a follow-up period of 5 years.

D4.6 The toxic effects observed in other mammals, notably bats, when excessive DDT accumulated in body fat is released in the body during starvation, etc. is unlikely to have the same impact on humans, due to their low relative fat content, which means that even if all accumulated DDT (about 10mg) were to be released at once, it would still be insufficient to produce toxic effects.

D4.7 The greatest potential human health risk from DDT appears to arise following the concentration of DDT and DDE in the breast milk of lactating mothers in areas exposed to high levels of DDT use through malarial control or agriculture. It has been shown that infants in many developing countries, including Zimbabwe (Chikuni, Skare et al., 1991), are ingesting DDT residues, sometimes at levels much higher than WHO recommendations, in their mother's milk and this has been linked with increased levels of hyporeflexia (Jensen, 1983; Bouwman, Cooppan et al., 1990). The long-term consequences of this exposure are not known.

D4.8 Over the years, DDT has been linked with a range of teratologic, mutagenic and cancer risks, but the evidence is equivocal (Jukes, 1970; Spindler, 1983). Although new facets of the biological activity of DDT are still being discovered (Kelce, Stone et al., 1995), the general conclusion remains valid, ie that DDT is one of the safest pesticides ever developed with respect to human health.

D4.9 The low doses being used and the infrequent applications used in tsetse fly control make it unlikely that any direct health threat to either tsetse control staff or local populations would arise from use of DDT in spraying when carried out according to standard procedures.

D4.10 Long-term contamination of local populations in tropical countries arises mostly from use of pesticides in agricultural pest and malarial vector control spraying rather than through tsetse fly control. Indirect risk through exposure to residues from food could have been assessed from the measurements made of residues in plant and animal tissues likely to be consumed by local population. as part of the study. This was done for fish from Lake Kariba, the most likely route of contamination by DDT residues from tsetse fly control.

D4.11 Given the existing literature on the absence of serious risk to humans from low doses of DDT, the complexity of the appropriate level of epidemiological study required, and the low infrequent dosage being used, it was inappropriate for this study, as proposed, to undertake any practical work to investigate impacts on human health (see Annex C3).

D5 Direct toxic effects on non-target organisms at the site of application

D5.1 Evidence of the direct toxic effect of DDT to most taxa of organisms had been well established by 1985 (see reviews in (Moore, 1965; Edwards, 1970; Pimentel, 1971; Edwards, 1973; Perring and Mellanby, 1977; Brown, 1978); also (WHO, 1989) which, although published in 1989, contains only 2 references later than 1984.

D5.2 Studies of the direct toxic effects of DDT in the tropics are much fewer despite the many studies which report residue levels in different species . This lack of data on DDT impacts in the tropics is partly a reflection of a wider lack of detailed ecological studies of all kinds in the tropics but may in part be due to the fact that, although there is evidence that even closely related taxa can show quite different sensitivities to DDT, there are few data which indicate that similar taxa with similar ecological attributes from temperate or tropical regions show consistently different responses to the same level of exposure to DDT. Thus much of the extensive literature on DDT effects on non-target organisms in temperate countries is relevant to tropical countries as well.

D6 Direct toxic effects on mammals

D6.1 By 1985, it was well established that DDT could be detected in the tissues of most mammals in areas where DDT had been used (Brown, 1978); that DDT could be detected at low levels (<0.1ppm) in the tissue of game well away from sites of application (Walker, Hamilton et al., 1965); that different species accumulated DDT to different degrees following the same overall exposure, for example, mice less than shrews ((Brown, 1978); p204-5); that DDT applications of up to 1.36kg/tree caused mortality of gray squirrels and red bats (Lasiurus borealis); and that bats were considerably more sensitive to DDT than mice, with an oral LD50 of 30mh/kg for bats as opposed to 400 mg/kg for mice (although other studies report both higher and lower values for mice). If any general conclusions could be derived from the extensive research conducted in temperate climates, they were that predators accumulated more DDT than herbivores and that the main route of uptake was via soil residues and terrestrial invertebrates rather than through vegetation.

D6.2 By 1985, it was also well understood that mammals would only accumulate DDT residues up to a threshold set by the balance between rate of exposure and the rate of excretion and metabolic breakdown.

D6.3 The mammalian species most at risk were those which had a large proportion of lipid (fat) to body weight, lived long enough in a contaminated habitat for substantial bioaccumulation to occur, and were subject to periods of low food supply when fat reserves were mobilised. This applies particularly to bats and (increasingly) to top predator marine mammals (seals and toothed whales).

D7 Direct toxic effects on birds

D7.1 In general, birds appear to be more sensitive to DDT applications than are mammals, but in 1961 the US Fisheries and Wildlife Service concluded that annual DDT applications of 1.12kg/ha or less were without undesirable side-effects on birds (Brown, 1978) p221).

D7.2 The widespread mortality to robins and other songbirds in the US following application of DDT to shade trees at doses of 0.5-3kg/tree was one of the major impacts which triggered public concern about pesticide fuelled by the publication of Silent Spring. In these cases, death was the indirect result of the birds eating earthworms (and other invertebrates) that had accumulated sufficient DDT to ensure that ingestion of around 100 worms would give a lethal dose (around 3mg for a robin). The importance of indirect rather than direct routes for accumulation of DDT are clear from results demonstrating that direct spraying of nestlings at doses of up to 6kg/ha had no effect, whilst birds fed on spruce budworm larvae collected from an area sprayed at only around 1kg/ha suffered 20% mortality. The long persistence time of DDT in temperate climate soils makes this kind of indirect impact especially significant, as new birds moving into areas made vacant by kills will still accumulate lethal doses for a number of years, particularly after repeated applications.

D7.3 The potential for adult birds to receive an indirect lethal dose by bioaccumulation along food-chains make insectivorous birds and top predators, especially those eating fish or birds, particularly vulnerable to DDT.

D7.4 In addition, the conversion and storage of DDT in the form of DDE produces a second, additional impact in birds which has no parallel in mammals: eggshell thinning. This phenomenon was first documented in golden eagles and peregrine falcons in the UK (Ratcliffe, 1967) and subsequently found to be widespread in other raptors, especially those feeding on birds and fish, rather than small mammals, and also in other fish-eating birds (cormorants, pelicans and gulls). Direct experimentation soon established DDE contamination of the mother bird as the causative agent, the DDE acting to reduce calcium deposition in the eggshell via a number of disruptions of enzymatic and hormonal processes (Wiemeyer and Porter, 1970; Blus, Gish et al., 1972).

D7.5 Although linear relationships between levels of DDE and degree of eggshell thinning were demonstrated for most of these species the slope of the line differs for different species, with the dose producing 20% thinning ranging from about 12ppm (wet weight) in prairie falcon to over 150ppm (wet weight) in herring gulls and great blue heron. This differential response of particular species to the same amount of DDE, plus the difficulty of establishing the relationship between DDT application rate and exposure risk for different bird species, make accurate predictions of impact extremely difficult. However, a general rule did emerge that bird populations would be in decline if eggshell thinning of more than 10% of normal values was occurring (Brown, 1978; p252-3).

D8 Direct effects on reptiles

D8.1 Reptiles are susceptible to both direct toxic effects from DDT spraying as well as impacts arising from ingestion of DDT-contaminated prey. Few data exist for DDT effects on reptiles in the literature up to 1985, or since that time, with the exception of studies of pesticide residues in crocodile eggs in Kenya (Skaare, Ingebrigsten et al., 1991), and the recent discovery of links between sex reversal and persistent organochlorine residues in Lake Apopka, Florida (reported in Kelce, Stone et al., 1995).

D8.2 The results reported here therefore make a useful contribution to the scientific knowledge base, but provide little real guidance as to what levels of DDT use might be acceptable from the viewpoint of reptile biology, except perhaps to indicate that impacts of lizards will be negligible if DDT use is set at a level which will not produce greater impacts on more sensitive species of greater concern to the general public.

D9 Direct impacts on fish

D9.1 Fish can accumulate DDT directly from the surrounding water to an astonishing degree, up to many thousands of times the surrounding concentrations (Johnson, 1968).

Although it is well established that DDT can cause mortality in adult fish and also interfere with reproduction and fry survival, the extreme variation in response of particular species has thwarted the search for general rules (Ramesh, Tanabe et al., 1992; Rowan and Rasmussen, 1992). The risk of DDT contamination to fish obviously varies with the method of application (aerial spray v. ground spray; the proximity to water (tsetse control in riverine fringes in West Africa have had significant direct impacts on fish, (Koeman and Penning, 1970)) ; the nature of the substrate (fine mud sediments strongly adsorb pesticides); the residence time of water (closed lake systems will accumulate long-lasting residues).

D10 Direct impacts on invertebrates

D10.1 The original Swiss patent on DDT comments on "the strong action of DDT on a wide variety of arthropods" so it is no surprise to find that DDT has toxic effects on many invertebrates. In general, arthropods appear to be more sensitive than other invertebrate groups (earthworms, slugs and snails) and some general, but non-linear relationships between DDT levels in soils and in earthworms were published as early as 1968 (Wheatley and Hardman, 1968). Because of the great diversity of invertebrate species, the range of responses to DDT treatments would be expected to be, and is, wider and more complex than in any other animal group. One extreme example is the extraordinary behaviour of a species of euglossine bees in Amazonian Brazil, which actively collect DDT from the walls of houses sprayed for mosquito control; these bees may contain DDT residues of up to 2000ug per bee with no ill effects, compared with an LD50 of just 6ug per bee for honeybees (Roberts, Alecrim et al., 1982).

D10.2 Although as early as 1968 Dempster concluded that it was impossible to predict the full effect of application of a pesticide to an ecological community, some general rules did emerge from the many hundreds of experiments conducted in the period 1945-1970. One of these was that the natural enemies of insects (i.e. other invertebrate predators and parasites) tended to be more susceptible to DDT than the herbivorous species towards which the pesticide was targeted. For example, one of the more consistent results observed was an increase in soil collembolan numbers as a result of the greater susceptibility of predatory mites to DDT.

DDT BIBLIOGRAPHY ANNEX E

Abelson, P. (1992) The use of DDT in tsetse fly control : an economic assessment of the environmental impacts. Unpublished. ODA.

Aitken, T. H. G. and H. Trapido (1961) Replacement phenomenon observed amongst Sardinian anopheline mosquitoes following eradication measures. Int. Union Conserv. Nature Natur. Resources, Tach. Meeting, Warsaw 1960, Proc. 8: 106-114.

Barrett, J.S. (1994) Economic issues in trypanosomiasis control : case studies from Southern Africa. DPhil thesis. University of Reading.

Bidleman, T. F., U. Wideqvist, et al. (1987) Organochlorine pesticides and polychlorinated biphenyls in the atmosphere of southern Sweden. Atmospheric Environment. 21: (3) : 641-654.

Blus, L. J., C. D. Gish, et al. (1972) Logarithmic relationship of DDE residues to eggshell thinning. Nature 235: 376-377.

Bouwman, H., R. M. Cooppan, et al. (1990) Levels of DDT and metabolites in breast milk from Kwa-Zulu mothers after DDT application for malaria control. Bulletin of the WHO 68: 761-768.

Brown, A. W. A. (1978) Ecology of pesticides. John Wiley and Sons, New York.

Busvine, J. R. (1989) DDT: Fifty years for good or ill. Pesticide Outlook. 1(1): 4-8.

Cade, T. J., J. L. Lincer, et al. (1971) DDE residues and eggshell changes in Alaska falcons and hawks. Science 172: 955-957.

Chikuni, O., U. Skare, et al. (1991) Residues of organochlorine pesticides in human milk from mothers living in the greater Harare area of Zimbabwe. Central African Journal Of Medicine. 37: (5) : 136-141.

Cole, U. K., R. L. Metcalf, et al. (1976) Environmental fate of insecticides in model ecosystems. International Journal of Environmental Studies 10: 7-14.

Cottam, C. and E. Higgins (1946) DDT: its effect on fish and wildlife. Circular 11; U. S. Fish and Wildlife Service.

Dempster, J. P. (1975) Effects of organochlorine insecticides on animal populations. Organic insecticides: persistent organic pollutants. Academic Press, London.

Edwards, C. A., Ed. (1970) Persistent pesticides in the environment. CRC Monoscience Series. Butterworth, London.

Edwards, C. A. (1973) Persistent pesticides in the environment. CRC Press, Cleveland, Ohio.

Forsyth, D. J. and T. J. Peterle (1973) Accumulation of chlorine-36 ring-labelled DDT residues in various tissues of two species of shrew. Arch. Environ. Contam. Toxicol. 1: 1-17.

Goldberg, E. D. (1975) Synthetic organohalides in the sea. Proceedings of the Royal Society of London: Series B 189: 277-289.

Goldberg, E. D. (1991) Halogenated hydrocarbons: past, present and near-future problems. The Science of the Total Environment 100: 17-28.

Hohl, A. and C. A. Tidsell (1993) How useful are environmental safety standards in economics? - The example of safe minimum standards for protection of species. Biodiversity and Conservation 2: 168-181.

Howell, D. E. (1948) A case of DDT storage in human fat. Proc. Oklahoma Acad. Sci. Proceedings of the Oklahoma Academy of Science 29: 31-32.

Iwata, H., S. Tanabe, et al. (1993) Distribution of persistent organochlorines in the oceanic air and surface seawater and the role of oceans on their global transport and fate. Environmental Science and Technology. 27: (6) : 1080-1098.

Jensen, A. A. (1983) Chemical contaminants in humans' milk. Residue Review 89: 2-128.

Johnson, D. W. (1968) Pesticides and fishes: a review of selected literature. Trans. Am. Fish Soc. 97: 398-424.

Jukes, T. H. (1970) DDT and tumours in experimental animals. International Journal of Environmental Studies 1: 43-46.

Kelce, W. R., C. R. Stone, et al. (1995) Persistent DDT metabolite p,p'-DDE is a potent androgen receptor antagonist. Nature 375: 581-585.

Koeman, J. H. and J. H. Penning (1970) An orientation survey on the side-effects and environmental distribution of insecticides used in tsetse control in Africa. Bulletin of Environmental Contamination and Toxicology 5: 164-170.

Koeman, J. H. and J. H. Penning (1970) The side-effects and environmental distribution of insecticides used in tsetse fly control in Africa. Bulletin of Environmental Contamination and Toxicology 5: : 164-170.

Kurtz, D. A., Ed. (1990) Long-range transport of pesticides. Lewis Publishers Inc., Michigan, USA.

Kutz, F. W., P. H. Wood, et al. (1991) Organochlorine pesticides and polychlorinated biphenyls in human adipose tissue. Review of Environmental Contamination and Toxicology 120: 1-82.

Logan, J. A. (1953) The Sardinian Project: An experiment in the eradication of an indigenous malarious vector. Johns Hopkins Press, Baltimore.

Logan, J. W. M. and P. Schofield (1984) The environmental impacts of insecticides on non-target organisms in tropical and subtropical developing countries: 1970-1983. TDRI Information Service Annotated Bibliographic Series 3. Tropical Development and Research Institute.

Loganathan, B. a. G. and K. Kannan (1994) Global organochlorine contamination trends: an overview. Ambio 23: (3) : 187-191.

Matthiessen, P. (1984) Environmental contamination with DDT in western Zimbabwe in relation to tsetse fly control operations. The Final Report of the DDT Monitoring Project. TDRI/ODA.

Matthiessen, P. (1985) Contamination of wildlife with DDT insecticide residues in relation to tseste fly control operations in Zimbabwe. Environmental Pollution, B Chemical and Physical. 10: (3) : 189-211.

Matthiessen, P. (1985) DDT insecticide in Zimbabwean wildlife and their potential environmental impact. Zimbabwe Science News. 19: (1) : 3-8.

Mellanby, K. and P. Muller (1992) The DDT Story.

Metcalf, R. L. (1973) A century of DDT. Journal of Agricultural and Food Chemistry 21: (4) : 511-519.

Moore, N. (1970) Pesticides know no frontiers. New Scientist 46: 114-115.

Moore, N. W. (1965) Pesticides in the environment and their effects on wildlife. Monks Wood Experimental Station, England, Blackwell Scientific Publications, City.

Mueller, P. (1955 and 1959) DDT. The insecticide dichlorophenyltrichloroethane and its significance (Two volumes) . Birkhauser Verlag, Basle and Stuttgart.

Muir, D., R. J. Norstrom, et al. (1988) Organochlorine contaminants in Arctic marine food chains: accumulation of specific polychlorinated biphenyls and chlordane-related compounds. Environmental Science and Technology. 22: (9) : 1071-1079.

National Academy of Sciences (1991) Malaria Obstacles and Opportunities. Washington, D.C.

Natural Resources Institute (1994) DDT in the Tropics. The impact on wildlife in Zimbabwe of ground-spraying for tsetse fly control.

Norstrom, R. J. and D. C. G. Muir (1994) Chlorinated hydrocarbon contaminants in arctic marine mammals. The Science of the Total Environment 154: 107-128.

Perfect, J. (1980) The environmental impact of DDT in a tropical agro-ecosystem. Ambio 9: 16-21.

Perring, F. H. and K. Mellanby, Ed. (1977) Ecological effects of pesticides. Linnean Society Symposium Series. Academic Press, London.

Peterle, T. J. and R. H. Giles (1964) New tracer techniques for evaluating the effects of an insecticide on the ecology of a forest fauna. Report to US Atomic Energy Commission 1207. Ohio state University Research Foundation.

Peterle, T. J. and J. O. Keith (1991) Wildlife toxicology.

Pimentel, D. (1971) Ecological effects of pesticides on non-target species. Office of the President, Office of Science and Technology, Washington, DC.

Ramesh, A., S. Tanabe, et al. (1992) Characteristic trend of persistent organochlorine contamination in wildlife from a tropical agricultural watershed, South India. Archives of Environmental Contamination and Toxicology. 23: (1) : 26-36.

Ratcliffe, D. A. (1967) Decrease in eggshell weight in certain birds of prey. Nature 215: 208-210.

Roberts, D. R., W. D. Alecrim, et al. (1982) Male Eufriesia purpurata, a DDT-collecting euglossine bee in Brazil. Nature 297: 62-63.

Rowan, D. J. and J. B. Rasmussen (1992) Why don’t Great Lakes fish reflect environmental concentrations of organic contaminants? - An analysis of between-lake variability in the ecological partitioning of PCBs and DDT. Journal of Great Lakes Research. 18: (4) : 724-741.

Rudd, R. L. (1964) Pesticides and the living landscape. Faber and Faber, London.

Sheail, J. (1985) Pesticides and Nature Conservation. The British experience 1950-1975. Clarendon Press, Oxford.

Skaare, J. U., K. Ingebrigsten, et al. (1991) Organochlorines in crocodile eggs from Kenya. Bulletin of Environmental Contamination and Toxicology 47: 126-130.

Sleicher, C. A. and J. Hopcraft (1984) Persistence of pesticides in surface soil and relation to sublimation. Environmental Science and Technology. 18: (7) : 514-518.

Spencer, W. F. and M. M. Cliath (1972) Volatility of DDT and related compounds. Journal of Agricultural and Food Chemistry 20: (3) : 645-649.

Spindler, M. (1983) DDT, health and risk aspects. : 1-34.

Tanabe, S. H. Iwata, et al. (1994) Global contamination by persistent organochlorines and their ecotoxicological impact on marine mammals. Science of the Total Environment. 154: (2-3) : 163-177.

Tinker, J. (1970) Pesticides - time for firm decisions. New Scientist 46: 15-17.

Voldner, E. C. (1995) Global usage of selected persistent organochlorines. The Science of the Total Environment 160/161: 201-210.

Walker, C. H., G. A. Hamilton, et al. (1965) Residues of DDT in the fatty tissues of big game animals in the States of Idaho and Washington in 1962. ARS 21. USDA ARS.

Wania, F. and D. Mackay (1993) Global fractionation and cold condensation of low volatility organochlorine compounds in polar regions. Ambio 22: (1) : 10-18.

Wania, F. and D. Mackay (1995) A global distribution model for persistent organic chemicals. The Science of the Total Environment 160/161: 211-232.

Wheatley, G. A. and J. A. Hardman (1968) Organochlorine insecticide residues in earthworms from arable soils. Journal of Science of Food and Agriculture 19: 219...

WHO (1976) Data Sheets on Pesticides: DDT. Data Sheet on Pesticides 21. World Health Organisation.

WHO (1979) DDT and its derivatives. Environmental Health Criteria 9. World Health Organisation.

WHO (1989) DDT and its derivatives - environmental aspects. Environmental Health Criteria. (83) :

Wiemeyer, S. N. and R. D. Porter (1970) DDE thins egg-shells of captive American kestrels. Nature 227: 737-738.

Wigglesworth, V. B. (1945) DDT and the balance of nature. Atlantic Monthly 176: 107-113.

Zeidler, O. (1874) Ber. Deut. Chem. Ges. 7: 1180.

F1. Dynamics of DDT

F1.1 Sprayed soils contained significantly higher levels of DDT, with 1 - 200 ppm beneath sprayed trees compared to 0 - 0.1 ppm in unsprayed soil. However, there are higher rates of dissipation under tropical conditions, by photolysis and volatilization, compared to temperate zones, with a half-life of 2 - 9 months in this study compared to 3 - 10 years in temperate zones.

F1.2 There remains, however, considerable risk and uncertainty about the final fate of DDT. There was little discussion of global processes and pathways for redistribution of DDT, known to flow through water and air from tropical and temperate regions towards colder polar regions, and to represent a persistent hazard to organisms at the head of the food chain, in particular mammalian marine predators. These global issues were the most critical factors in the final stages of the debate in Europe and America which led to the demise of DDT.

F1.3 Even within Zimbabwe, little knowledge was gained about the fate of DDT within the Lake Kariba ecosystem. However, a study conducted in 1990 in Lake Kariba (Berg et al., 1992)[12] quantified in detail the pathways of DDT through different trophic levels in the lake ecosystem, and although it showed very low levels of DDT in the lake, about 100 times below the WHO safe limits for human risk, this study remained cautious about the possible ecological effects in the lake.

F2 Critical soil processes

F2.1 Overall microbial activity (including leaf litter decomposition, CO2 production, and nitrification) were not affected by DDT residues. Litter decomposition by macro-invertebrates with high DDT residues was reduced, but this was localised to the sites of sprayed trees, and therefore the overall risks of loss of soil fertility were considered to be low.

F3. Terrestrial invertebrates

F3.1 The natural spatial and temporal variation in the abundance and diversity of woodland invertebrates was high, which meant it would have been difficult to detect effects of DDT. The study showed that variation in invertebrate populations (biomass, abundance and diversity) in sprayed and unsprayed sites was inconsistent.

F3.2. For example, surface-dwelling invertebrates (over 72,000 animals from 575 species were recorded in the study) showed reduced abundance and diversity in sprayed sites compared to unsprayed sites, but similar biomass between sites. This was at an intensively

12 Berg H, Kiibus M & Kautsky N (1992) DDT and other insecticides in the Lake Kariba ecosystem. Ambio 21,7:444-45

studied area and yet, over a more extensive sampling area, no consistent differences were found that could be attributed to DDT. Similarly inconsistent, soil-dwelling invertebrates (over 14,000 animals from 122 species were recorded) showed reduced species diversity in sprayed areas in some taxonomic groups (nematodes and some mites), but not in other groups (other sub-orders of mites). And further, in all cases there were no differences in species abundance. Some of these results are consistent with DDT-induced changes in temperate agricultural soils.

F3.3 These effects may have been due to DDT, or to seasonal or habitat variation. There may have been no DDT impacts, or genuine impacts of DDT may simply have been masked by high natural environmental variation. In this case, it is likely that DDT impacts are secondary to natural population fluctuations and dynamics.

F3.4. Finally, many species whose abundance appeared unaffected by DDT did carry detectable residue burdens. Particularly high levels were found in some ant species, which were the favoured food of the White-headed Black Chat, which suffered severe population decline (see below). These high and persistent levels of residues indicate that invertebrates are an important component of the ecological impact of DDT ground-spraying.

F3.5. Although difficult to detect, one cannot ignore the potential indirect and direct impacts on invertebrates. High DDT residues were detected, with clear links in the food chain to woodland birds and lizards. Mopane woodland ecology is poorly known, many new species were found during the study, and ecosystem functioning has been little studied. The study has thus been able to do little more than guess at the ecological implications of any changes in the invertebrate fauna resulting from DDT ground-spraying. The high natural environmental variability (spatial variation in microhabitats and temporal variation over the seasons in temperature, humidity, etc.), which lead to variation in invertebrate diversity and abundance and which may mask the effects of DDT, means that very substantial changes in invertebrate populations need to be shown to confirm any impact of DDT. Thus, although severe impacts were not seen, unrecorded lower level impacts with a potential impact on ecosystem function cannot be ignored.

F4. Lizards

F4.1 While species diversity (19 species were recorded) did not differ between sprayed and unsprayed areas, the abundance of the most common lizard, the striped tree skink, was considerably reduced (39% fewer sightings) in areas sprayed more than twice. Residue concentrations also increased with years of exposure in this species. No such effects, however, were found in other lizards.

F4.2. It was concluded that while the skink was adversely affected by DDT, its populations would recover once spraying stopped and residues dissipated.

F5 Woodland birds

F5.1 Species richness of the common woodland birds was similar in sprayed and unsprayed areas, but most species were less common in the sprayed areas, where 35 - 39% fewer birds were counted. While this difference was attributed to characteristics of the vegetation in 10 species, at least 9 species were significantly less common in sprayed areas. These species typically all fed on arthropods on or near the ground, a major source of DDT contamination from sprayed trees. This result was matched by an investigation of DDT residue concentrations, which were highest in species feeding on arthropods from tree trunks and the ground, subject to greatest concentration of DDT spraying, and lowest in canopy feeders.

F5.2 Residues that accumulated within 1 - 3 months of spraying were found to have dissipated to one-tenth of initial concentrations after one year. By comparison, in unsprayed sites residues were one-hundredth of this initial level.

F5.3 Two species showed a dramatic decline, to 10% of their original numbers after three annual treatments of DDT. One, the White-headed Black Chat, bred successfully and its food supply was not reduced, concluding that it accumulated lethal concentrations of DDT after repeated spraying. The chat had been depleted over very wide areas of north west Zimbabwe by ground-spraying treatments. A number of other species may also have been similarly depleted.

F5.4 In one raptor species, the African Goshawk, a predictable correlation was shown between eggshell thinning, DDE content, and number of past spray treatments. Together with smaller numbers of occupied nest sites and higher rates of site desertion in sprayed areas, this strongly suggests a population decline due to DDT ground-spraying. By analogy with European Sparrowhawks, recovery might take 10 to 20 years.

F5.5. Although habitat and rainfall were generally the most important determinants of woodland songbird densities, certain species were shown to be particularly susceptible to DDT spraying. The prognosis for population recovery appeared to be uncertain for these species, as population dynamics and long-term exposure to DDT were not studied. For example, the scarcity of chats 7 years after spraying in some habitats, and the persistence of DDT in their preferred invertebrate foods, suggest a recovery period of 10 years or more, after cessation of DDT spraying, and depending on the rates at which residue concentrations dissipate in the environment and the food chain. However, prediction of the levels of DDT that are within the range of tolerance of the affected species, and the patterns of recovery that are likely after spraying ceases, remain uncertain. Also uncertain are the effects of DDT on the majority of less common woodland birds.

F6 Nocturnal mammals

F6.1. Bats were the main species studied (30 species recorded). They are likely to be most susceptible to poisoning from insecticides because they are efficient bio-accumulators, due to their pronounced fat cycles related to reproduction and migration, and because of their longevity and low reproductive rates. Bats are also a good indicator group at the community level because of their species richness and their diversity of feeding guilds.

F6.2 The impacts of DDT on bats were extrapolated from concentrations of residues found in body fat. Mortality was projected when lethal concentrations were reached as body fat fell below 1% of bodyweight, such as would happen in periods of acute stress during seasonal droughts. Such concentrations were found in individuals of 5 species, and mortality was predicted at 0% in unsprayed areas and from 35-100% in sprayed areas. Highest risk was projected for species roosting in trees subjected to direct spraying with DDT. Otherwise, there was a strong relationship between degree of exposure to spraying and DDT residue levels.

F6.3 Despite these predictions and the observed residue levels, there were no apparent signs of DDT impacts at the community level. There were no population parameters that showed significant differences between sprayed and unsprayed sites (body weights, age and sex ratios, reproductive states and successes, foraging activity), with one exception, the lower number of adult males in one species in sprayed areas. Further, the relative abundance of bats was determined more by habitat and season than by DDT treatment site.

F6.4 As elsewhere in this study, it remains difficult to extrapolate from impacts on individuals to the ecosystem, or from residue levels to population decline, since there are numerous environmental variables that need to be taken into account.

F7 Fish

F7.1 Although DDT is acutely toxic to fish, no fish kills have been attributed to DDT in Lake Kariba. The rivers flowing into Lake Kariba are seasonal, with the exception of the Zambesi, and their fish fauna is poor.

F7.2 In 5 intensively studied species in one watershed river, one was more abundant in unsprayed upstream areas, and 2 were more abundant in downstream sprayed areas. There were no DDT effects on species composition in this river. However, fish from the sprayed areas had significantly higher residue levels, with the highest levels found in the predatory catfish, due probably to consumption of contaminated invertebrate prey. There were no differences between sprayed and unsprayed sites in the growth and mortality of one species, the red-eye labeo. Rather, growth rates were related to annual rainfall levels. In another species however, the linespotted barb, the most highly contaminated population showed highest mortality. This population also showed fastest growth rates, possibly due to reduced feeding competition amongst survivors. The most contaminated catfish, from the sprayed site, probably provided a substantial source of contaminated food for fish-eating birds.

F7.3 In a study of estuaries on the lake fed from sprayed and unsprayed watersheds (17 species were recorded), variations in catches were attributed to seasonal changes and habitat differences, rather than DDT levels. Further, concentrations of DDT residues were variable between species and inconsistent across sites, and did not reflect the history of spraying near the site, but rather the feeding habits and mobility of the fish species in question.

F7.4 Growth and mortality parameters in species that were significantly contaminated did not show any DDT effects on growth performance, and if they did this was dependent on the species. Nor were there any differences in the number of eggs present in fish from treated and untreated sites. Residues in eggs from sprayed sites were, however, high enough to put fry survival at risk.

F7.5 There was thus no evidence from the fish studies of any significant DDT impacts on fish fauna, no consistent effects on population parameters, no adverse effects on growth and mortality. Any effects that were detected were minor. However, once again, the natural environmental variables presented considerable difficulties for the study, which in turn may have left a number of uncertainties in the conclusion that DDT spraying has no effect on fish populations. This was compounded by the fact that so little is known about the ecology and biology of many of the lake fish, and perhaps most significantly that the boundaries of the sprayed and unsprayed study sites neither represented the limits of DDT contamination in the lake, nor the boundaries to the movements of the fish studied. Also uncertain are the effects of DDT on the majority of less common fish, and other aquatic fauna.

F8 Waterbirds

F8.1. The fish eagles of Lake Kariba were the main focus for this study, as key predators at the head of the aquatic food chain (550 pairs were recorded on the lake). DDT residues were found in every fish eagle egg that was sampled, with greatest concentrations found at the eastern end of the lake. These high concentrations were correlated with the lowest success in egg hatching (less than 50%), with greatest eggshell thinning (up to 20% thinner than normal), and with areas most recently ground-sprayed, clearly implicating tsetse control operations as the source of contamination.

F8.2 Comparison with data from 1980 showed that residue levels had fallen in areas not ground-sprayed since then, but risen in areas recently sprayed. All of these results are consistent with those found in North American bald eagles and European white-tailed sea eagles in the 1960s and 1970s.

F8.3 However, fish eagle nest densities were highest at the eastern end of the lake, where hatching success was poorest. The conclusion drawn was that despite demonstrable effects of DDT on hatching success in fish eagles, this was not limiting population size. Further, threats to hatching success from DDT have declined with its widespread disuse in the region since the 1980s, and specifically its progressive withdrawal from use in tsetse control. Greater threats to populations are currently presented by the increased human settlement along the lake shores, resulting in loss of safe nest sites and in increased predation on eagle chicks by people, and damage by elephants to nesting trees in national parks.

F8.4 There was also some evidence of DDT contamination of other waterbirds (e.g. the reed cormorant), at levels that may cause eggshell thinning.

F9 Risk to human health

F9.1 The possible risks to human health were never intended to be a major component of the project : only if studies indicated the possibility of significant accumulation of DDT or its residues through consumption of contaminated fish were epidemiological studies to be instituted through the Ministry of Health (Annex D3).

F9.2 These studies were never deemed necessary. DDT residue levels in the commercial catches of six fish species were found to be well below the MRL, nor was there any risk of the ADI being exceeded for adults (NRI, p.183). The major uncertainty, however, concerns the health risk for children. In 1986 a study by the Wildlife Society reported that DDT residues in the breast milk of women living around Lake Kariba exceeded WHO guidelines (The Herald. July 1986). High levels of DDE in breast milk have been linked with hyporeflexia in infants. The long-term effects of hyporeflexia on child development are not known.

F9.3 The relative contributions of DDT use for malaria control, tsetse control, and agriculture are difficult to disentangle. The NRI report concluded that the "incremental effect of tsetse fly control ... is probably relatively low unless fish are a significant part of the diet" (NRI, p.183). It went on to recommend adoption of the precautionary principle - and a switch from DDT to deltamethrin - for malaria control, but not for tsetse control.

F9.4 In the opinion of the evaluators, the conclusions of the report are questionable. DDT use in tsetse control was a major source of DDT residues in fish in Lake Kariba (Matthiesson); fish were a significant part of the diet for local populations; residue levels in breast milk among women around Lake Kariba were known to be high; and hyporeflexia in infants had been linked to DDT residues. To advocate a shift from DDT for malaria control, but not for tsetse control, appears strange. Malaria control programmes were probably an insignificant source of human DDT intake compared with food (Mpofu, 1987).

F9.5 Many of those consulted as part of the evaluation cite human health concerns as a major uncertainty associated with DDT use, and as the major weakness in the DDTIA conclusions. It is not clear why the concerns about DDT in breast milk did not trigger the option of an additional medical research component.

F9.6 It can be argued that the solution did not necessarily lie in complex epidemiological studies. These would have been well beyond the scope and resources of this project as designed, and would have required a major and long-term medical research project in its own right. It is an open question whether even this would have answered the health question to the satisfaction of the public, NGOs and governments. These questions aside, the conclusion of this evaluation is that human health aspects warranted far more attention that they received.

F10 Deltamethrin

F10.1 Deltamethrin is a synthetic pyrethroid. It is known to be more toxic than DDT to crustacea and fish, although the risk of exposure may be limited by careful application near water bodies. Deltamethrin may also affect terrestrial arthropods more severely than DDT. The ecological consequences of this are not known, but possibly it may affect insectivorous vertebrates through food depletion. However, unlike DDT, deltamethrin does not bioaccumulate and it degrades quickly in the environment.

F10.2 Two deltamethrin trials were conducted in 1989 and 1990, which were monitored by the project. In the sprayed areas, 80%-90% of deltamethrin deposits had dissipated within 2 months. However, a wide range of invertebrates on tree trunks were affected by the spray, and populations remained low over a two month period. Their long-term fate was not studied.

F10.3 The study of the impacts of deltamethrin on birds, lizards and mammals was compromised by the prior treatment of the site with DDT. Although an observed population decline of some birds was probably due to the effects of DDT, deltamethrin may have contributed to this by reducing invertebrate food availability. This work was inconclusive, and the project recommended further study to confirm the greater safety of deltamethrin over DDT.

F10.4 In parallel with this project, the EC-funded SEMG project was studying non-target impacts of deltamethrin and endosulphan during tsetse control operations using aerial spraying and odour-baited targets[13] . They found that the dosage used in tsetse control had limited effect on the non-target fauna of the savanna in Zimbabwe, particularly compared to the impacts of other land uses. In aquatic ecosystems, deltamethrin affected a number of aquatic organisms, but endosulphan was more toxic to surface-active fish. In terrestrial ecosystems, endosulphan had less impact than deltamethrin, which knocked down arthropods in particular. However, these all showed a high rate of recovery. On odour-baited targets, a number of non-target taxa are attracted to the screens, but their fate is unknown. In a study of one invertebrate group (horse flies), there was no evidence of a decrease in diversity and abundance during long-term target operations. There were no effects on humans, and little or no residues of either chemical were measured.

F10.5 In general, the alternative, non-persistent, synthetic pyrethroid insecticides appear to have a much lower environmental impact than DDT.

13 SEMG (1993) Environmental Monitoring of Tsetse Control Operations in Zambia and Zimbabwe: impact of aerial spraying and odour-baited targets on ecosystems. Saarbrucken.

F11 Economic assessment

F11.1 In 1992 ODA commissioned an economic assessment of the environmental impacts of DDT use in tsetse control, based on NRI's findings (Abelson,1992). The main conclusion was that "the economic costs ... of the environmental impacts of DDT use for tsetse control in north-western Zimbabwe were very low". The main exception to this conclusion would be the application of DDT in major wildlife areas where important species were vulnerable to its use. Most importantly, the report further qualified the main conclusion by stating that the "results of the NRI study cannot by themselves determine whether tsetse fly control by ground spraying with DDT, or by other techniques, is warranted". To determine this, many other costs and benefits (eg. from the construction of infrastructure in wilderness areas, or long-term land use changes) would need to be taken into account.

F11.2 NRI went beyond these conclusions in its main report. Given the higher cost of using deltamethrin, and the limited ecological impact of DDT, the report suggested that DDT should be used and the savings invested in a compensatory project to protect wildlife habitat (NRI, p.24).

F11.3 There are three main problems with these conclusions. First, there is reason to doubt whether the economic costs of DDT use are as low as suggested by Abelson. The strong opposition to DDT use because of its global persistence, demonstrated effect on a few species, and health uncertainties, suggests that the "willingness-to-pay" within Zimbabwe to avoid these concerns would be significant.

F11.4 Second, there is reason to doubt whether the comparison with deltamethrin is sound, partly for reasons given above. Furthermore, although DDT may be cheaper14 , there are suggestions from TTCB work that deltamethrin might be more effective than DDT at this level and frequency of application (W.Shereni & A.Pope). If deltamethrin were able to eradicate tsetse in a single application, rather than by two applications with DDT, this would largely offset the higher cost of deltamethrin. Further trials would be needed to demonstrate this.

F11.5 Finally, as Abelson emphasised, the study cannot justify or otherwise the use of DDT for tsetse control. The study was at best a partial comparison of the environmental impact of DDT versus deltamethrin. It did not assess the environmental impacts of different control techniques (eg. ground-spraying versus targets), nor did it assess the indirect environmental effects of any tsetse clearance by whatever method, such as converting tsetse-infested wildlife areas to agro-pastoral land use. The solution posited by the NRI report (use DDT and put the funds saved by not using deltamethrin into habitat conservation) is only one of many possible options, the full economic and environmental costs and benefits of which would need to be analysed.

14 Barrett estimated that the direct costs of ground spraying with deltamethrin were approximately double that of DDT, or 70% more if indirect costs were also taken into account (Barrett, 1994, 4.5). However, it was also suggested that the costs of deltamethrin might fall if large amounts were purchased in hard currency. Comparative border price data are lacking. Recent cost data from India suggest that DDT is still markedly cheaper (DDT 50 WDP = Rs. 48/kg.; Deltamethrin 2.5% WP = Rs. 720/kg.), but this may only reflect the high import tariff on deltamethrin.

Refereed Publications PUBLISHED AND IN PRESS

Douthwaite, RJ 1992	Effects of DDT on the Fish Eagle *Haliaeetus vocifer* population of Lake Kariba in Zimbabwe. **Ibis** 134: 2509-258
Douthwaite, RJ 1992	Effects of DDT treatments applied for tsetse fly control on White-browed Sparrow-weaver (*Plocepasser mahali*) populations in NW Zimbabwe. **Afr. J Zool**. 30: 233-244
Douthwaite, RJ 1992	Effects of DDT treatments applied for tsetse fly control on White-headed Black Chat (*Thamnolaea arnoti*) populations in Zimbabwe. Part I: populations changes. **Ecotoxicology** 1: 17-30
Douthwaite, RJ and Tingle, CCD 1992	Effects of DDT treatments applied for tsetse fly control on White-headed Black Chat (*Thamnolaea arnoti*) populations in Zimbabwe. Part II: cause of decline. **Ecotoxicology**, 1: 101-115.
Douthwaite, RJ Hustler, CW Kruger, J and Renzoni A 1992	DDT residues and mercury levels in Reed Cormorants on Lake Kariba: a hazard assessment. Ostrich, 63. 123-127.
Lambert, MRK 1993	Effects of DDT ground-spraying against tsetse flyies on lizards in Zimbabwe. **Environmental Pollution** 82.3 231-237
Tingle, C.C.D; Lauer, S and Armstrong G. *1992*	Dry season, opigeal invertebrate fauna of mopane woodland in northwestern *Zimbabwe*. *Journal of Arid Environments* 23(4): 397-414
Tingle C.C.D 1993	Bait location by ground-foraging ants (Hymenoptera: Formicidae) in mopane woodland selectively sprayed to control tsetsefly (Diptera: Glossinidae) in Zimbabwe. **Bulletin of Entomological Research** 83: 259-265.

Douthwaite, RJ 1993	Effects on birds of DDT applied for tsetse fly control in Zimbabwe, In: Wilson RT (Ed), Birds and the African Environment: Proceedings of the Eighth Pan-African Ornithological Congress. Annales Musee Royal de l'Afrique Centrale (Zoologie), 268:608-610.
Hartley, RR & Douthwaite, RJ 1994.	Effects of DDT treatments applied for tsetse fly control on the African goshawk in north-west Zimbabwe. African Journal of Ecology, 32: 265-272.
Tingle, C.C.D & Grant IF 1995.	Effect of DDT selectively applied for tsetse fly(Glossina spp) control on litter decomposition and soil fauna in semi-arid mopane woodland in Zimbabwe (*Acta Zoologica Fennica*) 196: 364-368
Tingle, C.C.D 1995.	Some effects of DDT used to control tsetse fly on woodland invertebrates in Zimbabwe. *Acta Zoologica Fennica* 196: 361-363

Presented at conferences with abstract published by organisers in an Abstract Book.

Grant, IF; Tingle,CCD; Douthwaite, RJ; McCarton,B; and McWilliam, A, 1991	The environmental effects of DDT used to control tsetse fly in Zimbabwe. SETAC-Europe Founding Conference. Environmental Sciences and sustainable Development, Sheffield, UK, 7-10 April 1991.

In preparation or published but details not available.

Crick, HQP	Control in woodland soils and bark in NW Zimbabwe.
Grant, IF	Contamination, distribution and dynamics of DDT applied for tsetse fly control in woodland soils and bark in NW Zimbabwe.

Grant, IF	Effects of DDT, applied for tsetse fly control, on critical soil processes in NW Zimbabwe
Lambert, MRK	A ground-spraying treatment with deltamethrin against tsetse flies in NW Zimbabwe has little short-term effect against lizards.
Lambert, MRK	Pesticides and herpetofauna in Africa, with special reference to reptiles.
McCarton, B	The effect of DDT ground-spraying on the growth and mortality of *Zambezi* Parrotfish *Hippopotamyrus discorhynchus* (Peters, 1852) and Butter Catfish *mystus depressirostris* (Linnaeus, 1762).
McCarton, B	The effects of DDT on the growth and mortality of fishes of the headwater streams of the Sengwa River, Zimbabwe.
McCarton, B	DDT in the fish consumed in Zimbabwe.
McWilliam, AN	DDT residues and the effect of DDT spraying to control tsetse flies on populations of *Scotophilus borbonicus* (Chiroptera: Vespertilionidae) in the Zambezi Valley, Zimbabwe.
McWilliam, AN	DDT residues and the effect of DDT spraying to control tsetse flies on populations of *Nycticeius schlieffenii* (Chiroptera: Vespertilionidae) in the Zambezi Valley, Zimbabwe.
McWilliam, AN	DDT residues and the effect of DDT spraying to control tsetse flies on populations of *Eptesicus somalicus and E. capensis* (Chiroptera : Rhinolophidae) in the Zambezi Valley, Zimbabwe.
McWilliam, AN	DDT residues and the effect of DDT spraying to control tsetse flies on populations of *Rhinolophus hildebrandtii* (Chiroptera : Rhinolophidae) in the Zambezi Valley, Zimbabwe.

McWilliam, AN	DDT residues from insectivorous bats (Mammalia: Chiroptera) in areas of the Zambezi Valley, Zimbabwe, treated with DDT to control tsetse flies.
McWilliam, AN	Effects of DDT spraying to control tsetse flies on the diversity and activity of insectivorous bats (Mammalia: Chiroptera) in the Zambezi Valley, Zimbabwe.
McWilliam, AN	Effects of DDT spraying to control tsetse flies on the relative abundance of bush babies and genet cats in the Zambezi Valley, Zimbabwe
McWilliam, AN	Notes on the morphology and systematics of insectivorous bats (Mammalia: Chiroptera) in north-west Zimbabwe.
McWilliam, AN	The aerial insect fauna of mopane woodland in the Zambezi Valley, Zimbabwe.
McWilliam, AN	History and extent of DDT use in Zimbabwe: implications for wildlife.
McWilliam, AN	Climatic variation in mopane woodland, north-west Zimbabwe

Unrefereed Reports

Lambert, MRK; Grant, IF; Smith, CL; Tingle, CCD; & Douthwaite, RJ	Effects of deltamethrin ground-spraying on non-target wildlife. NRI 1991.

Poster Papers and Lectures

Douthwaite, RJ	Effects of DDT on birds in Zimbabwe. 20th International Ornithological Congress, 2-9 December 1990, New Zealand.
Douthwaite, RJ	Effects of DDT applied for tsetse fly control on birds in Zimbabwe. 8th Pan-African

	Ornithological Congress, 30 September - 5 October, Burundi
Lambert,MRK	Pesticides and African Herpetofauna, especially reptiles. 1st World Congress of Herpetology, 11-19 September,1989, UK.
Lambert MRK	Effects of DDT ground-spraying against tsetse flies on non-target lizards and the deltamethrin alternative in NW Zimbabwe. 6th Meeting of the European Herpetological Society, 19-23 August, 1991, Hungary.
Tingle, CCD	The effects of DDT used to control tsetse fly on woodland invertebrates in Zimbabwe. 11th International Colloquium on Soil Zoology, 10-14 August, 1992, Finland. (To be published as a short communication in the conference proceedings in **Acta Zoologica Fennica**).
Tingle, CCD & Grant, IF	The effect of DDT on litter decomposition and soil fauna in semi-arid woodland. 11th International Colloquium on Soil Zoology, 10-14 August, 1992, Finland. (To be published as a paper in the conference proceedings in **Acta Zoologica Fennica**).

Book

Douthwaite, R J & Tingle C C D (eds) 1994	DDT in the Tropics: the impact on Wildlife in Zimbabwe of Groundspraying for Tsetse Fly Control, Chatham, UK, Natural Resources Institute. ISBN. 0 85954 364 1.

Project Expenditure, Actual and Forecast

ANNEX H

	1987/88 Actual	1988/89 Actual	1989/90 F'cast O/T	1990/91 Forecast	1991/92 Forecast	TOTAL FORECAST	
STAFF COSTS						**Current £**	
Ornithologist	24,478	24,259	35,000	37,000	15,000	135,737	
Fish Biologist (TCO)	10,656	19,271	21,000	15,000		65,927	
Ecologist (TCO)	14,921	23,865	23,000	24,000	15,000	100,786	
Local Support	75	1,101	5,000	3,000		9,176	
Soil Scientist (Grant)	0	4,763	5,00	5,000		14,763	
Herpetologist Lambert)	0	0	5,000	18,000		23,000	
Entomologist (C, Smith)	0	0	0	15,000		15,000	
Management		1,672	0	2,000		3,672	
Procurement		0	0			0	
(F'casts include contingencies)							
TOTAL STAFF COSTS	50,130	74,931	94,000	119,000	30,000	368,061	
TRAVEL AND SUBSISTENCE							
Vehicle running	1,527	4,834	5,000	4,000		15,361	
Air Fares	2,838	0	6,000	13,000		21,838	
Subsistence	2,123	0	-	0		2,123	
UK Travel				2,000	2,000		
Field Allowance	623	2,581	2,000	1,000		10,204	
(F'casts include contingencies)							
TOTAL TRAVEL & SUBSISTENCE	7,111	7,415	13,000	20,000	2,000	49,526	
VEHICLES AND EQUIPMENT							
Landrovers		15,626					
Camping Equipment		966					
Sampling Equipment		20,028					
(F'casts include contingencies)							
TOTAL VEHICLES & EQUIPMENT	47,012	36,620	4,000	1,000	0	88,632	
SUPPORT SERVICES							
Boat Hire	103	4,571	5,000	1,000		10,674	
Aerial Survey	1,065	0	4,000	1,000		6,055	
Pesticides Analysis	3,550	497	21,000	59,000		84,047	
Office Supplies / PTC	189	965	2,000	1,000		4,152	
Laboratory Consumables	476	685	2,000	1,000		4,161	
Report Preparation and Production	88	0	0	18,000	6,000	24,088	
(F'casts include contingencies)							
TOTAL SUPPORT SERVICES	5,471	6,716	34,000	80,000	6,000	133,187	
Price contingencies 4%						0	
Physical contingencies 5%	740					740	
TOTAL	**110,646**	**125,682**	**145,000**	**220,000**	**38,000**	**640,146**	

1, "Actual" costs for 1987/88 and 1988/89 and "forecast out-turn" 1989/90 are taken from DDTIA Annual Reports and Review Mission Reports.

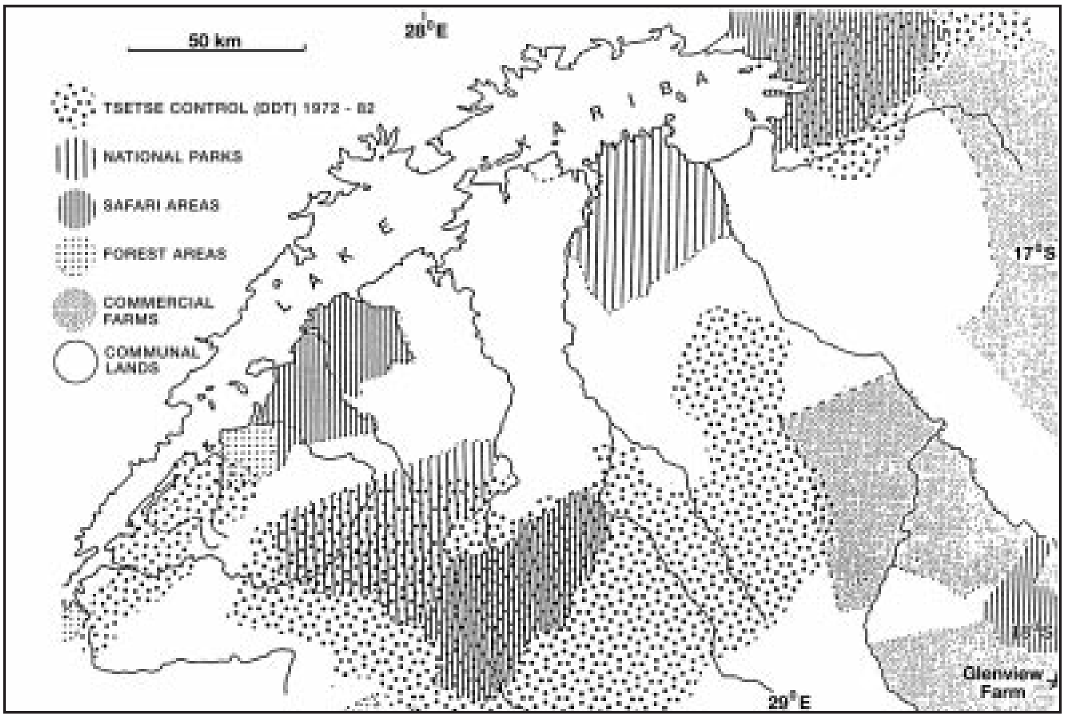
2, Minor arithmetical error in 1990/91 forecast for support services, which should read £81,000.
1990/91 total also incorrect, should read £221,000, Data from Third Annual Review Mission, March 1990.

MACSTATS	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	TOTAL CURRENT £
Budget			1,000	270,000	55,000		
Expenditure	187,235	122,206	199,495	279,726	132,286	11,581	932,529

ESTIMATED TOTAL EXPENDITURE using project data for the first two years and MACSTATS thereafter, and including an allowance of £10,000 in 1992/93 for report publication and limited free distribution in Zimbabwe £865,758

MAP

Land use in the area of western Zimbabwe bordering on Lake Kariba, showing the total area sprayed with DDT 1972-19



Source: Matthiessen (1984)


Lake
Kariba
Siabuwa
HARARE
ZIMBABWE
Bulawayo
200 km

The Department for International Development (DFID) is the British government department responsible for promoting development and the reduction of poverty.

Further copies of this Report can be obtained from Evaluation Department, Department for International Development, telephone 0171 917 0243. The Report is also available on the Internet at our Website address.

DFID
94 Victoria St
London
SW1E 5JL
UK

DFID
Abercrombie House
Eaglesham Rd
East Kilbride
Glasgow G75 8EA
UK

Switchboard: 0171-917 7000 Fax: 0171-917 0019
Website: www.dfid.gov.uk
email: enquiry@dfid.gtnet.gov.uk
Public enquiry point: 0845 3004100