CHAPTER 5.1.

APPLICATION OF BENEFIT/COST ANALYSIS TO INSECT PEST CONTROL USING THE STERILE INSECT TECHNIQUE

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SUMMARY

Before embarking on area-wide integrated pest management (AW-IPM) programmes involving eradication, exclusion, or suppression of insect pests using the sterile insect technique (SIT), and/or other area-wide control measures, not only their technical but also their economic feasibility needs to be assessed. They may require significant initial capital investments to achieve long-term returns in subsequent periods, and may raise questions about the distribution of benefits or the justification of public or private pest control efforts. A consistent and transparent system is needed to analyse the benefits and costs of such programmes and to demonstrate their value, or in some cases to assess appropriate contributions to the costs by the various stakeholders who gain the benefits. Benefit/cost analysis (BCA) provides such a framework, and has been applied to many AW-IPM programmes that integrate the SIT, in

V.A. Dyck, J. Hendrichs and A.S. Robinson (eds.), Sterile Insect Technique. Principles and Practice in Area-Wide Integrated Pest Management, 481–498.

which it has been used to demonstrate the expected value of area-wide eradication, exclusion or suppression. This chapter outlines the process of BCA in which itemized future costs and benefits are compared in terms of present values. It also provides a review and examples of the application of BCA to the SIT. A checklist of BCA inputs, and some examples of benefit/cost outputs, are also presented.

1. INTRODUCTION

The principle of the benefit/cost analysis (BCA) is to provide a model framework in which all costs and benefits, applicable to an area-wide integrated pest management (AW-IPM) programme such as pest suppression, exclusion, or eradication that incorporates the sterile insect technique (SIT) (Hendrichs et al., this volume), can be compared with alternative management options over a specified period of time. The analysis informs decision-making by structuring estimates of all costs and benefits, including externalities such as environmental and social impacts, but it does not prescribe choices. Ultimately decisions depend on social, political and commercial values and judgements. The BCA is a very helpful tool for making the decision process transparent for governments, investors and beneficiaries.

The BCA model provides a common framework for assessing and comparing the overall flow of benefits and costs from different management options over time. This is very important for comparing area-wide programmes using the SIT (which generally have substantial initial costs, but which provide long-term benefits through subsequent suppression, exclusion or eradication) with individual and short-term control (such as by conventional pesticide application). In the BCA the monetary value of all identifiable benefits and costs are estimated as objectively as possible over the expected period during which the programme will operate. Since the benefits and costs are in the future, there is inevitably some uncertainty in these estimates. The BCA model needs to be flexible so that the various management options and expected scenarios can be tested, taking into account uncertainties, and demonstrating the sources and influence of the uncertainty. For example, Vo (2000) presented two scenarios for an assessment of the New World screwworm *Cochliomyia hominivorax* (Coquerel) in Jamaica, in which the major uncertainty was programme cost. For some species, for example the Mediterranean fruit fly *Ceratitis capitata* (Wiedemann), rearing costs are well known (Quinlan et al. 2002), but there may be considerable uncertainty about other variables such as reinvasion frequency in the case of exclusion or eradication programmes.

Sensitivity analysis, the process of testing the model with a realistic range of values, is important in BCA to indicate how risks associated with the programme could affect decisions. Ideally the economic framework should be prepared in parallel with the technical feasibility assessments of a programme so that each can inform the other. In this way the final analyses can be efficiently directed to the technically most effective and economically viable plans. The BCA may be needed both before and after programme implementation, first to decide on how to proceed, and later to evaluate performance and suggest operational improvements.

1.1. Timescale and Geographic Scope

The initial steps in the BCA include defining the timescale and the likely geographic scope of the programme. The time period may include: (1) a preparatory phase (research, baseline-data collection and feasibility studies, construction of the insect production facilities, etc.), (2) a control phase (which could include a series of zones through which treatments are applied in succession as suppression, exclusion or eradication is achieved), and (3) a reasonable period beyond the control stage. This post-intervention phase should be long enough for benefits to establish before there is the inevitable time-related increase in uncertainty about reinvasion (but not in the case of a suppression programme), new pest entry or other circumstances that could affect the expected benefits or costs. The first two phases are determined largely by technical constraints, although there may be opportunities to reduce them by spending more money. The geographic scale may also be determined by technical considerations (islands, topography, limit of host range) or by economic factors (too little return in areas of marginal productivity or lower pest attack).

A cost function is likely to be composed of three parts: (1) variable costs per area to be treated for control, (2) variable costs for all other related management activities (surveillance, follow-up treatment, etc.), and (3) fixed costs associated with operating the programme. The benefits would include a function based on replacing current costs and losses in the area to be controlled, plus any additional market opportunities that may arise through the pest control achieved, and the reduction or elimination of pesticide applications and residues. Costs and benefits may need to be attributed to particular production sectors or uses (for example, production of meat, milk and draught power in tsetse fly *Glossina* spp. control programmes) or to geographic areas (for example, selection of individual regions where benefits might be greatest). Environmental costs and benefits, discussed later in this chapter, should be included along with direct monetary values from improved production and cost savings. An increasingly important issue in pest management BCAs is how much of the cost can be recovered from stakeholders and how this can be achieved.

1.2. Available Benefit/Cost Analyses

Many suppression, exclusion and eradication programmes have been undertaken or proposed, and most of them have had either formal or informal BCAs (Mumford 2004; Dyck, Reyes Flores et al., this volume). Examples of BCAs for AW-IPM programmes that integrate the SIT include:

- Mediterranean fruit fly: California (Dowell et al. 2000, CDFA 2003), Florida (FDACS 2003), the Maghreb (IAEA 1995), eastern Mediterranean (Enkerlin and Mumford 1997), South Africa (Mumford 1997), Portugal (Mumford and Larcher-Carvalho 2001, Larcher-Carvalho and Mumford 2004, IAEA 2005), Western Australia (Fisher et al. 1994, Mumford et al. 2001) (Box 1), Chile (UN 1997), Tunisia (Knight 2001), and Argentina (De Longo et al. 2000)
- Tsetse: Kabayo and Feldmann (2000), Msangi et al. (2000), Knight (2001), Kamuanga (2003), Shaw (2003), and Shaw (2004)
- New World screwworm: Vo (2000), Wyss (2000, 2002)

Box 1. Mediterranean Fruit Fly in Western Australia

The Mediterranean fruit fly has been a pest of commercial and backyard fruit throughout much of Western Australia since it was introduced to the state around 1900 (Fig. 1). It imposes costs on fruit growers through insecticide treatments, fruit losses, and the presence of insecticide residues and the insects themselves. Backyard growers also suffer and get less enjoyment from their fruit trees. It causes problems for the international export of Western Australian fruit, and also to other Australian states. South Australia, in particular, is faced with the costs of quarantine and frequent eradication of contained Mediterranean fruit fly outbreaks originating from Western Australia.

A pilot eradication project using the SIT was conducted at Broome, Western Australia, and showed that eradication of the Mediterranean fruit fly in Western Australia is technically feasible. In an analysis of the eradication of the fly in Western Australia (Mumford et al. 2001), it was clear that eradication, in a series of geographical zones, would take several years. The model was therefore based on the concept of summing the individual costs and benefits across each zone, allowing for a phased extension of the eradication across the state with a rolling quarantine to protect the eradication frontier as it progressed. The principal inputs within each zone affecting costs and benefits were the total areas to be treated and the values of losses that would be prevented with eradication. The selection of zone boundaries was based on:

- Climate (mainly the effect of winter temperature on Mediterranean fruit fly development)
- Phased increase in the treatment area to build-up expertise and capacity
- Treatment areas determined using satellite imagery of likely host presence and agricultural census data
- Maximum annual treatment area of 1000 km^2 (reflecting managerial capacity)
- Phased decrease in the treatment area as the programme winds down through lower-risk areas, to maintain capacity in the event of renewed outbreaks in any fly-free area
- Existing local government administrative districts to be used as the basis of both statistics and management

- Old World screwworm *Chrysomya bezziana* (Villeneuve): Tweddle and Mahon (2000)
- Codling moth *Cydia pomonella* (L.): Canada (DeBiasio 1988, Dyck et al. 1993, Bloem and Bloem 2000, Bloem et al. 2000), Syria (Mumford and Knight 1996), and South Africa (Mumford 1997)

For comparison with control using the SIT, some other non-SIT control cost and general loss estimates for fruit flies exist for Egypt (Joomaye et al. 2000), islands in the Indian Ocean (Price and Seeworoothun 2000), and Pakistan (Stonehouse et al. 1998).

The economic conditions that favour area-wide management include an efficient and effective integration of a technique such as the SIT, a clearly articulated demand by stakeholders, good management capacity, homogeneous risks so that benefits are fairly evenly distributed, a mechanism to capture benefits and recover costs, and since the SIT is species-specific it also relies on there being a single dominant pest species (Klassen 2000, Lindquist 2000, Mumford 2000).

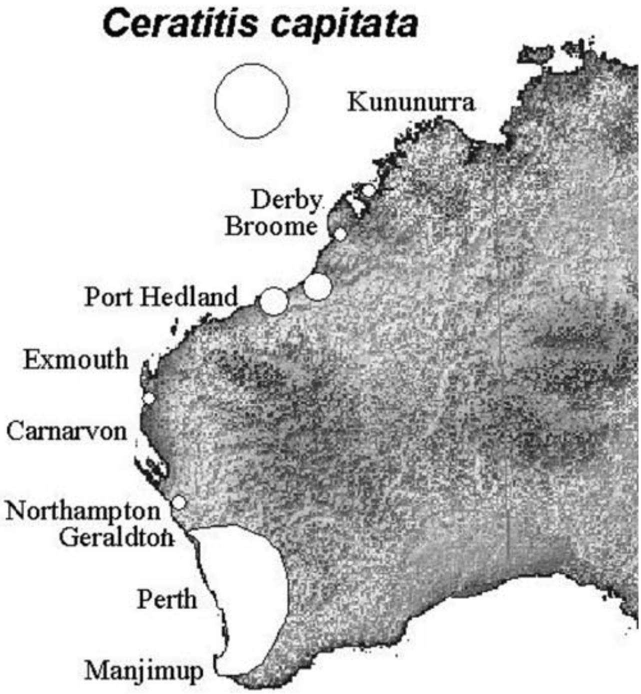

Figure 1. Map of western part of Australia showing areas infested with Mediterranean fruit fly (white circles). Large infested area in the south is around Perth, and six small areas occur farther north along the coast. (Map from A. J. Jessup and B. Woods, reproduced with permission.)

1.3. Economic Benefits of AW-IPM Programmes that Integrate SIT

The benefits of programmes using the SIT have been widely described, and vary enormously with the species concerned, and the scale and objective of the programme (Enkerlin 2003; Bloem et al., this volume; Enkerlin, this volume; Vargas-Terán et al., this volume). For example, it has been estimated that, if all species of tsetse flies and the diseases they transmit were eradicated in all of sub-Saharan Africa (which is not feasible or even appropriate since most species are not of economic importance (Feldmann et al., this volume)), the overall benefit would total USD 4500 million per year (of which USD 1200 million per year are the direct losses from trypanosomosis-affected cattle and associated current control costs) (OAU 2000). However, critics of the SIT for tsetse eradication cite higher costs in areas with multiple species, and the high costs of reducing initial populations to levels at which the SIT can work efficiently (Hargrove 2003). Such analyses could also be used to set target cost levels for more efficient sterile insect production and release technologies to achieve returns comparable with conventional control.

Establishment of the Mediterranean fruit fly in California would threaten losses estimated at between USD 1000 million and 3600 million per year (CDFA 2003), but the release of sterile insects in the preventive programme has maintained the fly-free status. The successful eradication of the Mediterranean fruit fly in Chile in 1995 opened up approximately USD 100 million per year in additional fruit markets (IAEA 1999). On a much smaller scale, in South Africa grape growers on 4000 hectares in the Hex River Valley were estimated to save over USD 150 per hectare per year in conventional insecticide costs, plus the added value of entering low-residue markets, through using the SIT to suppress the Mediterranean fruit fly (Mumford 1997). Suppression with the SIT offers similar advantages for Mediterranean fruit fly control in Israel, Portugal, Spain, and other countries where ecological circumstances indicate that at present continual reinfestation is likely, and the cost of quarantine may be relatively high. While suppression does not have the finality that gives eradication such political appeal, it also does not have the high costs of certification and quarantine. Furthermore, because there would be an ongoing need for sterile insects, there may be greater potential interest for private investment in SIT production facilities and delivery services (Mumford 2000, Quinlan et al. 2002).

For a practical decision on the merits of eradication, exclusion, or suppression using sterile insects, these benefits must be set against expected costs, which for many AW-IPM programmes are now well documented in a range of national circumstances. Issues remain, however, about how to capture the benefits within the various economic sectors that gain from control, and to transfer some of this to the public or cooperative sectors that provide the service. AW-IPM programmes that integrate the SIT have traditionally been public or largely public programmes, but may increasingly be partly or wholly funded directly by beneficiaries (Dyck, Reyes Flores et al., this volume).

2. BENEFIT/COST ANALYSIS FORMAT

The output of the BCA is likely to appear as a spreadsheet-based time-profile indicating inputs and outputs by year, location and sector (which could be crop/livestock type, urban/rural, public/private, etc.) depending on the needs of the commissioning agency. The spreadsheet models the flows of inputs and benefits as each area reaches the year assigned for particular management actions. An example output appears in Table 1 and Fig. 2.

The model structure has a set of cost and benefit components specified for each area and each year. Each of these refers to a standard set of cost, price and production parameters per area to give the model consistency, while allowing the flexibility to analyse different SIT control plans. Different plans could, for instance, include changing the sequence of zones to be controlled, or the number or size of zones targeted for eradication in each year. Some values may need to be expressed with specified levels of uncertainty associated with them, e.g. the cost of sterile flies may not be known before a factory is built, but costs from similar factories give a good approximation. Sensitivity analysis would demonstrate the range of outcomes using input values with some variation around the most likely expected values.

Table 1. Output scenario for a possible multi-zone 6-year Mediterranean fruit fly eradication in Western Australia (Mumford et al. 2001), including a 2-year pre-eradication phase, 6 years of eradication starting from the south-western districts of the state, and a continuing extra quarantine post-eradication (additional cost beyond present quarantine). Two years of pre-eradication demonstrations and survey cost USD 0.66 million per year. After Year 10 it is expected that post-eradication costs would continue at USD 0.13 million per year, mainly for quarantine and marketing to maintain the advantage of eradication. Benefits would increase as the area under cultivation is assumed in this scenario to double from Year 1 to Year 20 (Fig. 2 and Box 2)

	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Zone/phase	South-west	South	Perth East	Perth	Central	North	Post-eradi-cation
Fly challenge	Low	Medium	High	High	High	High/ Medium	
SIT area (km^2)	260.0	554.4	1019.6	978.4	73.0	69.1	
Costs (USD million)							
Bait (pre-SIT)	0.208	1.173	2.930	2.925	0.194	0.248	
Environ. costs pre-SIT control	0.125	0.704	1.758	1.755	0.116	0.149	
Direct SIT costs	1.378	2.885	5.234	5.021	0.391	0.362	
Quarantine post-eradication		0.055	0.115	0.209	0.201	0.016	0.014
Monitoring		0.156	0.333	0.612	0.589	0.044	0.042
Misc. expenses	0.303	0.635	1.151	1.105	0.125	0.125	0.125
TOTAL	2.014	5.609	11.521	11.628	1.615	0.944	0.181
Benefits (USD million)							
No spraying	0.010	0.139	0.375	0.393	0.482	0.574	0.606
No residual loss	0.020	0.257	0.632	0.662	0.767	0.987	1.043
Extra local sale	0.075	0.223	0.232	0.295	0.312	0.330	0.348
Export access/ residue benefits	0.000	0.032	0.158	0.248	0.383	0.617	0.782
Garden fruit	0.014	0.039	0.067	0.094	0.072	0.102	0.102
Environmental benefits	0.015	0.108	0.269	0.282	0.342	0.423	0.447
No S. Australia quarantine	0.000	0.066	0.206	0.206	0.464	0.483	0.500
No Kununurra fly-free zone	0.000	0.007	0.021	0.021	0.046	0.048	0.050
No post-harvest research						0.125	0.125
TOTAL	0.134	0.870	1.959	2.203	2.868	3.688	4.003
Net (Benefit/Cost) (USD million)							
Total	-1.880	-4.738	-9.561	-9.426	1.253	2.744	3.822
Cumulative	-3.205	-7.943	-17.505	-26.931	-25.678	-22.934	-19.112
NPV 20 years	7.969						

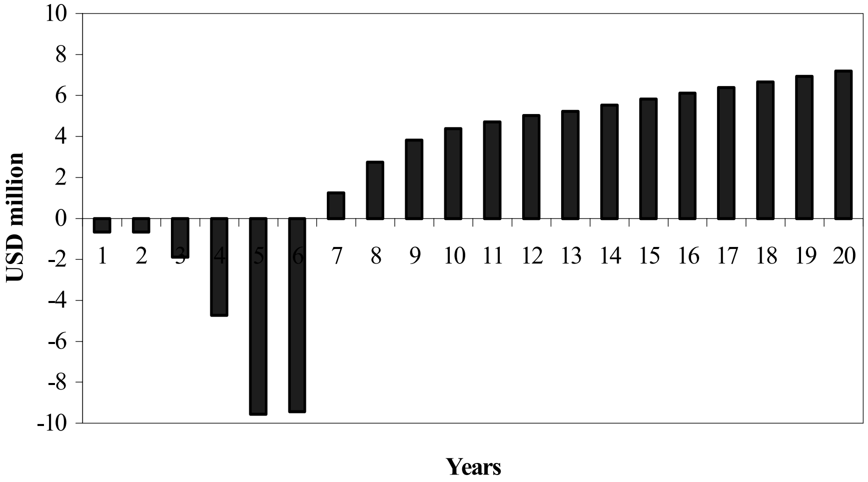

Figure 2. Annual net projected benefit/cost for one scenario of the Western Australia Mediterranean fruit fly eradication programme before any discount rate is applied (Mumford et al. 2001). The itemized values of costs and benefits for years 3 through 9, and the net present value with discount rate applied, are shown in Table 1. The benefit/cost analysis demonstrates that, under the assumptions applied in this scenario, the net present value is positive, and the initial investment could be justified by the later returns.

Many of the BCA models referred to in this chapter are related to the general format of a generic Mediterranean fruit fly BCA model under development at the International Atomic Energy Agency (W. Enkerlin, J. D. Mumford, and A. W. Leach, unpublished spreadsheet models). While each case has specific elements of geography, ecology or market conditions, there are many common principles and a growing globalization of SIT infrastructure. For instance, large and efficient production facilities (Quinlan et al. 2002) can ship sterile insects to an international market at competitive prices — New World screwworms from Mexico to Libya, Jamaica, and Panama, and medflies from Guatemala to the USA, Israel, and South Africa. Many items of equipment used in rearing and aerial release are now common across many programmes. Unfortunately, components of costs for sterile insects and their application are not standard throughout the world; there are large local cost and salary differences. In addition, economies of scale may also play a role. Major advances continue to be made in insect mass-rearing processes, which should reduce production costs of many SIT-targeted species (IAEA 1999; Parker, this volume).

The time dimension for BCA predictions is very important, since there is a trade-off between adding the extra benefits over a longer term after most of the cost has been completed, and adding greater uncertainty of further pest invasion, market changes, etc. While eradication may be seen by many as a once-and-for-all achievement, with an indefinite stream of benefits, experience shows that, for some pests under some situations, reinvasion occurs frequently (for example, the Mediterranean fruit fly has reoccurred in California and Florida following

Box 2. Case Example — Western Australia Mediterranean Fruit Fly Eradication Plan

An economic study was conducted to look at the overall costs and benefits of a potential technical programme to eradicate the Mediterranean fruit fly in Western Australia (Mumford et al. 2001).

The study developed a benefit/cost framework for the analysis, and collected data and subjective estimates of costs and benefits that could be applied to the programme. It was estimated that the total treatment area would be approximately 2000 km^2. It was assumed that an eradication effort would be a phased programme over six years, with a maximum control area of around 1000 km^2 per year in the peak years (Table 1). This would require the release of about 100 million sterile male flies per week. A phased programme would require considerable publicity and internal quarantines to protect the fly-free areas as the eradication moved on to new areas. Given the scale of the operation, much of this would need to rely on public cooperation, rather than very expensive physical quarantine barriers, such as manned roadblocks. Intensive monitoring would be needed to prove that eradication had taken place. The overall cost of eradication was estimated to be about USD 35 million. The likelihood of success for such an eradication programme would be very high, given the well-established technology. The phased programme would move from less climatically suited areas into Perth, leaving the smaller infestations in the north to be treated last (Fig. 1).

The principal benefits of Mediterranean fruit fly eradication would be: (1) reduced conventional pesticide and application costs, (2) reduced pest losses to growers (current insecticide control is not perfect), (3) reduced pesticide residues (increasingly important in international markets), (4) improved market access, (5) community benefits to the environment, backyard production and enjoyment, and (6) lower costs to government for quarantine, emergency control and continued research on conventional control improvement. Approximately 68% of the direct benefits arise from reduced production costs and new market opportunities, the remainder from reduced community/government costs. Both growers and the public would benefit, and could be expected to contribute directly or indirectly to an area-wide eradication programme, as well as participating in its management.

The analyses indicated that, if horticultural areas double over the next 20 years, the net benefits at present values for Mediterranean fruit fly eradication are likely to be positive (almost USD 8 million net present value (NPV) for 20 years). Even if the area were to increase only slightly (at least 18%), a break-even result is likely. Uncertainty analysis indicates that additional research on the presence of non-commercial hosts in riverine and urban areas, and on the extent of residual losses despite current conventional control, may make the analyses both more precise and more positive (as some non-host areas are likely to be eliminated from control). Increasing demands for residue-free produce in export markets, and the withdrawal of many conventional fruit fly insecticides, may make SIT-based eradication essential, rather than merely desirable, to the future of export horticulture in Western Australia.

eradications, although the benefits of even short-term eradication exceed the costs in such major exporting areas). So while longer timeframes would give a greater apparent return to an eradication programme, assuming the costs of maintaining quarantine or preventive control are not prohibitive, the probability of losing the benefits through a new outbreak increases as more years are added to the anticipated flow. In any event, future discounting reduces the impact of extending the time horizon.

Benefits and costs that arise in future years should be compared in terms of their equivalent present values, so that all the values are directly comparable, since the same nominal value further in the future is worth less in present terms. The net benefit (benefit minus cost) over the whole programme period being considered would be expressed as a net present value (NPV). The discount rate is used to calculate these net present values. The discount rate is a measure of the value that people place on having money now rather than later. It is generally considered to be equal to the interest rate on savings minus the inflation rate. In relatively stable economies the discount rate ranges from about 5–9%; it is likely to be higher in less stable economies (Mumford 2000). The US government guideline on the discount rate suggests a central value of 7% for public benefit programmes, with sensitivity analysis using the wider values above (OMB 2003). While a common discount rate, such as 10%, could be used in all analyses, this would not demonstrate the differences in future values that actually occur in different economies. To calculate present value, the following formula is used:

$$\text{Present value} = \text{Future value}/((1+\text{Discount rate})^{\text{Number of Years}}) \qquad (1)$$

At a discount rate of 0.07 (7%), this formula indicates that a value of USD 100 in 10 years has a present value of only USD 51, and USD 100 in 20 years is worth only USD 26 in present terms. Therefore long time frames do not add as much benefit as may be imagined, particularly where discount rates are high, while they add greatly to the uncertainty of the estimates.

3. MODEL INPUTS

3.1. Costs

The following cost items must be predicted:

- Pest management treatments (the combination of the SIT and related technology to be applied, based on technical selection and specification of control activities and locations; variable costs to be determined per unit area, plus initial and subsequent annual fixed costs).
- Management area (this is the main driver for costs, since most costs are variables based on treatment application per unit area).

Cost categories (examples are given for some of the important cost categories, mainly based on values for the Mediterranean fruit fly, one of the most commonly controlled pests using the SIT, but some of the categories are too site-specific to give meaningful examples):

- Pre-treatment preparation (demonstrations, trials to prove the effectiveness of techniques, and to build technical capacity and public confidence).
- Surveys (pest population, host areas, current control practices and losses).
- Population reduction needed prior to the SIT (by bait or other treatment) to bring populations to a low-enough density for effective SIT control:
    - For the Mediterranean fruit fly, approximately USD 6000 per km^2 (Mumford et al. 2001).
- Environmental costs (mainly pesticides used for pre-SIT population reduction):
    - Pimentel and Lehman (1993) suggested that social and environmental costs from pesticide use in the USA amounted to approximately USD 2 for every USD spent on pesticide active ingredient. This is an average figure calculated for all US agriculture, and included damage to operator health, public health through residues and run-off, and losses of wildlife and domestic animals.

  - Mumford et al. (2001) used a variable figure for environmental costs based on expenditure for pesticide active ingredient to control Mediterranean fruit flies in Western Australia of USD 1 per USD of pesticide active ingredient. The lower figure, compared with Pimentel and Lehman (1993), was based on smaller areas with relatively low-toxicity treatment, often distant from major urban areas and water supplies.
  - Kovach et al. (1992) proposed an environmental impact quotient (EIQ) for pesticides, which gives an economic value for the environmental damage of many individual pesticides, particularly those used in horticulture.
  - Environmental and health impacts can be quantified in monetary units using willingness-to-pay methods, or by establishing aspiration levels (Farnsworth 1986).
- SIT costs (approximate figures for the Mediterranean fruit fly, as of 2004):
  - Production: About USD 250–500 per million irradiated male pupae at the factory. The current cost of purchasing irradiated male pupae from Moscamed Guatemala, with the largest Mediterranean fruit fly rearing facility, is about USD 200 per million pupae (Hendrichs et al. 2002). (The release rate would be 100 000–150 000 (pupae) per km^2 per week; numbers may depend on host density.)
  - Shipment: The current cost of air-freight shipment of pupae from Guatemala to Israel is about USD 250 per million pupae (J. P. Cayol, personal communication). Of course this cost would be lower if the production facility were located nearer to the release site. Intercontinental air shipment may cause mortality and loss of vigour, reducing effective numbers by 50% by the time flies are released.
  - Local fly emergence, handling and aerial release: Cost is about USD 150–200 per million male pupae (Mumford et al. 2001; J. P. Cayol, personal communication).
  - Local fly release alone: Cost is about USD 1100–2000 per km^2 per year of application (assumes 52 weekly releases) (Mumford et al. 2001).
- Quarantine (only for eradication or exclusion — prevention of re-entry, and management of outbreaks post-eradication).
- Monitoring (during eradication activities and post-eradication) and certification (only for eradication — intensive monitoring post-eradication to prove pest free status):
  - For the Mediterranean fruit fly, a certification trap grid of 10 traps per km^2, inspected fortnightly, costing USD 2 or 3 per trap per inspection (Mumford et al. 2001); monitoring during exclusion or preventive programmes may cost less, e.g. 4 traps per km^2 in the preventive release programme in California (Dowell et al. 2000).
- Miscellaneous costs (administration, publicity, marketing the improved pest free quality produce from the area).
- Additional management and infrastructure costs to cope with possible increased pressure on land use after pests are eliminated.

A time-profile of the inputs, with changes over time, a time limit for analysis, and an agreed discount rate, are also needed.

The management operations are specified according to the technical needs of the programme, for example pre-SIT bait applications. The economic analysis can be used to choose between different technical options, e.g. the order in which zones are treated in a phased eradication may have significant economic implications. There may be technical or managerial limits on the size of treatment zones, which affects the pace of eradication. The release rate of sterile insects, pre-SIT control regimes, and standards for monitoring, are all based on previous experience gained in successful eradication programmes, on the ecological circumstances in the area, or, for new SIT species, on field research in pilot programmes.

The treatment area in each year consists of all the pest-host areas within a zone, along with some additional areas along the edges of host areas. Depending on the pattern of hosts, it may be necessary to include areas that do not contain the pest but for practical reasons must be included in the treatment area. Treatment areas may be predicted by land-use images from satellite or aerial photos, and/or from ground surveys. Crop areas, livestock densities, and production levels are often available from agricultural statistics, and households can be obtained from census records. Local surveys of vegetation, animals, and households may be needed where information is scarce.

Prior to the SIT treatments, there may be a need for trial runs to evaluate procedures, or to provide some stakeholders with demonstrations of operations and impacts. All subsequent operations can be treated as either direct area functions in the BCA spreadsheet, or as indirect area functions (for instance, environmental costs are likely to be determined by the volume or value of pesticide used, which will itself be area-related).

The timescale for the analysis should include the preparatory phase, the operational phase, and the ongoing period during which benefits and any further costs can be confidently expected to accrue. The endpoint for the analysis should be chosen after consideration of ecological, market and quarantine uncertainties, which increase over time, and the effect of future discounting, which makes long-term future values relatively less significant in present terms.

3.2. Benefits

The following groups of benefits are likely to accrue:

- Reduced direct and indirect costs of current control (this requires technical specification and information on the proportion of users for each current practice, obtained by survey).
- Reduced residual losses to crops or livestock due to target pests that an SIT treatment would eliminate (such losses occur despite current control efforts, either because little or no control is applied in many low-input farms, or control is often not completely effective even when fully applied). The lack of fully effective controls is often a substantial motivation for the SIT, whether eradication, exclusion or suppression.
- For livestock — reduced veterinary, surveillance and treatment costs.
- For livestock — shorter time for animals to reach market weight.

- Reduced environmental impacts from pests that affect natural vegetation or wildlife, which would be prevented through control: NPB (1999) and Pimentel and Lehman (1993) discussed the environmental impacts of invasive insect species. Mumford (2001) described the ways in which economic values can be put on non-crop losses in natural environments.
- New market opportunities or improved retention of existing markets (e.g. due to reduced pesticide residues on produce) or certified disease- or insect-free status.
- Greater impetus to invest in agriculture in areas in which pests have been controlled.

A time-profile of benefits and their distribution (geographical, sectors, etc.) is needed, along the same lines as for costs.

3.3. Input Format

A typical spreadsheet for the BCA would consist of the following example data pages: a delineation of areas; a catalogue of data on the number of square kilometres per district (total area, and area of particular pest hosts, or density of hosts); SIT-treatment areas by zone (excluding areas the target pest would not inhabit due to climatic conditions or a lack of hosts); potential and residual losses due to the pest (affected by productivity in the area, climate, susceptibility of hosts to pest); current control costs, including social and environmental costs of current control practices, lost market opportunities (due to residues, residual pest damage or quarantine exclusion), SIT-treatment costs, including additional monitoring and quarantine costs and pre-treatment preparation, and a discount rate for the country; and the input summaries for each scenario (e.g. Table 1).

4. MODEL OUTPUTS

4.1. Net Present Value and Internal Rate of Return

Model outputs should indicate: summaries of costs and benefits over a timeline agreed to for the analysis of the strategy, and economic indicators (such as net present value, pay-back period, and internal rate of return) for each proposed strategy. The net present value is the sum of the present values of future net returns, using the discount rate to calculate back to the present from the expected future nominal values. The pay-back period is the number of years before the cumulative benefits exceed the cumulative costs, which is a measure of the riskiness of a programme. The internal rate of return is the discount rate that would give a net present value of zero to the stream of net benefits resulting from the programme. The programme would exceed break-even if actual discount rates were expected to be below this value.

The output of the BCA provides a comparison of the stream of net benefits, expressed in present values. Strategies with higher net present values are preferred, although sensitivity analysis may indicate that some high returns are associated with greater risk. Cases of eradication require a long-term commitment to ensure that the investment in eradication is protected, and this can add considerable cost. The net present value is based on the calculation based on the average of each input value, but each of these inputs may be uncertain. Where probability ranges have been estimated for various input values, it is possible to use simulation software such as Crystal Ball® or @Risk® to calculate the range and frequencies of output values.

4.2. Interpretation and Apportioning of Benefits

The distribution of benefits can be apportioned by sector, e.g. commercial versus backyard, by geographical zone, by public/private finance, etc. This has important implications for the political desirability of a programme, the relative role of various stakeholders, and the potential for cost recovery. The initial benefits are likely to go to commercial producers for programmes involving fruit flies, codling moths, or other agricultural pests. Consumers may subsequently benefit from lower prices if production becomes more efficient later and residue levels are reduced.

Many countries now have policies that require the government to seek to recover costs, wherever possible, from public programmes such as insect eradication, e.g. the New Zealand Biosecurity Act 1996. The BCA could form the basis for determining not only what expenditure will be needed for a successful programme, but, through the assessment of the benefits, how that expenditure should be shared. However, identifying benefits does not directly indicate who should pay. Some costs, e.g. non-monetary environmental costs, are difficult to recover, and may only be practical for society as a whole to bear, or to claim compensation from government (Mumford 2001). In other cases, too many beneficiaries may be involved from which to collect individually, e.g. where urban householders benefit. Any area-wide insect management programme will encounter the issue of free-riders who do not contribute directly (Lindquist 2000). Where these benefits contribute to the broader public good, it may be more efficient to fund programmes centrally from government and thus spread the cost through general taxation. Where the benefits are geographically isolated, and beneficiaries few in number and well organized, such as in the current Hex River Valley Mediterranean fruit fly control programme in the South African table-grape industry (ARC Infruitec 2003), a levy on growers is a practical and fair way to pay for part of the costs (Dyck, Reyes Flores et al., this volume).

5. BENEFIT/COST ANALYSIS CHECKLIST

- Planning and feasibility studies (technical and economic) that provide initial descriptions of inputs, and estimates of costs and effectiveness
- Current pest losses (without control and in spite of control, for crops or livestock, over several seasons)
- Market exclusion due to pest presence, damage or pesticide residues
- Current control practices (area treated, effectiveness, cost, environmental impact)
- Area to be treated overall

- Areas within the overall area in which pest hosts occur (by management units, which would be a minimum area in which the pest population may be controlled using the SIT, e.g. the unit for aerial application may be 500 m^2)
- Pre-programme monitoring for hosts and populations
- Publicity to make the public aware of the area-wide programme
- Regulatory controls (such as hygiene, local quarantine inspections, reporting of pest occurrence)
- SIT costs:
  - Pre-release insecticide baiting (or alternative population reduction practices)
  - Sterile insect production
  - Sterile insect storage and transport
  - Sterile insect release
  - Field monitoring (for operational management)
- Field monitoring for pest free certification
- Post-control area quarantine
- Marketing to capture benefits of pest and pesticide reduction/elimination
- Agreed programme timescale for analysis and applicable discount rates

This checklist provides guidelines on the basic information that ideally would be used in the BCA. More precise information will give more confidence in the analysis, but may be expensive to obtain. Therefore some compromises between uncertainty and cost may be required. The goal is to provide transparent comparisons of specified strategies, with as much objectively agreed information as possible, and with any uncertainties explicitly identified and included.

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