CHAPTER 11

THE BENEFITS AND COSTS OF SPECIFIC PHYTOSANITARY CAMPAIGNS IN THE UK

Examples that illustrate how science and economics support policy decision making

A. MACLEOD

Central Science Laboratory, Sand Hutton, York YO41 1LZ, UK.
E-mail: a.macleod@csl.gov.uk

Abstract. Three examples of benefit/cost analyses (BCA) conducted in recent years in the UK to support phytosanitary policy are summarized. Following the first UK outbreak of *Thrips palmi*, the costs incurred during the eradication campaign were compared with potential-losses forecast by modelling the spread and impact of *T. Palmi* in glasshouse crops over ten years. The resultant BCA justified the strict statutory action taken to achieve eradication. The second example, the eradication of a plant pathogen, *Ralstonia solanacearum*, from a river system showed that the expense of a statutory campaign is justified only if eradication can be achieved within a few years. A more protracted campaign would lead to costs outweighing benefits. A third analysis examining the economic impact of implementing EU control measures on *Diabrotica virgifera virgifera*, an insect pest of maize that is currently spreading across Europe, highlights the importance of assessing the cost of implementing measures as well as the benefits of avoiding losses caused by the target pest. This last example shows that strict implementation of control measures can be more costly than the damage likely to be caused by the pest. The strengths and weaknesses of benefit/cost studies, and their future use in relation to plant health issues are discussed.

I am grateful to Prof. Lansink and the Frontis organization for inviting me to participate in the workshop. Benefit/cost analyses were funded by Defra Plant Health Division.

Keywords: benefit/cost analysis; *Diabrotica virgifera virgifera*; economic evaluation; *Thrips palmi*; plant health; potato brown rot; quarantine; *Ralstonia solanacearum*; western corn rootworm

INTRODUCTION

The international trade in plants and plant products acts as the primary mechanism for the unintentional introduction of non-indigenous pests (Levine and D'Antonio 2003). For example, over 80 % of non-indigenous pests that established in the USA between 1980 and 1993 have been assessed as having entered the USA unintentionally through international trade (Jenkins 1999). The World Trade Organization (WTO) Agreement on Sanitary and Phytosanitary Measures (SPS Agreement) allows member countries to protect crops and other plants from the risks

A.G.J.M. Oude Lansink (ed.), New Approaches to the Economics of Plant Health, 163-177

of pest introduction that can arise from international trade by applying protective measures to trade pathways. The SPS Agreement requires that such protective measures be based on risk assessment techniques developed by a relevant international organization. For phytosanitary issues, the International Plant Protection Convention (IPPC) is the relevant organization. In developing a global standard for plant pest risk analysis (FAO 2003), the IPPC recommends that, when selecting appropriate risk management options, those measures with an acceptable benefit to cost ratio should be considered (FAO 2003, part 3.4). Using benefit/cost analysis (BCA) to inform phytosanitary policy is a relatively recent development. Early examples include Rautapaa (1984), who examined the benefits and costs of maintaining Finland free from *Liriomyza trifolii*, the chrysanthemum leaf miner, and Pemberton (1988), who examined the benefits and costs associated with excluding the highly contagious bacterial disease potato ring-rot, caused by *Clavibacter michiganensis* ssp. *sependonicus*, from the UK. Despite these examples, the application of economic analysis to protecting plants from exotic pests was still in the stages of early development towards the end of the 20th century (Krystynak 1991). More recently, Sumner (2003) considered that there was still relatively little economic analysis of government policies related to exotic agricultural pests although he did recognize that where such activity took place the policy evaluation was being conducted at a more rapid pace. Now, when developing phytosanitary policy, governments increasingly require detailed economic impact analyses to inform and help shape quarantine decisions.

This paper provides three examples of summaries of BCA studies that have examined the actual or potential economic impacts of implementing phytosanitary campaigns against quarantine pests in the UK.

EXAMPLE 1: *THRIPS PALMI* – AN INSECT PEST IN GLASSHOUSES

Background and the UK outbreak

Thrips palmi is a polyphagous pest that feeds on the midribs and veins of leaves and stems of more than 50 plant species from over 20 families. Hosts include a wide range of economically important vegetable and ornamental plants. Originating in South East Asia, *T. Palmi* was found in India in the 1960s and has become an increasingly important pest around the world as it has spread within tropical regions of Africa, Australia, South America, Hawaii and the Caribbean, and in sub-tropical regions of Florida and Japan. Since 1978, *T. Palmi* has become the most serious pest of a number of glasshouse and field crops in southern and western Japan, regularly causing crop losses (Kawai 1990). The first European outbreak of *T. Palmi* occurred in the Netherlands in 1988 (Vierbergen 1996). If *T. Palmi* established in the UK, glasshouse grown aubergines, chrysanthemums, cucumbers, Cyclamen, Ficus, orchids and sweet peppers would be principally at risk. Phytosanitary measures designed to inhibit the establishment of *T. Palmi* in Europe have been justified through pest risk analysis (MacLeod and Baker 1998). As a quarantine pest for the European Union (EU) (European Commission 2000) the UK National Plant Protection Organisation (NPPO) policy is to exclude *T. Palmi*, destroying interceptions and eradicating outbreaks if they occur. The first ever UK outbreak of *T. Palmi* was confirmed at a glasshouse site producing ornamental cut flowers in April 2000. An intensive treatment programme including soil, compost, foliar and space treatments was undertaken to eradicate the pest (MacLeod et al. 2004) and no movement of planting material from the site was allowed. After 15 months of intensive treatment and monitoring, eradication was declared in July 2001. To achieve eradication both the business at the outbreak site and the NPPO had to incur significant costs. An ex-ante BCA was therefore conducted to investigate whether such expenditure had been justified.

The insecticide application records before and during the eradication campaign were compared to determine the additional chemical-treatment costs. Together with the costs of additional hygiene measures, the cost of the outbreak to the producer was approximately £ 1,835 ha^{-1} $month^{-1}$ (derived from MacLeod et al. 2004). This was more than six times the normal monthly cost for pest control at the site. Based on labour inputs, NPPO costs during the eradication campaign were approximately £ 123,000. In total the combined eradication costs to the NPPO and the grower were approximately £ 178,000.

Modelling the economic impacts of Thrips palmi spread from the outbreak site

A model was developed to assess the potential economic impact that could result from the spread of *T. Palmi* from the outbreak site had an eradication policy not been followed. The model considered the expansion of *T. Palmi* through protected horticulture in the UK over ten years at two rates. First, a rapid rate similar to the spread of *Frankliniella occidentalis*, a thrips species that previously spread through UK glasshouses over a three-year period from its first finding in June 1986 (Jones et al. 2005). Secondly, a slower rate, based on *T. Palmi* in Japan, where 62.5 % of the endangered area became occupied over ten years. Estimates of potential yield losses projected over 10 years were based on damage reports in the literature (Table 1).

***Table 1**. Basic data for glasshouse crops at risk from Thrips palmi in the UK*

Crop	Area at risk (ha)	Crop value (£ ’000)	Potential yield loss (%)	Value of potential losses (£ ’000)	Ref. for yield loss estimate
Cucumbers	172	38,539	10	3,854	Kawai (1986)
Protected ornamentals	99[a]	14,705	1	147	See text
Sweet peppers	48	7,799	8	624	Nuessley and Nagata (1993)
Aubergines	11	2,548	15	382	Nagai (1991)
	330	63,591		5,007	

[a] Out of 990 ha protected ornamental production, 10 % was assumed to be *T. Palmi* hosts

There are no quantitative reports of *T. Palmi* damage to ornamental hosts. Given the polyphagy of *T. Palmi*, it has been estimated that about 10% of total ornamental production is susceptible (Mumford et al. 2000) and that in serious outbreak years feeding damage would cause a reduction of between 1 and 10 % in the value of affected hosts, due to losses in yield and/or quality and increased pest control costs (Kehlenbeck 1996). Accordingly, it was estimated that additional annual financial costs worth approximately 1 % of the value of protected ornamental production would be incurred within the infested area. The difficulty in estimating potential impacts was compounded by uncertainty in the level of damage caused by *T. Palmi* populations in each year. Estimates of severe damage, or high impact, in which populations caused maximum damage were taken from data in the existing literature and low or less severe impacts, where populations caused ten times less damage, as suggested by Kehlenbeck (1996), were selected to represent the range of possible impacts. It was anticipated that during the period of *T. Palmi* spread government and industry would undertake research to investigate ways to control and limit *T. Palmi* damage. Consequently costs of £ 50,000 per annum were allowed for. As a quarantine pest in four continents, exports of hosts liable to carry *T. Palmi* could be lost. Additional export certification could mitigate such losses. Such additional costs would be borne by government. Tables 2 and 3 show model outputs summarizing the annual area of glasshouse occupied from scenarios of fast spread (Table 2) and slow spread (Table 3) together with the present value of economic impacts caused by *T. Palmi* under scenarios of high and low impact. The HM-Treasury-recommended discount rate at the time of the *T. Palmi* outbreak was 6.5 % (HM Treasury 1997) and was used to determine present values.

Table 2*. Glasshouse area occupied and present value of projected economic impacts in a scenario of fast Thrips palmi spread with high or low impacts*

Year	Glasshouse area occupied (ha)	Present value of industry and government costs				Combined costs	
		High crop impact (£ ’000)	Low crop impact (£ ’000)	R & D (£ ’000)	Additional certification (£ ’000)	High (£ ’000)	Low (£ ’000)
1	2	3	0	47	21	71	68
2	82	111	11	45	20	175	75
3	248	316	32	42	18	377	92
4	330	397	40	40	17	454	97
5	330	374	37	37	16	428	91
6	330	353	35	35	16	404	86
7	330	333	33	33	15	381	81
8	330	314	31	31	14	359	77
9	330	296	30	30	13	339	72
10	330	279	28	28	12	320	68
						3,306	807

Table 3*. Glasshouse area occupied and present value of projected economic impacts in a scenario of slow Thrips palmi spread with high or low impacts*

Year	Glasshouse area occupied (ha)	Present value of industry and government costs				Combined costs	
		High crop impact (£ ’000)	Low crop impact (£ ’000)	R & D (£ ’000)	Additional certification (£ ’000)	High (£ ’000)	Low (£ ’000)
1	2	3	0	47	21	71	68
2	26	35	4	45	20	99	68
3	49	62	6	42	18	123	67
4	69	83	8	40	17	140	65
5	92	104	10	37	16	158	64
6	116	124	12	35	16	175	63
7	139	140	14	33	15	188	62
8	158	150	15	31	14	195	60
9	181	163	16	30	13	205	59
10	204	173	17	28	12	213	57
						1,567	634

The financial benefits resulting from *T. Palmi* exclusion can be considered as the costs that are avoided if the UK had to ‘live with’ the pest. Comparing the range of the benefits from eradication with the costs involved in achieving eradication gives a series of benefit/cost ratios (Table 4).

Table 4*. Benefit/cost ratios of Thrips palmi eradication*

		Rate of spread	
		Fast	slow
Economic impact during *T. Palmi* spread	High	3,306 : 178 (19 : 1)	1,567 : 178 (9 : 1)
	Low	807 : 178 (5 : 1)	634 : 178 (4 : 1)

The benefit/cost ratios range from 4:1 to 19:1, depending upon the rate of spread and whether impacts are low or high and show that the policy of eradication was justified. The potential loss of exports is not included in the above analysis. Had such losses been included then the benefits of exclusion would be much higher (MacLeod et al. 2004).

EXAMPLE 2: THE ERADICATION OF *RALSTONIA SOLANACEARUM* FROM THE RIVER TRENT BY REMOVAL OF HOST PLANTS FROM RIVERBANKS

Background

Potato brown rot is caused by the bacterium *Ralstonia solanacearum* race 3, biovar 2, and is a serious EU quarantine disease of potatoes that severely limits potato production in temperate and tropical regions of the world (Smith et al. 1997). The disease can be distributed via seed and ware potatoes, potato waste and, crucially for the purposes of this analysis, via contaminated river water used for irrigation. In accordance with EU Council Directive 98/57/EC, contaminated watercourses are designated and, to inhibit spread of the bacterium, irrigation of potatoes using contaminated water is prohibited.

Potatoes are the most extensively irrigated crop in the UK (MacKerron 1993). Irrigation can have a beneficial impact on yields, especially for early potato varieties. Irrigation also helps to control tuber quality, especially the incidence of common scab, caused by the soil-borne bacterium *Streptomyces scabies.* A British Potato Council analysis shows that, over four seasons, lack of irrigation led to a 40 % yield penalty and a 2-3-fold increase in common scab on packing varieties. Because the effect of irrigation on yield and quality is so large, potato growers always ensure that crops are irrigated whenever possible (Allen and Scott 1992).

Solanum dulcamara is a common native plant that can be found throughout the UK. Where *S. dulcamara* grows on riverbanks and extends its roots into water contaminated with *R. solanacearum*, it can become infected with *R. solanacearum* allowing the bacterium to persist and provide a source of inoculum to further contaminate the water. In 1998 the UK NPPO began a trial programme to remove *S. dulcamara* from the River Great Ouse and the River Nene, which were designated contaminated waterways. Annual costs for the removal of *S. dulcamara* averaged £1,260 km^{-1} of river (2003 prices) (MacLeod 2004).

Removing Solanum dulcamara from banks of the River Trent

During a national survey of major waterways in 2003, the River Trent and canals and tributaries linked to the Trent were found to be infected with *R. solanacearum* (Defra 2003). At 274 km long, the Trent is one of the major rivers of England. Using a geographic information system it was estimated that *S. dulcamara* would have to be managed along 210 km of watercourses in the region. Local NPPO officers responsible for the area estimated that 744 ha of potatoes would be affected by a ban on using irrigation water from the River Trent and designated watercourses in the region. In order to investigate whether the policy of enforcing an irrigation ban was justified, an ex-ante BCA was conducted. Based on costs of previous work on the rivers Great Ouse and Nene, the cost of removing *S. dulcamara* from the River Trent was calculated to be approximately £ 265,000 per annum.

Potato growers who irrigate from the Trent obtain relatively high yields of between 48 and 53 t ha^{-1}. Based on the gross margin budget for high-yielding potatoes (Nix 2003), a grower with these yields may expect margins of between £

2,000 and £ 2,400 ha^{-1}. Over the 744 ha potentially affected by the irrigation ban, aggregate margins of between £ 1.5 million and £ 1.8 million would therefore be expected. Without irrigation, margins could fall by 15 to 40 % with losses of £ 0.9 million to £ 1.5 million. To avoid such losses, farmers could invest in pumps that can incorporate peroxygen chemical disinfectants that cleanse contaminated water by rapidly oxidizing organic matter killing *R. solanacearum*, thereby allowing crops to be irrigated. This would maintain potato yield and quality (BPC 2002). Using such disinfectants would increase variable costs by between £ 282 and £ 353 ha^{-1}, which amounts to approximately £ 232,000 to £ 266,000 across the 744 ha at risk. However, potatoes from fields irrigated with disinfected water would have to be tested for the presence of *R. solanacearum* in the first year before they were marketed. This would cost £ 115 per 25 tonnes (CSL 2003) and would probably be borne by the NPPO. Testing costs could amount to a one-off cost of between £ 164,000 and £ 181,000.

Benefits and costs of the phytosanitary campaign on the River Trent

Results from similar work on other rivers suggest that it takes at least four years to remove *S. dulcamara* and eradicate *R. solanacearum* from watercourses. The present value of industry and government costs during a four year programme on the River Trent is in the range of £ 2,058,000 to £ 2,205,000 (Table 5).

Table 5. *The present value of costs for a four year campaign on the River Trent*

Year	NPPO costs (£ ’000)		Industry costs (£ ’000)		
	Removal of *S. dulcamara*	Tuber testing	Irrigate with disinfectant	Discount factor*	PV sum of costs (£ ’000)
1	265	164 to 181	232 to 266	1.000	661 to 712
2	265	0	232 to 266	0.966	477 to 510
3	265	0	232 to 266	0.943	467 to 499
4	265	0	232 to 266	0.902	447 to 478
					2,058 to 2,205

* The most recent recommended HM Treasury discount rate of 3.5% was used in this analysis. The rate differs from that used in example 1 since HM Treasury revised its recommendations in the light of existing and forecast changed economic circumstances (HM Treasury 2003).

Assuming success was achieved in the fourth year, then irrigation bans would be removed, growers’ margins would return to existing levels and the extra costs of £ 232,000 to £ 266,000 incurred, due to disinfecting water, would be removed in perpetuity assuming that *R. solanacearum* did not return. The present value of these perpetuities would be from £ 5,777,000 to £ 6,623,000. Comparing the benefits of maintaining growers’ gross margins in perpetuity after *R. solanacearum* has been eradicated, with costs of a four-year programme of *S. dulcamara* removal, the benefit/cost ratios vary from 2.6 : 1 to 3.2 : 1 (Table 6).

Table 6. *Benefit/cost ratios of removal of Solanum dulcamara from banks of the River Trent*

	From (£ '000)	To (£ '000)
From (£'000)	5,777 : 2,058 (2.8 : 1)	6,623 : 2,058 (3.2: 1)
To (£'000)	5,777 : 2,205 (2.6 : 1)	6,623 : 2,205 (3.0 : 1)

However, there is some uncertainty as to how long it may take to achieve eradication of *S. dulcamara* from the river so benefit/cost ratios were calculated for campaigns lasting 1 to 10 years. Figure 1 shows that the mean benefit/cost ratio improves if eradication can be achieved in under four years. Campaigns that last up to ten years approach the point where there is no net benefit in implementing the policy.

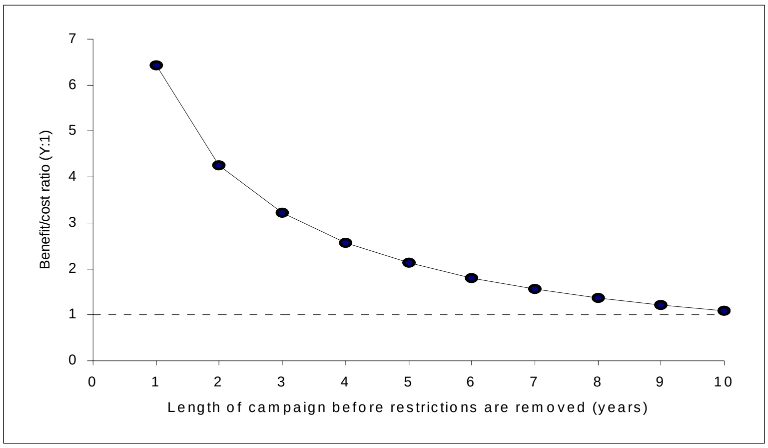

Figure 1. *Changes to the mean benefit/cost ratio through time*

The BCA study was used to inform policy with regard to the River Trent. Given the low benefit/cost ratio and the uncertainty in achieving eradication within four years, and bearing in mind the assumptions used in the analysis, a policy of removal of *S. dulcamara* from the banks of the River Trent was not followed.

EXAMPLE 3: BENEFIT/COST ANALYSIS OF EUROPEAN COMMUNITY MEASURES AGAINST THE WESTERN CORN ROOTWORM (*DIABROTICA VIRGIFERA VIRGIFERA*) IN THE UK

Background

Diabrotica virgifera virgifera, the western corn rootworm (WCR), is a univoltine oligophagous chrysomelid beetle from North America where it is one of the two most serious pests of continuous grain maize (Oerke et al. 1994). WCR was first detected in Europe in the former Yugoslavia in 1992. It is thought that WCR may have been introduced in 1990 by military air transport from North America (EPPO 1996). Since its arrival, WCR has spread annually with severe damage being reported for the first time in 1996. Due to the threat that this pest poses to EU member states the insect was added to the list of regulated pests in EU Plant Health legislation in January 1998 (European Commission 1998). Rotating maize with other crops can provide good control of WCR. Specific EU management measures designed to inhibit the spread of WCR include delay of harvest, use of insecticides and the restriction of growing maize within 1 km of an infested field for two years. Despite such measures WCR has spread within the EU and by June 2003 was detected in five of the then 15 EU countries (EPPO 2004) including the UK (Cannon et al. 2005). Following the finding, an ex-ante BCA was conducted to assess the impact of implementing the specific EU management measures designed to limit WCR spread.

The western corn rootworm in the UK

In the UK the vast majority of maize is grown for animal feed. MacLeod et al. (2005) developed two alternative scenarios and, using a stochastic Monte Carlo simulation model, annual costs associated with each scenario were estimated for a ten-year period. The first scenario estimated costs resulting from yield losses in continuous maize as a consequence of the NPPO not implementing EU measures. Annual rates of spread from the initial sites of infestation in SE England were selected from a triangular probability distribution, with parameters based on spread reported in the literature. By identifying the regions where maize is grown and overlaying it with climatic areas suitable for WCR development, the annual area of endangered maize could be determined (Baker et al. 2003). The model also used a triangular distribution of the minimum, most likely and maximum annual maize area suitable for WCR development. The model combined the annual area suitable for WCR establishment with the annual rate of spread and provided output in the form of maize area occupied by WCR each year and projected forward ten years. From 10,000 model iterations, the mean annual area occupied was used to calculate potential future losses in yield in unrotated maize. Evidence from European countries suggests that there is a time lag of approximately five years between the first finding of WCR and reports of economic damage in continuous maize (EPPO 2003). Around 20 % of maize in UK is grown continuously and hence is most at risk from WCR. Yield losses are predicted to be between 10 and 30 %. The second scenario estimated the costs to maize growers of implementing the EU measures. The annual area suitable for WCR establishment was randomized but used a slower rate of WCR spread. Under EU regulations, once a maize field is found to be infested with WCR, EU measures, for example, rotation, should be implemented in the field and all other surrounding maize fields within a 1-km Focus Zone. Measures are also required in an outer Safety Zone, extending from 1 to 6 km from the infested field. Cannon et al. (2005) describe the measures applied in the Focus and Safety Zones in the UK during 2003 and 2004.

Scenario 1: Costs of not implementing EU measures
Without implementing EU measures, the first scenario showed that, on average, WCR would continue to spread for three years before stabilizing to occupy just over 39,000 ha of maize each year. Yield losses would be seen in continuous maize after five years. The present value of aggregate losses after ten years ranges from £ 1.9 million to £ 2.3 million (MacLeod et al. 2005). However, the vast majority of maize in the UK can be rotated and growers would not suffer significant additional costs from implementing rotation if WCR became established in the UK.

Scenario 2: Costs of implementing EU measures
By implementing the EU measures, maize growers growing continuous maize with severe constraints to change may incur additional costs averaging between £ 182 ha-1 for fields in the Safety Zone and £ 243 ha-1 for fields in the Focus Zone. Over a ten-year period of WCR spread, during which almost 7,200 ha of maize with severe constraints to rotation become infested, the impact of implementing EU measures on maize growers would have a present value of approximately £ 14.7 million (MacLeod et al. 2005). Under the statutory campaign, no yield losses would be incurred since populations of WCR are prevented from reaching damaging levels. Nationally, approximately 2 % of Inspectorate time was spent on WCR activities during 2004-2005. By apportioning the NPPO financial budget to areas of Inspectorate activity, it is estimated that implementation of the existing policy costs around £ 228,000 per year.

Benefit/cost analysis for WCR
Summing industry and government costs of implementing EU measures for the next 10 years, and comparing them with expected losses as a result of living with WCR, provides benefit/cost ratios of between 1 : 8 and 1 : 7. The stochastic model used to estimate the benefits and costs of implementing EU WCR control measures in the UK shows that strict implementation of the measures does not appear to be economically justified over the next ten years. Management measures, especially the prohibition of growing maize in demarcated zones, can impose substantial costs on maize growers who have severe constraints to change. In contrast, with no statutory measures in place, yield losses caused by WCR in continuous maize are likely to be significantly lower than the cost of measures resulting from forced rotation. Costs resulting from a forced change in rotation are potentially substantial for some

growers and, whilst it is acknowledged that assessing the cost of a change in rotation is difficult (Baufeld 2003) and thus not included amongst the costs of impacts considered by the EU *Diabrotica* project by Vidal (2003), not including such costs can seriously underestimate the impact of management measures on maize growers. The present UK policy with regard to WCR is to adopt a *light* approach (Cannon et al. 2005) that balances the EU requirements with a pragmatic approach to pest management.

DISCUSSION

The examples given show how BCA can be a useful tool providing information for phytosanitary policy decision making. BCA has a number of strengths that make it a useful technique. Firstly it requires scenarios to be formulated, providing a structured framework within which costs and benefits are identified and quantified. Taking such an approach, the *T. Palmi* BCA reinforced the justification for implementing an eradication campaign. The analysis could inform future policy decisions if an outbreak of *T. Palmi* were to occur in the UK again. BCA provides a useful mechanism for dealing with uncertainty and complexity, but it does not make difficult problems simple. There are always uncertainties concerning the size of costs and benefits and the likelihood that such costs and benefits will occur. Whilst a BCA justified removal of *S. dulcamara* from the Trent, uncertainties about implementing such a policy were so significant that removal action was not taken. Similarly uncertainties about the future climate and its influence on WCR (Baker et al. 2003) led to the light management of WCR despite the BCA showing that measures were not currently economically justified.

When examining plant pests, BCA studies will often assess the primary and clearest costs and benefits, such as loss in yield or quality and use of additional pesticides. These directly affect producers whose crops are at risk. However, this is a very narrow view of the economic impacts caused by quarantine pests (Bigsby 2001). Such analysis does not take into account other potential indirect costs and benefits, secondary and tertiary effects, which may result (FAO 2001). However, measuring indirect effects on non-market goods is a difficult process and is a general weak point in many BCA studies, including the examples provided. BCA studies that evaluate decisions that may have environmental consequences often encounter such difficulties. The weakness is partly due to the complex nature of ecosystems and the difficulty in forecasting the effects of decisions regarding one part of an ecosystem and its bearing on another part of the ecosystem (Hanley 1990). Without understanding dependencies and relationships between constituents of the ecosystem, there is a considerable challenge to design economic tools that can fully quantify all impacts that stem from particular decisions. Thus there is scope for research to improve methods for measuring and incorporating secondary economic effects into BCA. By assessing the impact on producers and other sectors of the economy and on the environment, decisions would then be made for the benefit of society as a whole, not just for agricultural or horticultural producers. Unless all costs and benefits are properly valued, and considered by policy decision makers, society will not receive the optimum output from the resources available and economic inefficiency will result. Nevertheless, an alternative, pragmatic approach can be adopted in economies such as the UK, where crops provide only 0.46 % of the GDP and horticulture contributes approximately 0.25 % to GDP (*Britain 1999: the official yearbook of the United Kingdom* 1999). In such an economy it is unlikely that additional costs from specific pest impacts will feed back into the national economy to such an extent that such elaborate analyses are justified. This is not to say that within any particular sector, pest impacts would be negligible. For example, forecasts of the potential economic impact of quarantine pests can be substantial, e.g., the tobacco whitefly, *Bemisia tabaci*, would have great impact on producer costs within the UK tomato industry (Morgan and MacLeod 1996) whilst an Asian longhorn beetle, *Anoplophora glabripennis*, can cause severe impacts on hardwood urban and amenity trees with significant recreational value (MacLeod et al. 2002).

BCA is not a panacea and in addition to the weaknesses identified above, it must be recognized that in developing scenarios, it is difficult to forecast producers' behavioural responses and what action they will take when adapting to particular pests. With a large amount of uncertainty there may be some considerable variation in any benefit/cost ratio making it difficult to interpret results. Where this is the case further research may be necessary to reduce uncertainty. However, this could add significantly to the time taken to conduct BCA. Finally it is recognized that BCA often compares between choices of control or no control. As such BCA does not provide information about the marginal effect of control, i.e., what is the effect of one more or one less unit of control effort? Thus BCA does not determine what the appropriate level of control should be (FAO 2001).

There have been calls for BCA to be adopted more widely by governments when considering quarantine regulations (Robertson 2001), but BCA can never be the only basis upon which policy decisions are made, especially in relation to phytosanitary matters, due to the complex nature of ecosystems. The complex inter-relationships between species and their interaction with a changing environment make it difficult to predict the biological consequences of pest introductions. Determining their potential economic impacts is equally complicated. However, this is the challenge that faces those that work in the phytosanitary arena and it provides opportunities for economists and biologists to collaborate to overcome such difficulties.

REFERENCES

Allen, E.J. and Scott, R.K., 1992. Principles of agronomy and their application in the potato industry. *In:* Harris, P.M. ed. *The potato crop: the scientific basis for improvement*. Chapman and Hall, London, 816-881.

Baker, R.H.A., Cannon, R.J.C. and MacLeod, A., 2003. Predicting the potential distribution of alien pests in the UK under global climate change: *Diabrotica virgifera virgifera*. *In: The BCPC international congress: crop science and technology: proceedings of an international congress held at the SECC, Glasgow, Scotland, UK, 10-12 November 2003*. British Crop Protection Council, Alton, 1201-1208.

Baufeld, P., 2003. Technical dossier on pecuniary losses and costs of containment measures in high-risk areas. *In:* Vidal, S. ed. *Threat to European maize production by the invasive quarantine pest Western Corn Rootworm (Diabrotica virgifera virgifera): a new sustainable crop management approach*. EU Research Report no. QLRT-1999-01110.

Bigsby, H.R., 2001. The 'appropriate level of protection': a New Zealand perspective. *In:* Anderson, K., McRae, C. and Wilson, D. eds. *The economics of quarantine and the SPS agreement*. Centre for International Economic Studies, Adelaide, 141-163.

BPC, 2002. *Monitoring and control of the potato brown rot bacterium in irrigation water*. British Potato Council, Oxford. British Potato Council Factsheet.

Britain 1999: the official yearbook of the United Kingdom, 1999. Office for National Statistics, London.

Cannon, R.J.C., Matthews, L., Cheek, S., et al., 2005. Surveying and monitoring western corn rootworm (*Diabrotica virgifera virgifera*) in England and Wales. *In:* Alford, D.V. and Backhaus, G.F. eds. *Plant protection and plant health in Europe: introduction and spread of invasive species: symposium held at Humboldt University, Berlin, Germany, 9-11 June 2005*. British Crop Protection Council., Alton, 155-160.

CSL, 2003. *Plant pest and disease identification price guide 2003/04*. Central Science Laboratory, Sand Hutton.

Defra, 2003. *Potato brown rot: 2003 monitoring programme: final results*. Department for Environment, Food and Rural Affairs. [http://www.defra.gov.uk/planth/pbr2.htm]

EPPO, 1996. Situation of *Diabrotica virgifera* in Serbia (YU). From: International Workshop "Western Corn Rootworm in Europe 95", Gödöllö (HU), 1995-11-08. *EPPO Reporting Service,* 1, 96/006. [http://archives.eppo.org/EPPOReporting/1996/Rse-9601.doc]

EPPO, 2003. Situation of *Diabrotica virgifera virgifera* in the EPPO region. From: Papers presented at the 7th Meeting of the EPPO ad hoc Panel on *D. virgifera* held jointly with the 9th International IWGO Workshop on *D. virgifera* in Belgrade, 2002-11-03/05. *EPPO Reporting Service,* 1, 2003/001. [http://archives.eppo.org/EPPOReporting/2003/Rse-0301.doc]

EPPO, 2004. *EPPO Plant quarantine information retrieval system, v4.3*. EPPO, Paris. [http://www.eppo.org/PUBLICATIONS/pqr/pqr.htm]

European Commission, 1998. EC Directive 98/1/EC of 8 January 1998 amending certain Annexes to Council Directive 77/93/EEC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. *Official Journal of the European Communities,* L 15 (21.1.1998), 26-33. [http://eur-lex.europa.eu/LexUriServ/site/en/oj/1998/l_015/l_01519980121en00260033.pdf]

European Commission, 2000. EC Council Directive 2000/29/EC of 8 May 2000 on Protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. *Official Journal of the European Communities,* L 169/1 (10.7.2000), 1-112 and subsequent amendments. [http://europa.eu.int/eur-lex/pri/en/oj/dat/2000/l_169/l_16920000710en00010112.pdf]

FAO, 2001. Economic impacts of transboundary plant pests and animal diseases. *In: The state of food and agriculture 2001*. FAO, Rome. [http://www.fao.org/docrep/003/x9800e/x9800e14.htm]

FAO, 2003. *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms*. Secretariat of the International Plant Protection Convention FAO, Rome. ISPM no. 11. [http://www.fao.org/DOCREP/006/Y4837E/Y4837E00.HTM]

Hanley, N., 1990. Are there environmental limits to cost benefit analysis? *In:* Van den Noort, P.C. ed. *Costs and benefits of agricultural policies and projects: proceedings of the 22nd symposium of the European Association of Agricultural Economists EAAE, October 12th-14th, 1989, Amsterdam, Netherlands*. Wissenschaftsverlag Vauk, Kiel, 202-212.

HM Treasury, 1997. *Appraisal and evaluation in central government: Treasury guidance*. HMSO, London.

HM Treasury, 2003. *The green book: appraisal and evaluation in central government*. The Stationery Office Books, London. [http://greenbook.treasury.gov.uk/]

Jenkins, P.T., 1999. Trade and exotic species introductions. *In:* Sandlund, O.T., Schei, P.J. and Viken, A. eds. *Invasive species and biodiversity management: papers presented at the Norway/United Nations UN conference on alien species, held in Trondheim, Trondheim, Norway, 1-5 July 1996*. Kluwer Academic Publishers, Dordrecht, 229-235. Population and Community Biology Series no. 24.

Jones, G.D., Perrings, C.A. and MacLeod, A., 2005. The spread of *Frankliniella occidentalis* through the UK protected horticulture sector:scales and processes. *In:* Alford, D.V. and Backhaus, G.F. eds. *Plant protection and plant health in Europe: introduction and spread of invasive species, held at Humboldt University, Berlin, Germany, 9-11 June 2005*. British Crop Protection Council., Alton, 13-18.

Kawai, A., 1986. Studies on population ecology of *Thrips palmi* Karny. X. Differences in population growth on various crops. *Japanese Journal of Applied Entomology and Zoology*, 30 (1), 7-11.

Kawai, A., 1990. Control of *Thrips palmi* in Japan. *Japan Agricultural Research Quarterly*, 24 (1), 43-48.

Kehlenbeck, H., 1996. *Nutzen-Kosten-Untersuchung "Auswirkungen der EG-Binnenmarktregelungen im Bereich der Pflanzengesundheit"*. Bonn, Köllen. Schriftenreihe des Bundesministers für Ernährung, Landwirtschaft und Forsten. Angewandte Wissenschaft no. 456.

Krystynak, R., 1991. The economic importance of plant protection programs in Canada. *Canadian Farm Economics*, 23 (1), 41-47.

Levine, J.M. and D'Antonio, C.M., 2003. Forecasting biological invasions with increasing international trade. *Conservation Biology*, 17 (1), 322-326.

MacKerron, D.K.L., 1993. The benefits to be gained from irrigation. *In:* Bailey, R.J. ed. *Irrigating potatoes*. Cranfield Press, Cranfield, 1-11. UK Irrigation Association Technical Monograph no. 4.

MacLeod, A., 2004. *Cost-benefit analysis of a campaign to remove Solanum dulcamara and eradicate Ralstonia solanacearum from the River Trent, and to end the current campaign on the River Witham/Fossdyke Navigation canal*. Unpublished Report to Defra Plant Health Division.

MacLeod, A. and Baker, R.H.A., 1998. Pest risk analysis to support and strengthen legislative control of a quarantine thrips: the case of *Thrips palmi*. *In: The BCPC international congress: crop science and technology: proceedings of an international conference, Brighton, UK, 16-19 November 1998. Volume 1*. British Crop Protection Council, Farnham, 199-204.

MacLeod, A., Baker, R.H.A. and Cannon, R.J.C., 2005. Costs and benefits of European Community (EC) measures against invasive alien species: current and future impacts of *Diabrotica virgifera virgifera* in England & Wales. *In:* Alford, D. and Backhaus, G. eds. *Introduction and spread of invasive species:symposium, 9-11 June 2005, Berlin, Germany*. British Crop Protection Enterprises. BCPC Symposium Proceedings no. 81.

MacLeod, A., Evans, H.F. and Baker, R.H.A., 2002. An analysis of pest risk from an Asian longhorn beetle (*Anoplophora glabripennis*) to hardwood trees in the European community. *Crop Protection*, 21 (8), 635-645.

MacLeod, A., Head, J. and Gaunt, A., 2004. An assessment of the potential economic impact of *Thrips palmi* on horticulture in England and the significance of a successful eradication campaign. *Crop Protection*, 23 (7), 601-610.

Morgan, D. and MacLeod, A., 1996. Assessing the economic threat of *Bemisia tabaci* and tomato yellow leaf curl virus to the tomato industry in England and Wales. *In: The BCPC international congress: crop science and technology: proceedings of an international conference, Brighton, UK, 18-21 November 1996. Volume 3*. British Crop Protection Council, Farnham, 1077-1082.

Mumford, J., Temple, M., Quinlan, M., et al., 2000. *Economic policy evaluation of MAFF's plant health programme: report to Ministry of Agriculture Fisheries and Food*. ADAS Consulting, London. [http://statistics.defra.gov.uk/esg/evaluation/planth/default.asp]

Nagai, K., 1991. Integrated control programs for *Thrips palmi* on eggplants (*Solanum melongena* L.) in an open field. *Japanese Journal of Applied Entomology and Zoology*, 35 (4), 283-289.

Nix, J., 2003. *Farm management pocketbook*. 34th edn. Wye College, London.

Nuessly, G.S. and Nagata, R.T., 1993. Pepper varietal response to thrips feeding. *In:* Parker, B.L., Skinner, M. and Lewis, T. eds. *Thrips biology and management: proceedings of the 1993 international conference on Thysanoptera*. Plenum Publishing, London, 115-118.

Oerke, E.C., Dehne, H.W., Schönbeck, F., et al., 1994. *Crop production and crop protection: estimated losses in major food and cash crops*. Elsevier, Amsterdam.

Pemberton, A.W., 1988. Quarantine: the use of cost:benefit analysis in the development of MAFF plant health policy. *In:* Clifford, B.C. and Lester, E. eds. *Control of plant diseases: costs and benefits*. Blackwell Scientific Publications, Oxford, 195-202.

Rautapaa, J., 1984. Costs and benefits of quarantine measures against Liriomyza trifolii in Finland. *EPPO Bulletin*, 14 (3), 343-347.

Robertson, D., 2001. Summing up. *In:* Anderson, K., MacRae, C. and Wilson, D. eds. *The economics of quarantine and the SPS agreement*. Centre for International Economic Studies, Adelaide, 387-395.

Smith, I.M., MacNamara, D.G., Scott, P.R., et al. (eds.), 1997. *Quarantine pests for Europe: data sheets on quarantine pests for the European Union and for the European and Mediterranean Plant Protection Organization*. 2nd edn. CAB International, Wallingford.

Sumner, D.A., 2003. Exotic pests and public policy for biosecurity: an introduction and overview. *In:* Sumner, D.A. ed. *Exotic pests and diseases: biology, economics and public policy for biosecurity*. Iowa State Press, Ames, 3-6.

Vidal, S., 2003. *Threat to European maize production by the invasive quarantine pest Western Corn Rootworm (Diabrotica virgifera virgifera): a new sustainable crop management approach*. EU Research Report no. QLRT-1999-01110.

Vierbergen, G., 1996. After introduction of *Frankliniella occidentalis* in Europe: prevention of establishment of *Thrips palmi* (Thysanoptera: Thripidae). *Acta Phytopathologica et Entomologica Hungarica*, 31 (3/4), 267-274.