

Use of decision trees in analysis of the potential gain from approved zone status under the ETJ shellfish health regime.

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Introduction

Britain has traditionally tried to protect its livestock, fish and shellfish production industries from many serious diseases by restricting imports of live animals- fish and shellfish to those from countries free of specified important diseases affecting particular classes of stock. Although the primary aim of the European Union has been to remove restrictions on trade between member states, the restriction of movements of stock to avoid the introduction of serious diseases into disease-free areas has also been enshrined in EU legislation. For aquaculture animals, the provisions enabling such controls were introduced in 1991 in directive 91/67 of the Council of the European Communities (OJ No. L 46/1). These allowed for the delineation of 'approved zones' free of one or more specified diseases within which introductions of susceptible species from outwith the approved zones can be banned. This paper considers the economics of establishing an approved zone in Great Britain for the diseases *Marteilia refringens* and *Bonamia ostreae*, to which the native flat oyster, *Ostrea edulis*, is susceptible.

The granting of an approved zone requires submission of evidence to the Commission, from three years of intensive testing to establish the disease-free status of the area. In Great Britain, this process of testing of shellfish in relation to the diseases was completed in 1995 and the decision was to be made whether to proceed with an application for approved zone status for these diseases.

The maintenance of an approved zone involves costs for the industry and national government in terms of additional monitoring of shellfish health status and the monitoring and application of controls on Imports. The bearing of these costs provides an uncertain gain in terms of a reduction in the risk of introduction of the disease(s)

into the area, and consequent losses, both of current shellfish stocks and future production of shellfish.

An appropriate methodology for analysing a decision of this sort, in which risk and uncertainty are central factors, is provided by statistical decision theory (Schlaifer 1959. Charnoff and Moses 1959. Raiffa and Schlaifer 1961) and specifically the use of decision trees. These have been found useful in a very wide range of applications from medicine (Keeler 1995) to accounting (Siedel 1991) to American football (Stoughton 1986). From the literature, it is clear that their main use has been in the business context (Coles and Rowley 1995, Boys 1990, Brookfield 1988). There is little in the literature to indicate their use in assisting national policy decision-making, yet risk and uncertainty is just as likely to be important in national decisions as business decisions. In this paper, the use of decision trees to analyse the potential gain to Britain from approved zone status for *Marteilia* and *Bonamia* is discussed. Particular problems addressed are those relating to the assessment of probabilities of disease outbreak, and issues relating to the time-frame of the analysis, given that the costs of enforcing an approved zone may be discontinued at any point (along with the approved zone), whereas the losses incurred in the event of an outbreak of the disease may continue for many years.

Clarification of the Decision Problem.

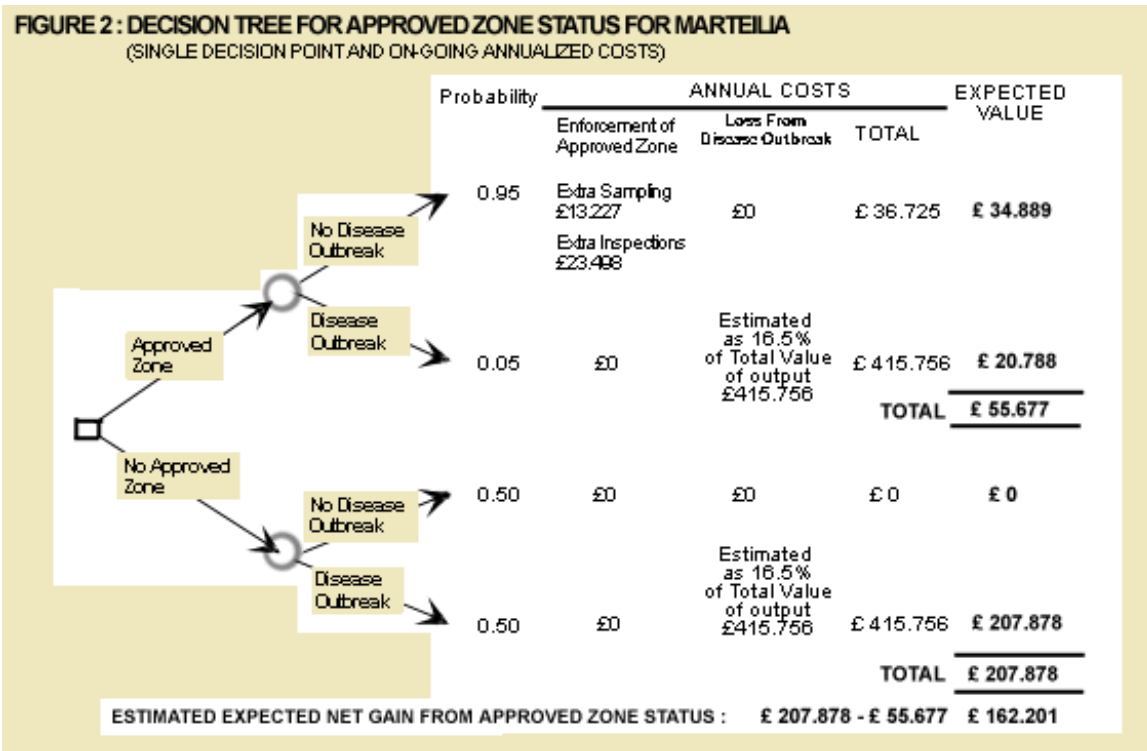
Whether or not the full concepts of statistical decision theory are to be applied to a decision problem, setting it down in the form of a decision tree can be helpful in providing a clear visual definition of the structure of the decision situation (Boys 1990). In the application considered in this paper, the decision problem initially required some clarification, in that application for approved zone status was being considered in relation to two diseases. So, were the two to be considered jointly or as separate decisions? The conclusion was that the possible approved zones constituted two separate decisions, but they were linked, in that most of the costs of monitoring shellfish health status and monitoring and controlling imports of shellfish for re-immersion would be incurred whether the approved zone were *Marteilia* or *Bonamia* alone, or for both. However, since there are some additional monitoring costs for *Bonamia* (sampling being required twice per annum for *Bonamia*, but only once for *Marteilia*) and since the potential loss in the event of an outbreak of the disease would be much greater in the case of *Marteilia* ^{1[1]}, the logical approach

^{1[1]} (a) because the evidence indicates more serious effects on production of the susceptible species *Ostrea edulis*, the native oyster, as a result of infection by *Marteilia* than infection by *Bonamia* and (b) because some of the main native oyster producing areas of Southern England would be excluded from an approved zone for *Bonamia* as the disease has been found there.

was first to assess the case for an approved zone Marteilia. The case for seeking approved zone status for *Bonamia*, in those areas free from the disease, would then be assessed as a second stage of the analysis. For the purpose here of examining the decision tree approach and methodological issues, it will be sufficient to consider the case for seeking an approved zone for Marteilia alone.

Initial simple decision tree based on a single decision point and on-going annualised costs.

The problem is of an insurance type, in which costs are incurred in applying the measures required for approved zone status in order to avoid the losses which would arise from the occurrence of the disease, in terms of reduced production. However, freedom from the disease is not guaranteed by the measures adopted with approved zone status. There is only a reduction in the likelihood of an outbreak. The basic structure of the decision tree for this problem is illustrated in Figure 1.



The square node represents the alternative choices of seeking or not seeking approved zone status. The branches emanating from the round nodes represent alternative uncertain events determining the outcome. The approach of statistical decision theory is that the outcome on each branch is valued and weighted by its probability. The total of probabilities sums to one for each of the initial choices. The sum of the values weighted by those probabilities is then the 'expected' value for

that choice and the solution is to choose the alternative with the most favourable expected value -- in this case, the lowest expected costs.

Evidence from the outbreak *Marteilia* in France in the late 1960s and early 1970s suggests that the production of native oysters is greatly reduced for an indefinite period (Alderman 1979), certainly extending to over twenty years. Hence, an initial simple approach to the problem was to view the policy and its outcome in terms of annual costs, regarded as being in perpetuity. Thus, for the topmost branch in Figure 1, i.e. an approved zone and no disease outbreak, the annual costs are those required to maintain and enforce the approved zone. On the other hand, the annual cost on the bottom branch of the tree is the estimated reduction in GDP due to the lost oyster production. If there is an outbreak of the disease despite the operation of an approved zone, the views of industry experts were that it would be likely TO spread fairly rapidly through the main production areas as a result of shell movements. Thus, the approved zone is assumed to be abandoned in the event of disease outbreak, and the costs on this branch have been put at the same level as on the bottom branch. There are zero costs on the fourth branch representing the situation if no approved zone is sought but Britain remains free of the disease nevertheless.

Statistical decision theory allows the likelihood of uncertain events, for which there are no records of previous occurrence from which to derive objective probabilities, to be expressed as subjective probabilities, based on whatever related information and experience is available. In relation to the likelihood of an outbreak of *Marteilia* in Britain, the probabilities in Figure 1 were derived from discussions with marine scientists with knowledge of the disease, and also with those having intimate knowledge of the oyster industry. These discussions were put in terms of the probability of an outbreak occurring within a reasonable time horizon, namely ten years.

The annualised cost model, as presented in Figure 1, indicates that the expected costs of maintaining an approved zone are lower than the expected costs arising from not having an approved zone.

The analysis in terms of on-going annual costs is a simplification in that it ignores the question of when the outbreak of a disease might first occur²[2]. Thus, it may be considered to overestimate the losses from occurrence of the disease inasmuch as there may be some years without those losses before the outbreak occurs. On the other hand, no costs for enforcement of an approved zone have been included on the branch where an approved zone is adopted but subsequently given up because of disease outbreak. The effects of these simplifications tend to balance one another and, in the long-term context, are minor anyway. However, the analysis is open to theoretical criticism on these grounds. A more rigorous analysis was therefore developed, based on an annual decision model.

Analysis based on an Annual Decision Model.

(2) Establishment and maintenance of an approved disease-free status for an area is perceived by many in the industry to offer some marketing advantage, which might extend by association to the whole shellfish industry, not just the native oyster segment, certainly for hatcheries and sellers of part-grown stock for export from Britain. Potential markets in other approved areas would be unavailable, or access made more difficult, if GB were not an approved zone. Currently the impact of this would mainly depend on whether Eire, Northern Ireland, and Guernsey had approved status. Even a gain of just 0.1 per cent in the first-hand sale value of shellfish produced in GB as a result of approved zone status would almost cover the costs of enforcing the approved zone.

In this model both the potential outbreak of the disease and the decision whether to maintain approved zone status are considered on a year-by-year basis, as illustrated in the decision tree in Figure 2. As before, however, the spread of the disease is assumed rapid and, for convenience, the approved zone is assumed to be abandoned in the year after the occurrence of the disease.

Annual Probabilities

In order to analyse this decision tree it is necessary to obtain subjective probabilities for the likelihood of an occurrence of the disease within the next year, or any subsequent year, either with or without the controls applied in an approved zone. To try to estimate such probabilities directly is virtually impossible. It was difficult enough to try to get the people with relevant knowledge and experience to express as a numerical probability the likelihood of an outbreak of the disease occurring in the medium term (i.e. ten years). To ask them to agree on the very small probability of an outbreak in a given year would not have been feasible. However, given that there is no particular reason to expect the probability to vary between different years, the multiplication law of joint probabilities allows the probability for an outbreak in any year to be derived from the probability of an outbreak over a ten year period --

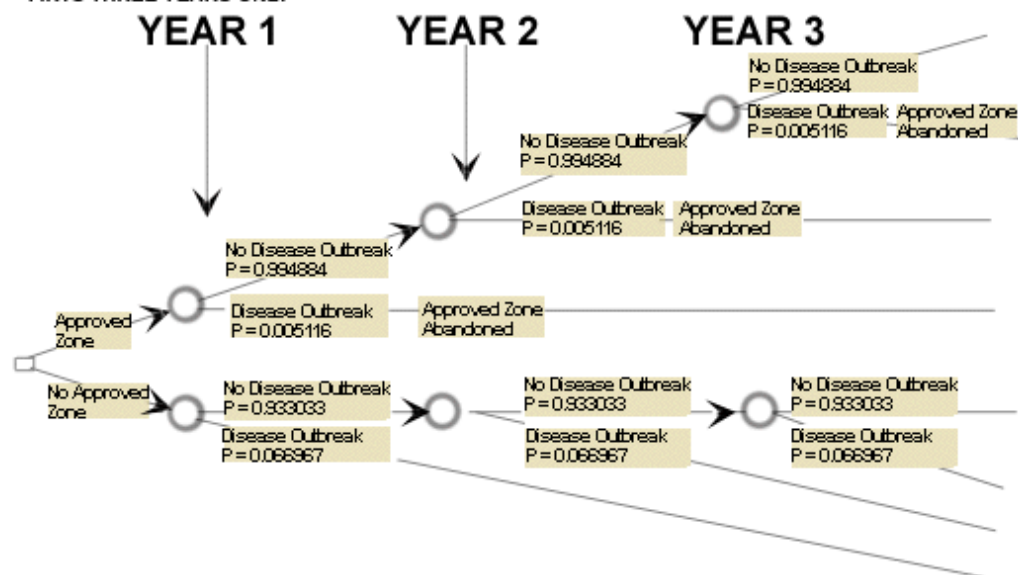
i.e. -- $P_a = [P_t]^{(1/10)}$

where p_a = annual probability

p_t = ten year probability.

Thus, part of the initial simplified annualised cost method provided the basis for making the more rigorous time-dependent analysis.

**FIGURE 2 : DECISION TREE FOR APPROVED ZONE STATUS FOR MARTEILIA - ANNUAL DECISION MODEL
FIRSTS THREE YEARS ONLY**



In Table 1, the results of an analysis over a ten-year time horizon are shown. The combined probabilities for no occurrence of the disease, both with and without an

approved zone can be seen to be coincident with those in the initial analysis in Figure I.

The Time Factor.

To complete the analysis on an annual decision basis, the time factor was included by discounting all future costs to present values. The present value for each branch of the tree can then be multiplied by the combined probability of that branch, thus giving the 'expected' value for that outcome. Finally by adding the expected values on all of the branches emanating from the initial decision to adopt an approved zone, the expected present value of that choice was obtained and can be compared with the similarly calculated expected present value for the alternative of no approved zone as shown in Table 1.

Table 1: Analysis of decision tree for approved zone status for Marteilia based on annual decision model run over 10-year period Probabilities, Discounted Costs, Expected Values, and Net Gain.

Approved Zone	Combined Probability	Sum of Annual Costs Discounted to Present Value	Expected Value of Discounted Costs
No Disease Outbreak	0.950000	£270.297	£256.782
Outbreak in Year 10	0.004885	£2,751.327	£13,441
Outbreak in Year 9	0.004911	£2,976.337	£14.615
Outbreak n Year 8	0.004936	£3,214.632	£15.867
Outbreak in Year 7	0.004961	£3,467.382	£17.202
Outbreak in Year 6	0.004987	£3,735.339	£18.627
Outbreak n Year 5	0.005012	£4,019,249	£20.146
Outbreak n Year 4	0.005038	£4,320,268	£21.766
Outbreak n Year 3	0.005064	£4,639.547	£23.495
Outbreak n Year 2	0.005090	£4,977.817	£25.337
Outbreak n Year 1	0.005116	£5,336,21 7	£27.301
TOTAL	1.000000		£454.579

No Approved Zone			
No Disease Outbreak	0.500000	£0	£0
Outbreak in Year 10	0.035887	£2,481.030	£89.036

Outbreak in Year 9	0.038462	£2,726.547	£104.870
Outbreak in Year 8	0.041223	£2,986,579	£123.116
Outbreak in Year 7	0.044182	£3,262.371	£144.137
Outbreak in Year 6	0.047353	£3,554,752	£168.328
Outbreak in Year 5	0.050752	£3,864.551	£196,1 32
Outbreak in Year 4	0.054394	£4,193.013	£228.075
Outbreak in Year 3	0.058298	£4,541.381	£264.754
Outbreak in Year 2	0.062482	£4,910.486	£306.819
Outbreak in Year 1	0.066967	£5,301 571	£355.030
TOTAL	1.000000		£1,980.297

NET GAIN FROM APPROVED ZONE

Present Value = £3,141,471 - £636,016 = £2,505,453

Annual Value * = £207,299

* i.e. net present Value converted to 10 year annuity at 6% discount rate.

There was, however, a difficulty in deciding what costs to include. Beyond the ten-year time horizon, no assumption was made as to further continuance of an approved zone, so only ten years of the costs of maintaining the approved zone were included on the branch representing adoption of an approved zone and no occurrence of the disease. But an outbreak of the disease would involve the costs arising from a loss of production extending many years into the future (25 years were assumed here). Although the present values for the more distant years are greatly reduced by the discounting process, this analysis, with costs for only ten years on one side but costs extending up to 25 years further on the other side seemed innately questionable, although it can certainly be argued that this correctly reflects this type of insurance problem where the oyster production lost in the event of disease outbreak cannot be re-established.

To address this concern a further analysis was carried out, in which the period covered was extended to 25 years, beyond which the discounting reduces any continuing costs to negligible significance. The results of this analysis are shown in Table 2. The present value of the gain from adopting an approved zone works out quite similar to that shown in the 10-year analysis in Table 1, but when converted to an annuity for the longer 25-year period, the annual gain is indicated to be just over £130,000, compared with £207,000 obtained from the 10-year analysis. The annual gain calculated in the initial simple analysis lies between these two values.

Table 2: Analysis of decision tree for approved zone status for *Marteilia* based on annual decision model, run over 25-year period probabilities, discounted costs, expected values and net gain.

Approved Zone	Combined Probability product of all probabilities on branch)	Sum of Annual Costs Discounted to Present Value (6% discount rate)	Expected Value of Discounted Costs present value x probability
No Disease Outbreak	0.879648	£270.297	£237.766
Outbreak in Year 25	0.004524	£566.658	£2.563
Outbreak in Year 24	0.004547	£660.123	£3.001
Outbreak in Year 23	0.004570	£759.296	£3.470
Outbreak in Year 22	0.004594	£864.560	£3.972
Outbreak in Year 21	0.004617	£976.298	£4.508
Outbreak in Year 20	0.004641	£1,095.304	£5.083
Outbreak in Year 19	0.004665	£1,221.542	£5.698
Outbreak in Year 18	0.004659	£1,354.972	£6.353
Outbreak in Year 17	0.004713	£1,495.554	£7.049
Outbreak in Year 16	0.004737	£1,645.317	£7.794
Outbreak in Year 15	0.004762	£1,803.801	£8.589
Outbreak in year 14	0.004786	£1,971.785	£9.437
Outbreak in Year 13	0.004811	£2,150.047	£10.343
Outbreak in Year 12	0.004836	£2,338.948	£11.310
Outbreak in Year 11	0.004860	£2,539.256	£12.342
Outbreak in Year 10	0.004885	£2,751.327	£13.441
Outbreak in Year 9	0.004911	£2,976.337	£14.615
Outbreak in Year 8	0.004936	£3,214.632	£15.867
Outbreak in Year 7	0.004961	£3,467.382	£17.202
Outbreak in Year 6	0.004987	£3,735.339	£18.627
Outbreak in Year 5	0.005012	£4,019.249	£20.146
Outbreak in year 4	0.005038	£4,320.268	£21.766
Outbreak in Year 3	0.005064	£4,639.547	£23.495
Outbreak in Year 2	0.005090	£4,977.817	£25.337
Outbreak in Year 1	0.005116	£5,336.217	£27.301
TOTAL	1.000000		£537.077

TABLE 2 (continued)

No Approved Zone	Combined Probability product of all probabilities on branch)	Sum of Annual Costs Discounted to Present Value (6% discount rate)	Expected Value of Discounted Costs present value probability
No Disease Outbreak	0.176777	£0	£0
Outbreak in Year 25	0.012688	£97,193	£1.233
Outbreak in Year 24	0.013599	£1 99,215	£2.709
Outbreak in Year 23	0.014575	£307,459	£4.481
Outbreak in Year 22	0.015621	£422.337	£6.597
Outbreak in Year 21	0.016742	£544.266	£9,112
Outbreak in Year 20	0.017943	£674.075	£12.095
Outbreak in Year 19	0.019231	£81 1,764	£15.611
Outbreak in Year 18	0.020612	£957.332	£19.732
Outbreak in Year 17	0.022091	£1,110.780	£24.538
Outbreak in Year 16	0.023676	£1 274.181	£30,168
Outbreak in Year 15	0.025376	£1,447.122	£36.722

Outbreak in year 14	0.027197	£1.630.430	£44.343
Outbreak in Year 13	0.029149	£1.824.936	£53.195
Outbreak in Year 12	0.031241	£2.031.054	£63.453
Outbreak in Year 11	0.033484	£2.249,614	£75.325
Outbreak in Year 10	0.035887	£2.481 .030	£89.036
Outbreak in Year 9	0.038462	£2,726,547	£104.870
Outbreak in Year 8	0.041223	£2.986.579	£123.116
Outbreak in Year 7	0.044182	£3,262.371	£144.137
Outbreak in Year 6	0.047353	£3,554,752	£168.328
Outbreak in Year 5	0.050752	£3.864.551	£196.132
Outbreak in Year 4	0.054394	£4,1 93,013	£228.075
Outbreak in Year 3	0.058298	£4.541.381	£264.754
Outbreak in Year 2	0.062482	£4.910.486	£306.819
Outbreak in Year 1	0.066967	£5.301 571	£355.030
TOTAL	1.000000		£2.379,611

Net gain from approved zone:

present value £1.667,337

Annual Value * £130.465

** i.e. Net Present Value converted to 25 year annuity at 6% discount rate*

Given the high level of uncertainty relating to many factors in the analysis, the point values should not to be viewed as of primary importance. They have to be regarded as uncertain pointers towards the general level of gain or loss. What may give confidence in the general conclusion of the analysis is the extent to which the results may be relatively insensitive to adjustment of some of the main uncertain parameters entering into the calculation. In Tables 3, 4 and 5 sensitivity analyses are presented for each of the three models described. They examine the sensitivity to varying the assumptions on the three most important uncertain factors entering into the calculations:

- (i) the reduction in the estimated probability of an outbreak of the disease if an approved zone is enforced.
- (ii) the level of economic loss assumed to result from an outbreak of the disease, expressed as a percentage of the total value of output of native oyster production in Britain.
- (iii) the total costs of enforcement of an approved zone for Marteilia.

These tables show that one or more of these values would need to be substantially different from our original estimate(s) before the conclusions would be altered from those first indicated (i.e. that there is likely to be a net gain from enforcement of an approved zone for Marteilia in Britain) and there is very little difference between the three analyses in that respect - e.g. it is shown in all three analyses that the reduction in the probability of an outbreak of the disease which accrues from enforcement of the approved zone would have to be less than 0.15 rather than the original estimate of 0.45, before the net gain indicated would revert to a net loss (unless a very low assumption is also made on the loss in GDP which would be incurred as a result of the disease outbreak).

Conclusion

Decision trees can provide a useful approach to the analysis of alternative options involving uncertain outcomes- not only in business management, but also in the evaluation of alternative policy options for government. The estimation of probabilities for uncertain events presents difficulties, particularly for events which have a very low likelihood of occurrence. However, as illustrated in this paper with respect to estimating the very small probability of an outbreak of *Marteilia* in Britain within any year, probability theory can help to overcome or minimise these.

The analysis presented here highlights a point of difficulty regarding the number of years covered in the decision tree evaluation when examining a problem in which some branches have outcomes with long-term effects. However, it also indicates that even a fairly simplistic decision tree model can be adequate to determine the appropriate conclusion, with sensitivity analysis offering possible reassurance as to the robustness of that conclusion within the inevitably uncertain parameters determining it.

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Table 3: Sensitivity analyses for simple annualised cost model

Original Estimate			
Total Coats of Enforcement	£20.000	£36.725	£50.000
£75.000			
Estimated Expected Annual Net Gain from Approved Zone Statua	£1 68,090	£152.202	£1 39,590
£115.840			

% of Total Value of Output		Original Estimate				
Lest by Disease Outbreak		33%	25%	16.5%	10%	6%
Reduction n Probability of Output due to Approved Zone		Enforcement	Estimated Expected	Annual Net Gain	from Approved Zone Statua	
Original Estimate	0.50	£380.867	£280.078	£172.989	£91.098	£40.704
	0.45	£339.292	£248.581	£1527202	£78.500	£33.144
	0.35	£256.141	£185.588	£110.626	£53.302	£18.026
	0.25	£172.989	£122.595	£69.051	£28.105	£2.908
	0.15	£89.838	£59.602	£27.475	£2.908	(£12.211)
	0.05	£6.687	<£3.392>	<£14.101>	(£22.290 >	(£27.329>

Table 4: Sensitivity analyses for annual decision model over 10 year policy horizon

Original Estimate						
Total Coats of Enforcement	£20.000	£36.725	£50.000	£75.000		
Estimated Expected Annual Net Gain						
from Approved Zone Statua	£223.684	£207.299	£194.293	£169.800		

				Original Estimate		
% of Total Value of Output Lest by Disease Outbreak		33%	25%	16.5%	10%	6%
Reduction n Probability of Output due to Approved Zone	Enforcement	Estimated	Expected	Annual Net Gain	from Approved Zone Statua	
Original Estimate	0.50	£508.391	£376.422	£236.206	£128.982	£31.110
	0.45	£450.576	£332.624	£207.299	£111.462	£25,1 14
	0.35	£377.880	£247.248	£150.951	£77.312	£12.774
	0.25	£228.289	£164.224	£96.155	£44.102	(£110)
	0.15	£121.131	£83.049	£42.579	£11.632	£13.604
	0.05	£15.969	£3.375	(£10.005)	(£20.237)	(£26.534)

Table 5 : Sensitivity analyses for annual decision model over 25 year policy horizon

Original				
Estimate				
Total Coats of Enforcement	£20.000	£36.725	£50.000	£75.000
Estimated Expected Annual Net Gain				
from Approved Zone Statua	£146.443	£130.465	£117.782	£93.897

Original						
% of Total Value of Output	Estimate					
Lest by Disease Outbreak	33%	25%	16.5%	10%	6%	
Reduction n Probability of Output due to Approved Zone	Enforcement	Estimated	Expected	Annual Net Gain		from Approved Zone Statua
	0.50	£328.988	£240.728	£146.961	£75.240	£31.110
Original Estimate	0.45	£296.015	£215.748	£130,466	£65.248	£25,1 14
	0.35	£228.143	£164.330	£96.529	£44.681	£12.774
	0.25	£157.278	£110.645	£61.096	£23.207	(£110)
	0.15	£83.063	£54.421	£23.988	£717	£13.604
	0.05	£5.240	(£4.536)	(£14.923)	(£22.866)	(£27.754)