A COMPARISON OF ALTERNATIVE MOSQUITO ABATEMENT METHODS USING BENEFIT-COST ANALYSIS[1]

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ABSTRACT. Benefit-cost analysis can be used to evaluate and compare projects that involve alternative mosquito control methods. A comparison of two such projects in Chatham County, GA indicated that source reduction was a contributing factor in the reduction of ground adulticide applications and quantities, and annual female densities per light-trap night of the predominant saltmarsh mosquito species in the area. Net benefits realized from source reduction were $591,319 as opposed to $409,823 and discounted net benefits were $377,729 versus $284,511 (source reduction project vs. chemical control project) demonstrating the relative effectiveness of the source reduction project in our application. Because of unique differences between areas and projects, generalizations of the above conclusion are cautioned, although the approach is easily adapted.

INTRODUCTION

Interest and concern over the relative performance of alternative mosquito abatement methods was rekindled following publication of a somewhat controversial study in 1975 (DeBord et al. 1975, Carlson and DeBord 1976). The results contradicted commonly held beliefs among mosquito control district (MCD) directors and mosquito control researchers alike, concerning the cost efficacy of two basic control measures, chemical control and source reduction. The former relies upon larvicide and adulticide materials to reduce mosquito population densities, while the latter involves the physical alteration of wetland and other areas, e.g., ditching and pond construction to reduce mosquito breeding sites.

The conclusions reached by DeBord et al. (1975) were that chemical control measures were more cost effective in controlling mosquitoes than source reduction methods, based on their analysis of annual data for 30 MCDs along the East Coast. A similar study which examined three MCDs in California reached contrary results, concluding that source reduction methods (mainly ditch construction) were more cost effective than chemical control methods in controlling *Aedes nigromaculis* (Ludlow) and *Culex tarsalis* Coq. (Sarhan et al. 1979, 1981). In a review of the DeBord et al. study, Langham and Lanier (1981) pointed out inadequacies in the use and interpretation of the data which caused the results to be biased towards chemical control, and hence, the reason why the conclusions were contradictory. In two other studies (Hansen et al. 1976, Shisler et al. 1979) average control costs (per unit costs) were compared between source reduction and larvicide control methods, illustrating the per-unit cost-effectiveness of source reduction over chemical control.

However, the above studies are limited in their usefulness when it comes to evaluating projects based on alternative control methods, although they provide point estimates of these control methods. The point we wish to emphasize is that information about point estimates of costs (e.g., annual per acre costs) are sometimes not sufficient to assist in the choice between projects that involve alternative control methods. To compare adequately and evaluate projects the focus should encompass the control technology, anticipated costs, effective life of the control methods, and project outcomes, involving both project effectiveness and expected benefits.

The approach in this paper differs from the previous research in that we evaluate both benefits and costs to compare a project involving chemical control with one involving source reduction over the life of the projects. Special attention is paid to the quality of project outcomes. A traditional benefit-cost approach is used to compare and evaluate both projects. The concept of economic benefit measures is also examined and our earlier treatment of economic benefits (Ofiara and Allison 1985) is advanced in this paper.

BENEFIT-COST METHODOLOGY

In order to evaluate benefits and costs among projects that involve capital outlays, i.e., investment decisions, benefit-cost analysis is commonly used among economists. It is most appropriate when both benefits and costs

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associated with a project are considered. The corresponding decision criteria allow for a rational judgment in choosing one project over another. Cost-effectiveness, on the other hand, ignores economic benefits and is used to determine the least-cost way to achieve a given objective.

Benefit-cost analysis allows evaluation of present and future dollars via discounting since most projects involve a time period. The basic present-value (PV) formula for benefit-cost analysis is:

$$1)\ PV = -C_o + \sum_{i=i}^{n} \frac{(B - C)_i}{(1 + r)^i},$$

where C_0 refers to the initial cost outlay (e.g., purchase of necessary machinery), B the benefits in each period, C the costs in each period, r the discount rate, and n the time stream (Just et al. 1982:297, Gittinger 1972:98, Mishan 1976:175). The present value of net benefits (benefits less costs, discounted) is the appropriate measure for comparing projects (e.g., chemical control versus source reduction) over time given equal scale (project size) and time period. The decision criterion is to select that project with the maximum of net benefits over time.

Benefit-cost analysis is quite flexible in handling a variety of situations that can occur in comparing projects. When time streams among projects are not equal, the procedure is to transform the time streams so that they are equivalent. This is easily accomplished by using a least common denominator (LCD), (e.g., a 3-year and 5-year project have a LCD of 15 years). When projects differ in scale, comparisons become complicated, and the use of a ratio of discounted benefits to discounted costs then becomes useful only when no extreme variation in scale is present (see Eckstein 1958, Mishan 1976 for a treatment of the scale issue).

Choice of an appropriate discount rate is also a concern to the analyst and has received considerable attention from economists (Bohm 1976, Mishan 1976, Just et al. 1982). Generally, real discount rates are used when net benefits are specified in constant dollars (i.e., after inflationary effects are removed); and nominal discount rates correspond to net benefits specified in current dollars (Just et al. 1982). Real rates of discount from empirical economic studies range 0–4% and nominal rates range 8–16% (Just et al. 1982:305–306). In distinguishing between constant dollars (real terms) and current dollars (nominal terms), it is helpful to note that constant dollars are current dollars *adjusted* for inflation. In sum, the tasks facing the analyst are to identify benefit and cost items, quantify and value these benefit-cost items, choose a time horizon and discount rate, and face an investment constraint.

CONCEPT AND MEASURE OF BENEFITS

Identification of benefit and cost items as well as valuation can become difficult. Benefits and costs can be both direct and indirect. The former refers to any benefits and costs that result from the project (e.g., mosquito control) to the investment company (here, the MCD). Indirect benefits and costs are more subtle and can be thought of as any effects that result from mosquito control and do not accrue to the MCD, that is, only benefits and costs that accrue to society. Additionally, economists sometimes consider both private and social benefits and costs. These arise when economists consider the resulting effects a project will have on society. If these effects are equivalent to the effects that accrue to the MCD, then, there is no divergence. An example of social costs (negative benefits) could arise where insecticides have detrimental effects on the environment, e.g., pollution (for further discussion of these concepts see Bohm 1976, Mishan 1976, Gittinger 1972).

Both chemical control and source reduction projects can realize benefits. Benefits in an economic sense are usually measured by the area under a demand curve for a market good. Points along a demand curve reflect amounts people would be willing to pay (WTP) rather than forgo consumption of the good in question, thus, the area under demand is a representative measure of total benefits (Bohm 1976, Mishan 1976, Just et al. 1982). Considering a specific price-quantity combination, total costs are represented by the area under demand where the demand curve is intersected by a price line. In economics theory, market price of a commodity is synonymous to costs for an individual consumer. The difference between total benefits and costs define net benefits, and is referred to as consumers surplus, that is, a surplus that accrues to consumers as a net economic benefit (the above concepts were illustrated in an earlier paper, see Ofiara and Allison 1986:280–281). Although, the concept of consumer surplus may appear straightforward, economists have debated over its appropriateness as a benefit measure for some time (Just et al. 1982 and Willig 1976 summarize this debate). Recent work has focused on operational techniques to calculate exact welfare measures from demand curves (Hausman 1981, Bergland and Randall 1984).

However, for goods such as public mosquito control that are characterized by an absence of market conditions, the WTP concept is still appropriate although benefit estimation becomes more complicated. Demand and the associated value for this type of good are not determined in the usual manner as for market goods because price-quantity data are absent. Economists have labored over the past two decades in devising and testing various techniques that can be used to assess the value and determine demand for nonmarket goods (see Hueth and Strong 1984, Cummings et al. 1986 for recent evaluations of nonmarket techniques).

The contingent market valuation (CMV) approach is but one technique. This technique is based on the premise of a realistically designed, though hypothetical market. An individual is asked to reveal preferences in the form of a bid (maximum amount willing to pay) contingent on the availability of the good in question. Commonly the level of the good is changed in increments and the individual is asked to reveal a corresponding bid at each increment. In a previous demonstration project, the CMV technique was used to value public mosquito control (Ofiara and Allison 1986).

CASE STUDY

Two areas were selected for this comparison with similar characteristics (e.g., proximity to saltmarsh areas, size, population, etc.) and with mosquito density influences from internal sources with minimal influence from external sources. Cost data, ground adulticide records and female mosquito population densities were obtained from the Chatham County Mosquito Control Commission (CCMCC), Savannah, GA. The community of Thunderbolt served to represent a chemical control project and Isle of Hope a source reduction project.

In this application, benefits were measured on the basis of WTP criteria (i.e., the area under a demand curve), and represent direct benefits to society. Costs represent direct, private costs only (i.e., program costs, maintenance costs), not external costs that arise when private and social costs diverge, e.g., pollution of the saltmarsh environment from pesticides. Because MCDs presently use low impact pesticides: insect growth regulators, ultra low volume formulations, and biological control material, we expect current impacts on the saltmarsh environment to be negligible in recent times. However, this issue would require a separate study to address and is beyond the scope of this paper. Additionally, the PV of net benefits formula, equation (1), used in this application was modified, whereby C_0 was assumed zero, i.e., the necessary machinery and equipment have been already acquired and the costs realized, hence, there were no initial cost outlays in either project.

During the period 1962–83, Thunderbolt mainly underwent chemical control efforts, while Isle of Hope received both chemical control and source reduction efforts (see Fig. 1, Ofiara and Allison 1985). Isle of Hope is located across a tidal river from the leeward side of Skidaway Island so that source reduction projects on Skidaway Island assisted in controlling saltmarsh mosquitoes at Isle of Hope. Ditching projects of saltmarsh areas on Skidaway Island commenced in 1962, then continued off-and-on and were completed in 1968. Maintenance costs were only realized during the 1962–68 period with tidal flushing occurring, so as not to require further maintenance activities. Isle of Hope additionally, received chemical control (ground adulticides) on a spot-treatment basis.

Annual female mosquito densities per light-trap night serve as the measure of effectiveness of the projects, and illustrate the differences among project outcomes and areas. Examining all female mosquito species collected over the 1962–83 period indicates that the observed mean density differed significantly across areas; 5.6 for Isle of Hope as opposed to 20.4 for Thunderbolt (5% level, *t*-test) (see Table 4, Ofiara and Allison 1985). A comparison of mean densities across time periods (1962–72 versus 1973–83) further revealed that for Isle of Hope only, mean densities were significantly different (5% level) prior to 1973 (the beginning of when the source reduction project is believed to demonstrate effectiveness) versus post-1972 (1973–83).

Further examination of light-trap data for the two primary target saltmarsh species, *Aedes sollicitans* (Walker) and *Ae. taeniorhynchus* (Wied.) identified by the CCMCC director provided results consistent with those of the total species counts. Observed mean densities were significantly different (5% level) across areas for both time periods and both species, and mean densities associated with *Ae. sollicitans* differed significantly (5% level) across pre-1973 and post-1972 periods for Isle of Hope. Considering the proportion of *Ae. sollicitans* and *Ae. taeniorhynchus* combined relative to total species per light-trap night indicated: 1) the observed mean proportion for the 1962–72 and 1973–83 period for Thunderbolt (82.1 and 70.6%, respectively) versus Isle of Hope (38.4 and

19.0%, respectively) were significantly different across areas at the 5% level; and 2) the mean proportion of these primary target species differed significantly (5% level) prior to 1973 as opposed to post-1972 for Isle of Hope.

A comparison of annual ground adulticide spray applications data revealed that the observed mean number of annual applications was 10.5 ± 2.9 and 24.3 ± 8.0 for 1962–72 and 1973–83 periods, respectively, for Thunderbolt and those corresponding to Isle of Hope were 10.3 ± 2.8 and 10.9 ± 2.6, respectively. The mean application level for the 1962–72 period was not significantly different across areas, implying that both areas received similar ground adulticide control measures prior to 1973; after 1972, mean ground adulticide applications were significantly different across areas (5% level), and the observed mean level of these spray patterns prior to 1973 versus post-1972 differed at the 5% level only for Thunderbolt.

Total costs associated with the source reduction project consist of fuel, labor, machinery and equipment operation costs for the ditching activity; labor costs for maintenance activities; and pesticide, fuel, labor, machinery and equipment operation expenses for spot treatment activities. Costs associated with the chemical control project comprise pesticide, fuel, labor, machinery and equipment operational costs.

Total costs of both projects, presented in Table 1, represent deflated (constant) costs for all the above activities (1967 = 100, U.S. Department of Commerce 1980, 1983, 1984). Although the source reduction project was almost twice the cost ($32,999) of the chemical control project ($16,513), it appears it was more effective in controlling adult densities of female mosquitoes as measured by light-trap data.

The approach used to measure benefits of mosquito control was based on a CMV technique described earlier. Maximum WTP measures for improvements in mosquito control served to represent benefits of the two projects, for the purpose of this paper. The main criterion in selecting a CMV approach was that it allowed for differences in mosquito concentration levels to be easily valued, thus reflecting differences in the quality among the two projects. Average benefits per capita were adjusted to constant dollars by the Consumer Price Index (1967 = 100, U.S. Department of Commerce, 1980, 1983, 1984) and projected on the basis of population estimates for both areas. Estimated total benefits were $624,318 for the source reduction project and $426,336 for the chemical control project in 1967 dollars (Table 1). Net benefits, benefits less costs, were $591,319 and $409,823 for the source reduction and chemical control projects, respectively. Discounted net benefits based on a 4% real discount rate were $377,729 associated with source reduction, a factor of 1.3 times larger than discounted net benefits for chemical control ($284,511).

DISCUSSION

Benefit-cost analysis is a methodology that can assist in establishing decision criteria useful in 1) the evaluation of alternative projects, and 2) comparisons between projects that involve alternative control methods. Benefits and costs of alternative control projects can differ among projects because of differences in project outcomes as well as differences in project scale. However, decisions involved with choosing a project over another can be complicated for goods that are normally exchanged in a market.

The complexity of decisions and benefit-cost applications increases when alternative projects involve goods or public services that are not exchanged in a market, i.e., nonmarket goods. This is the case with public mosquito control. In spite of these difficulties benefit-cost analysis is indeed useful and can be applied as illustrated in this paper.

The two areas selected in our example were meant to represent alternative control projects that would allow comparisons across projects. Because our study design was not based on an experimental design (unfortunately infeasible, involving projects such as these), areas were chosen that possessed fairly equal characteristics with the aid of the CCMCC director. Although the two areas selected were the best representative areas within the Chatham County MCD, the mosquito population and adulticide spray data suggest that relative population densities differed among areas at the outset of the projects.

The data indicate that ground adulticide spray patterns remained constant for Isle of Hope when relative mosquito densities declined significantly, while the number of spray applications more than doubled for Thunderbolt with relative densities remaining constant (20.0–1962—72, 20.8—1973–83). Also, for the pre-1973 period, average annual spray applications were essentially constant across both areas. This is significant because it is in the post-1972 period that source reduction activities begin to demonstrate effectiveness. Although both areas encountered fairly similar

Table 1. Costs and Benefits for Comparison of a Source Reduction Project (Isle of Hope) with a Chemical Control Project (Thunderbolt), Chatham County, Georgia, 1962-83.

	Source Reduction Project Costs and Benefits								Chemical Control Project Costs and Benefits							
						Discounted[b]								Discounted[b]		
Year	Total Costs	Avg. Benefits	Popula-tion	Gross Benefits[a]	Net Benefits	Costs	Benefits	Net Benefits	Total costs	Avg. Benefits	Popul-ation	Gross Benefits[a]	Net Benefits	Costs	Benefits	Net Benefits
1962	2,538	10.25	1,357[c]	13,915	11,377	2,440	13,379	10,939	NA	NA	1,925[e]	NA	NA	NA	NA	NA
1963	7,623	17.79	1,366	24,296	16,674	7,047	22,463	15,416	769	10.13	1,932	19,573	18,804	711	18,096	17,385
1964	7,337	10.00	1,375	13,750	6,413	6,522	12,224	5,702	480	10.00	1,939	19,390	18,910	427	17,238	16,811
1965	396	21.35	1,384	29,555	29,159	338	25,263	24,925	531	25.58	1,946	49,772	49,241	454	42,546	42,091
1966	4,703	24.87	1,393	34,639	29,935	3,866	28,471	24,605	543	16.78	1,953	32,771	32,228	446	26,935	26,489
1967	2,941	24.17	1,402	33,886	30,946	2,324	26,781	24,457	912	9.29	1,960	18,208	17,297	721	14,390	13,670
1968	1,399	23.20	1,411	32,729	31,330	1,063	24,872	23,808	757	8.92	1,967[f]	17,537	16,780	575	13,327	12,752
1969	911	22.01	1,420	31,258	30,347	666	22,840	22,174	973	4.24	2,358	9,986	9,013	711	7,297	6,585
1970	602	20.78	1,429[c]	29,698	29,096	423	20,866	20,442	586	17.35	2,750[g]	47,717	47,131	412	33,525	33,114
1971	136	19.93	1,562	31,124	30,988	92	21,026	20,935	111	16.64	2,711	45,101	44,991	75	30,469	30,394
1972	251	19.29	1,695	32,696	32,445	163	21,239	21,076	220	7.41	2,672	19,811	19,590	143	12,869	12,726
1973	600	18.16	1,828	33,195	32,595	375	20,734	20,359	621	6.98	2,632[h]	18,371	17,750	388	11,474	11,086
1974	370	13.66	1,961	26,793	26,423	222	16,091	15,869	645	6.29	2,647	16,649	16,005	387	9,999	9,612
1975	212	14.99	2,094	31,397	31,185	122	18,131	18,009	400	5.76	2,662[h]	15,341	14,941	231	8,859	8,628
1976	230	14.18	2,227	31,570	31,340	128	17,530	17,402	580	7.56	2,678[i]	20,246	19,666	322	11,242	10,920
1977	479	13.32	2,360	31,428	30,949	255	16,780	16,524	639	5.12	2,550	13,052	12,413	341	6,969	6,627
1978	389	12.38	2,493	30,853	30,464	200	15,839	15,639	732	4.76	2,428	11,550	10,817	376	5,929	5,553
1979	372	11.10	2,626	29,155	28,784	183	14,392	14,208	1,882	4.27	2,312	9,866	7,984	929	4,870	3,941
1980	351	9.79	2,757[d]	26,978	26,628	167	12,805	12,639	1,303	5.22	2,165[d]	11,298	9,995	618	5,363	4,744
1981	496	8.88	2,868[d]	25,457	24,961	227	11,618	11,392	1,302	1.71	2,354[d]	4,020	2,718	594	1,835	1,240
1982	270	8.37	2,973[d]	24,899	24,628	119	10,926	10,808	1,143	5.65	2,355[d]	13,309	12,166	502	5,841	5,339
1983	395	8.13	3,082[d]	25,048	24,653	167	10,569	10,402	1,382	5.48	2,328[d]	12,767	11,385	583	5,387	4,804
Total	32,999	-	-	624,318	591,319	27,109	404,837	377,729	16,513	-	-	426,336	409,823	9,947	294,459	284,511

Note: Dollars are constant (real) dollars deflated by the producer price index (PPI = 1967) for selected cost categories (e.g. pesticides, fuel, labor, and machinery/equipment) and then aggregated. Costs presented are aggregated costs. Average benefits represent per capita benefits adjusted by the consumer price index (1967 = 100). Population estimates for inbetween years calculated from the annual percent change between 2 years with census population estimates. NA refers to not available.

a. Product of average benefits ($/person) and population.

b. Discounted using a real discount rate of 4%.

c. Estimates from Rand McNally Commercial Atlas, various years.

d. Estimates from Neighborhood Survey, Chatham County - Savannah Metropolitan Planning Commission.

e. U.S. Dept. of Commerce. 1961. U.S. Census of Population: 1960. Number of Inhabitants, Georgia. Final Report PC(1)-12A. Washington, DC: U.S. Gov. Printing Off.

f. Estimate provided by Chatham County - Savannah Metropolitan Planning Commission.

g. U.S. Dept. of Commerce. 1971. U.S. Census of Population: 1970. Number of Inhabitants, Georgia. Final Report PC(1)-B12. Washington, DC: U.S. Gov. Printing Off.

h. U.S. Dept. of Commerce. 1976. 1973 "Revised," and 1975 Population Estimates, and 1972 "Revised," and 1974 Per Capita Income Estimates for Counties and Incorporated Places in Georgia. Current Population Report Series P25-658.

i. U.S. Dept. of Commerce. 1977. 1976 Population Estimates and Per Capita Income Estimates for Counties and Incorporated Places in Georgia. Current Population Report Series P25-749.

Source: Costs - Chatham County Mosquito Control Commission Monthly Records, 1962-83, and Benefits - Ofiara and Allison, 1986.

weather and tidal conditions, as well as other control activities such as larviciding, the differences in population counts among areas during the 1962–72 period suggest that the areas were not equal in potential mosquito abundance.

Suspected reasons for the difference if adulticide activities were equally effective for both areas over time are: 1) Thunderbolt historically had a greater relative abundance of mosquitoes prior to mosquito control in Chatham County; or 2) mosquito abundance at Thunderbolt was influenced more from external sources than from internal sources hence, mosquito populations were continually replenished from outside sources. If the assumption of equal effectiveness across areas and time is dropped, then the data suggest that mosquito populations in Thunderbolt required increasingly more frequent spray applications to achieve a constant population density level. This implies diminishing adulticide effectiveness (or equivalently increased mosquito resistance to adulticides), that spray applications were consistently poorly timed, or mosquito populations were recharged from untreated sources outside of Thunderbolt.

Overall, the data suggest that source reduction was a contributing factor in the reduction of ground adulticide applications and quantities, adult densities of female mosquitoes per light-trap night, and the proportion of primary target saltmarsh species relative to total species per light-trap night for Isle of Hope. Additionally, source reduction yielded net benefits of $591,319 (1967=100), $164,983 more than a strict chemical control project (a factor of 1.4 times greater). In discounted terms, net benefits were $377,729 or $93,218 more than the chemical control project. This evidence clearly demonstrates that the appropriate decision was selected in developing a mosquito control program for the Isle of Hope area and suggests that Thunderbolt could benefit from source reduction activities if source reduction is a feasible option for the Thunderbolt area.

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