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USING PRESENT VALUE AS A SIMPLE APPROACH TO COMPARE MOSQUITO LARVAL CONTROL METHODS

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ABSTRACT. Simple economic-based comparisons of source reduction and larvicide treatment are generally lacking in the mosquito control literature. The aim is to address this by developing an Excel tool that calculates the total present value (PV) of control methods. We use 15 years as the time frame, but this can be varied. Total PV is calculated based on the cost of each method at the start. A 3% discount rate is applied to recurring costs, and one-off costs are included throughout because they are part of the total PV. The data are based on information provided by mosquito control agencies in southeast Queensland, Australia. Values in the tool can be simply edited to reflect specific program characteristics. The outcome for the data used showed that source reduction is an appropriate option if maintenance is minimal. When major maintenance is needed, then larviciding may be the better option, particularly if money is the main consideration. However, if the frequency of applying larvicides increases, then source reduction becomes an increasingly attractive option.

KEY WORDS Comparisons, larviciding, present value, source reduction

INTRODUCTION

Mosquito control programs operate on the ground at the interface between habitat and mosquitoes. Integrated mosquito management includes an agency's specific mix of strategies for achieving control objectives. An essential requirement for optimal mosquito control is that the strategy is cost-effective (Del Rosario et al. 2014). Once the effectiveness of mosquito control is established, the next consideration would be the relative cost of implementing the component methods. Together, this represents the logic of cost-effectiveness tools for policy decision making (Musgrove and Fox-Rushby 2006). There are two essential objectives of effectiveness: one is to directly reduce mosquito production; the other is to reduce the disease and nuisance risk. For the first objective, it has been established that mosquito control does reduce larval populations. Evidence for this, for larviciding, includes the post-larviciding surveillance carried out by mosquito control agencies, as well as the insecticide efficacy laboratory experiments. Recently, Djenontin et al. (2014) showed "complete" larval control of *Anopheline* and *Culicine* mosquitoes using Vectobac GR (a *Bacillus thuringiensis*, var *israelensis* [*Bti*] de Barjac formulation). Kusumawathie et al. (2008) assessed the cost effectiveness of control using fish versus temephos (an organophosphate) in Sri Lanka. They found that fish provided control and were a potentially cheaper option than temephos. For source reduction, the long-term runnel project in an Australian saltmarsh showed that mosquito larvae were rare in the modified site (Dale 2007). This long-term control was similar in many of the runnel projects that were implemented in Australia in the 1990s and reassessed in 2016 (Knight and Dale, unpublished data). In the USA, source reduction has been carried out for decades and is part of many successful mosquito control programs (Rey et al. 2012).

For the second objective, assessing the reduction in disease risk related to mosquito control is more difficult, and relatively few research papers address this. However, evidence suggests that mosquito control does reduce disease incidence. Queensland, Australia, has the largest number of Ross River virus cases in Australia each year (Australian Government 2017). In Queensland, research showed that as integration increased within mosquito control programs the incidence of Ross River virus decreased (Tomerini 2007, Tomerini et al. 2011). Another study showed that reduction in dengue incidence was related to mosquito surveillance and control (Pepin et al. 2013). It is thus concluded that both source reduction and larviciding are effective mosquito control methods.

The issue then is to compare the "cost" of the methods over the longer term. There is very little research literature on this, at least in the context of mosquito management methods. Shisler and Schulze (1981, 1985) compared the cost of source reduction (Open Marsh Water Management) with that of larviciding in the northeastern USA. They found that source reduction costs less than the accumulated cost of larviciding after 3 years (and had examples of up to 7 years). In the 1981 paper, Shisler and Schulze used an inflation rate (10%); that is, the actual initial costs were increased each year, and this was used to calculate the cumulative cost of modification and compared with temporary control. In 1985, Shisler and Schulze noted that "The development of practical methods to evaluate the economics of mosquito control has not been adequately addressed

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in the literature. Complex theoretical manipulations of cost analysis data regarding mosquito control ... are often impractical for local mosquito control agencies."

Since then the issue has rarely been comprehensively assessed, although Shisler and Schulze (1985) discussed the factors that make estimating costs difficult. These included changes to or variations in the inflation/discount rate, variations in mosquito production from time to time, control methods, and chemicals (and costs). In their analyses, Shisler and Schulze used real historic cost data showing that areas treated and number of treatments could vary from year to year, but that overall "permanent" control (source reduction), estimated with a 10% inflation factor, was less costly than repeated chemical treatment.

The aim of this paper is to address the practical gap identified by Shisler and Schulze (1985) by providing a relatively simple method to compare the present value (PV) of mosquito treatment methods over, for example, 10 or more years. The treatment methods are those most commonly used in mosquito control in southeast Queensland, Australia: aerial larviciding, generally using *Bti* and /or methoprene, and runnelling, a relatively minor form of source reduction (Dale et al. 1993). This is comparable to the current methods of larval control in the USA: larviciding and source reduction, such as Open Marsh Water Management and Rotational Impoundment Management (Carlson and O'Bryan 1988, Rey et al. 2012). The method presented here is to compare the estimated PV of mosquito control methods, over time, and can be adapted to compare any forms of mosquito control.

Rationale

Our rationale is to compare different treatment types; expenditures in the future have to be adjusted to PVs so they can be compared with those in the initial project year and summed across the project life. This is an important step and is vital for assessing and comparing the true economic cost and returns of future streams of revenues and costs. It is standard practice in financial and economic analyses.

Realistic cost comparisons cannot be made without using "discount rates" to (generally) reduce estimated actual future cost (and benefit) values (for details see Australian Government 2016). The logic of discount rates is not always clear to people outside finance fields; that is, why should costs and benefits typically be worth less in the future? Surprisingly, it has nothing to do with inflation and its eroding impact on the purchasing power of a given sum of money. Economic analyses that compare monetary values over time should always adjust for inflation before the logic of discounting is applied. Discount rates are based upon people's "time value of money" after adjustment for inflation. The underlying logic is that most people would prefer a benefit given to them now, over the promise of the same benefit in the future (even if adjusted for inflation). Obversely, they would also select to have a cost later than right now (for example, if such punishment was inevitable, most people would select to have a painful slap of the wrist in a year rather than right now).

There are many reasons for these preferences and economists collectively label their impact in the concept of "(social) time preference rates." They include aspects such as the ability to invest and get greater real returns from revenue received now rather than in several years. There is also inherent uncertainty that any benefit or costs in the future, although promised, will not happen, and the psychological inclination of humans is to access gains and benefits now and defer or avoid costs.

Hence, discount rates need to be applied to cost and revenue streams, even after taking in to account the effect of inflation. These are typically based on prevailing low-risk interest rates or investment rates of return. Here we are directly concerned only with costs for practical reasons.

This study begins by applying the widely adopted private discount rate of 3% and using real data as provided by mosquito control agencies in Queensland, Australia. For the sensitivity analysis of the impact of changes in the discount rate applied, calculations have also been included based on a 7% discount rate. One-off costs are included in the year of expenditure and then for each year for the whole period. This is because the initial cost is part of the total cost.

Worked examples show the comparative costs over 15 years for aerial treatment with two larvicides (*Bti* and methoprene) and salt marsh source reduction (in this case runnelling). The starting values are actual costs/ha/year.

Assumptions

To develop a relatively simple yet useful method to compare mosquito control methods, some assumptions need to be made explicit at the start. They include the following:

- Both source reduction (runnelling) and aerial larviciding are equally effective. This is a conservative assumption because permanent control (source reduction) is considered to be significantly more effective than larviciding.
- All saltmarsh sites can be either runnelled or larvicided. This is necessary for comparisons, though it should be noted that, although all saltmarsh sites can usually be larvicided, not all salt marsh *can* be runnelled.
- Reliance is placed on the costs provided by mosquito control agencies.

Environmental considerations are outside the ambit of this paper and so are not included in the

Table 1. Parameterization of the model showing all input parameters for larviciding and values used to derive each figure.

Cost amounts in year 0	Enter discount rate (%)	Enter surveillance cost (US$)	Enter first recurring cost (US$)	Enter second recurring cost (US$)	Enter third recurring cost (US$)	Enter larviciding cost/ha, year 0 (V1, US$)	Enter larviciding cost/ha, year 0 (V2, US$)
Fig. 1A	3	24.00	0.00	0.00	0.00	330.00	440.00
Fig. 1B	7	24.00	0.00	0.00	0.00	330.00	440.00
Fig. 2A	3	12.95	65.70	0.00	0.00	333.00	444.00
Fig. 2B	3	25.90	65.70	0.00	0.00	666.00	888.00

model despite being an important consideration when choosing a control method.

METHODS

Data collection

Data were obtained on a cost/ha/year basis from several local government mosquito control agencies. For aerial larviciding, the most common method used in Australia, the data included application costs (chemicals, aircraft hire and personnel, generally as a single item) and mosquito larval surveillance. For source reduction, there were both recurring and one-off costs. Recurring costs included mosquito surveillance and minor annual maintenance. One-off costs included initial site survey, planning, and construction with major maintenance included for the year of implementation.

Calculations

To calculate the total PV of recurring costs for each year, the following formula was used, with a discount rate in this case of 3% (0.03):

$$1/1 + 0.03^{\text{year}}. \quad (1)$$

The model was set up in a workbook in Excel (Microsoft, Redmond, WA; or in any suitable statistics program). The input parameters used for both larviciding and source reduction (runnelling) calculations are shown in Tables 1 and 2, respectively, and are input into separate spreadsheets in the workbook with a third spreadsheet generating a graph. Table 3 is an example of the calculation in the first spreadsheet in the workbook for larviciding for years 0 to 10. Changes can be made to the variables in the parameterization row as indicated in Tables 1 and 2 with example parameters used to derive each figure (1A, 1B, 2A, and 2B); that is, the discount rate, surveillance costs/ha/year, and larviciding costs/ha/year can be changed, and the model automatically calculates everything else. For recurring costs this means simply multiplying the cost in year 0 by the discount factor (in column 2), and the result is shown in columns 3 and 4. Total PV in each year, shown in column 5, is the sum of columns 3 and 4 as in Table 3. The total PV over any period (up to 15 years in the spreadsheets) is the cumulative value as in column 6, which is what is graphed. All calculations are done automatically in the Excel workbook. The Excel workbooks containing larvicide and source reduction spreadsheets and the graph spreadsheets used here are available from the contact author.

RESULTS

The results compare the two methods (larviciding and runnelling), using real data and estimates, to demonstrate the approach as a management tool (all dollar values have been converted from A$ to US$). (On 9 May 2017 the conversion rate was A$1 = US$0.74.)

Larviciding

The PV for larviciding was determined on a per hectare basis using the main factors of which chemical was used and the frequency of application. For the example used here, initial chemical costs are for *Bti* at US$33/ha/treatment and for methoprene at US$44/ha/treatment. The model can be modified to include different chemicals at different initial costs and with different number of annual applications. The frequency of applications varied from 6 to 11 times a year. Ten to 11 times a year was common.

Table 2. Parameterization of the model showing all input parameters for source reduction (runnelling) and values used to derive each figure.

Cost amounts in year 0	Enter discount rate (%)	Enter surveillance cost (US$)	Enter first recurring cost (US$)	Enter second recurring cost (US$)	Enter third recurring cost (US$)	Enter site survey and planning cost (US$)	Enter construction time cost (US$)	Enter machine cost (US$)	Enter any other one-off cost (US$)
Fig. 1A	3	14.00	0.00	0.00	0.00	1,846.00	553.00	37.00	0.00
Fig. 1B	7	14.00	0.00	0.00	0.00	1,846.00	553.00	37.00	0.00
Fig. 2A	3	6.48	148.00	15.64	0.00	2,146.00	536.50	37.00	0.00
Fig. 2B	3	12.96	148.00	15.64	0.00	2,146.00	536.50	37.00	0.00

Table 3. Example of spreadsheet calculations of cumulative present value per hectare for larviciding for years 0 to 10 using a discount rate of 3%, surveillance cost of $24, and larvicide cost of $330 per hectare (as in Fig. 1A).

Year (1)	Discount 3% (2)	Present value/ha for surveillance in each year ($) (3)	Present value/ha larvicide in each year ($) (4)	Total present value/ha larvicide in each year (cols. 3 + 4, $) (5)	Cumulative present value/ha larvicide in each year (from col. 5, $) (6)
0	1.0000	24.00	330.00	354.00	354.00
1	0.9709	23.30	320.39	343.69	697.69
2	0.9426	22.62	311.06	333.68	1,031.37
3	0.9151	21.96	302.00	323.96	1,355.33
4	0.8885	21.32	293.20	314.52	1,669.85
5	0.8626	20.70	284.66	305.36	1,975.22
6	0.8375	20.10	276.37	296.47	2,271.69
7	0.8131	19.51	268.32	287.83	2,559.52
8	0.7894	18.95	260.51	279.45	2,838.97
9	0.7664	18.39	252.92	271.31	3,110.28
10	0.7441	17.86	245.55	263.41	3,373.69

The model shown in Fig. 1 uses 10 applications a year. An additional example of 20 treatments/year is included (Fig. 2B), which was the situation in 2016–2017 in parts of southeast Queensland.

Source reduction

For source reduction, mosquito larval surveillance was a recurring cost estimated at half the rate for larviciding, based on advice from local mosquito control agencies. One-off costs included initial site survey, planning and construction, and major maintenance. Construction was estimated at US$553/ha. The estimated one-off purchase cost of a runnel machine in 2016 A$ was around US$30,000, servicing around 800 ha (i.e., at US$37/ha).

A one-off cost of US$1,846/ha was estimated for planning and constructing the runnels. This was based on a runnel machine constructing 400 m/day, and the median construction was around 400 m/ha (though the quartile range was wide at 200–700 m/ha).

Maintenance data were scarce, and we relied on the memory of those field crews who had been working in the area since the 1990s, when many runnels were constructed. We used two scenarios for maintenance. There was either minor maintenance every year as part of the mosquito surveillance program, using shovel or brush-cutter, or more intensive maintenance every 5 years. For the latter we used a worst-case scenario whereby the runnels were reconstructed using the machine (at an estimated current cost of US$553/ha, but the appropriately discounted value was used for the year of implementation).

Comparisons

Figure 1 compares the 3% and 7% discount rates, and Fig. 2 illustrates how the frequency of larviciding may affect the outcomes. Figure 1A**,** with a 3% discount rate, shows that source reduction (runnelling) with minimal maintenance has a lower PV compared to larviciding early in year 5 if the expensive larvicide (V2) is used or by year 7 if using lower cost larvicides (V1). The situation is different if intensive (5-year) maintenance is required for the source reduction method. In that case, if expensive larvicides are used the PV becomes less than that for larviciding by year 6; however, if the cheaper larvicides are used, the PV remains higher until around years 9 to 10. A 7% discount rate used for sensitivity analysis changes the picture somewhat (Fig. 1B). For source reduction with minimal maintenance the PV becomes less than that for the expensive larvicide after year 5 and later in year 8 for the cheaper one. If significant maintenance is needed, then the source reduction PV becomes less than that for the expensive larvicide by year 8, but only by year 13 for the cheaper one.

Figure 2A shows the situation if frequency of application. When there are 10 larvicide treatments each year, source reduction does not have a lower PV than the expensive larviciding until around year 8 for the minor maintenance option and not until year 11 with major maintenance. For the cheaper larviciding option (V1), the PV is mostly lower than both source reduction options. Even so, there is relatively little difference between PVs for the larviciding and source reduction options. However, increasing the number of treatments to 20 times a year (Fig. 2B**)** results in a very different situation whereby source reduction has a lower PV than larviciding, even after only a few years.

DISCUSSION

Relevance and application to management

Management strategies can be assessed by examining the graphs (and the underlying data in the workbooks). The scenarios can be easily changed for all the variables. Experimenting with the model by changing values and variables shows what might

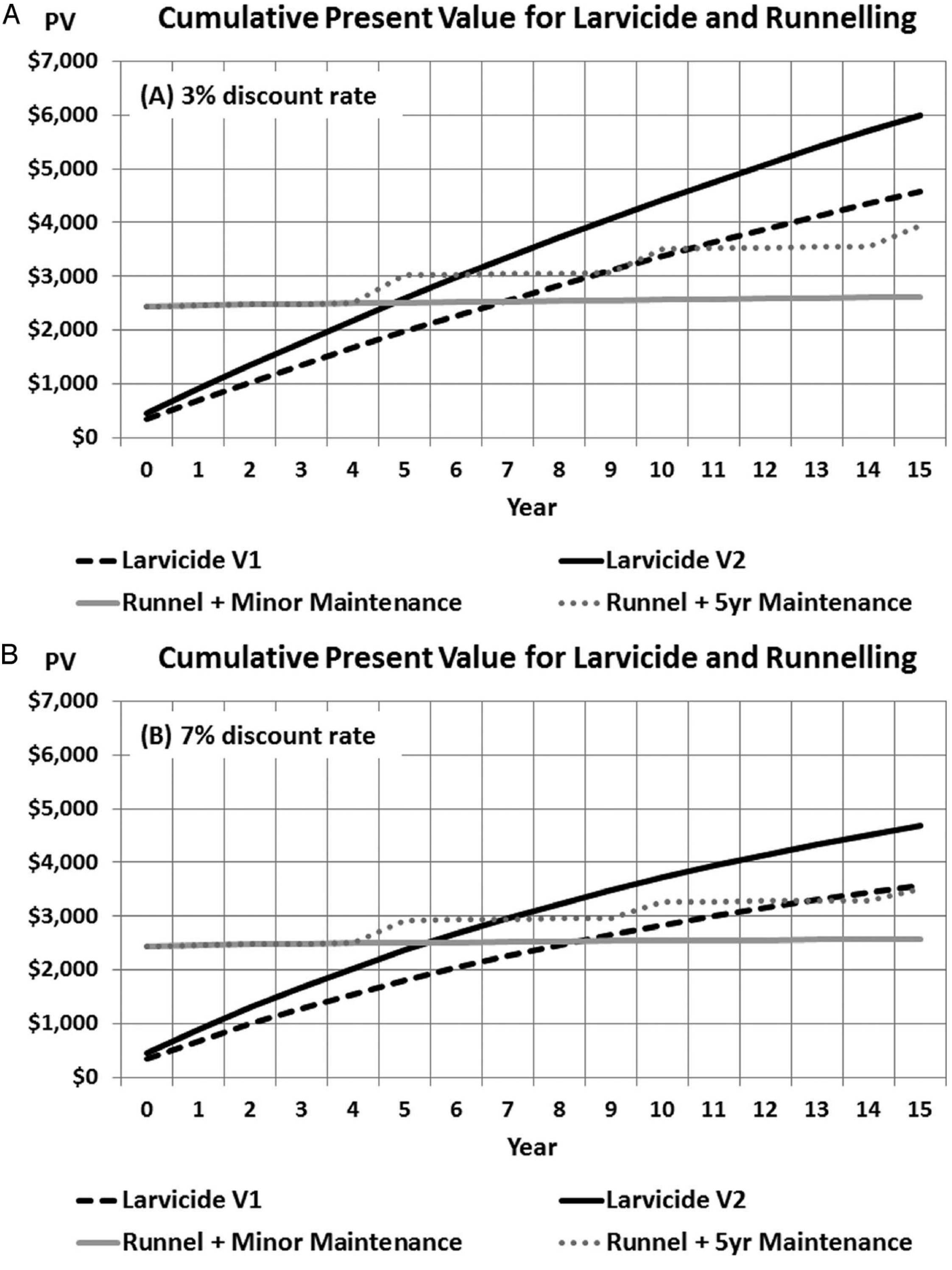

Fig 1. Comparing larviciding at two rates with source reduction (runnelling) with minimal or major five yearly maintenance; (A) is the 3% discount rate, (B) is the 7% rate. Larvicide V1 is generally *Bti*; larvicide V2 is generally methoprene; PV means present value.

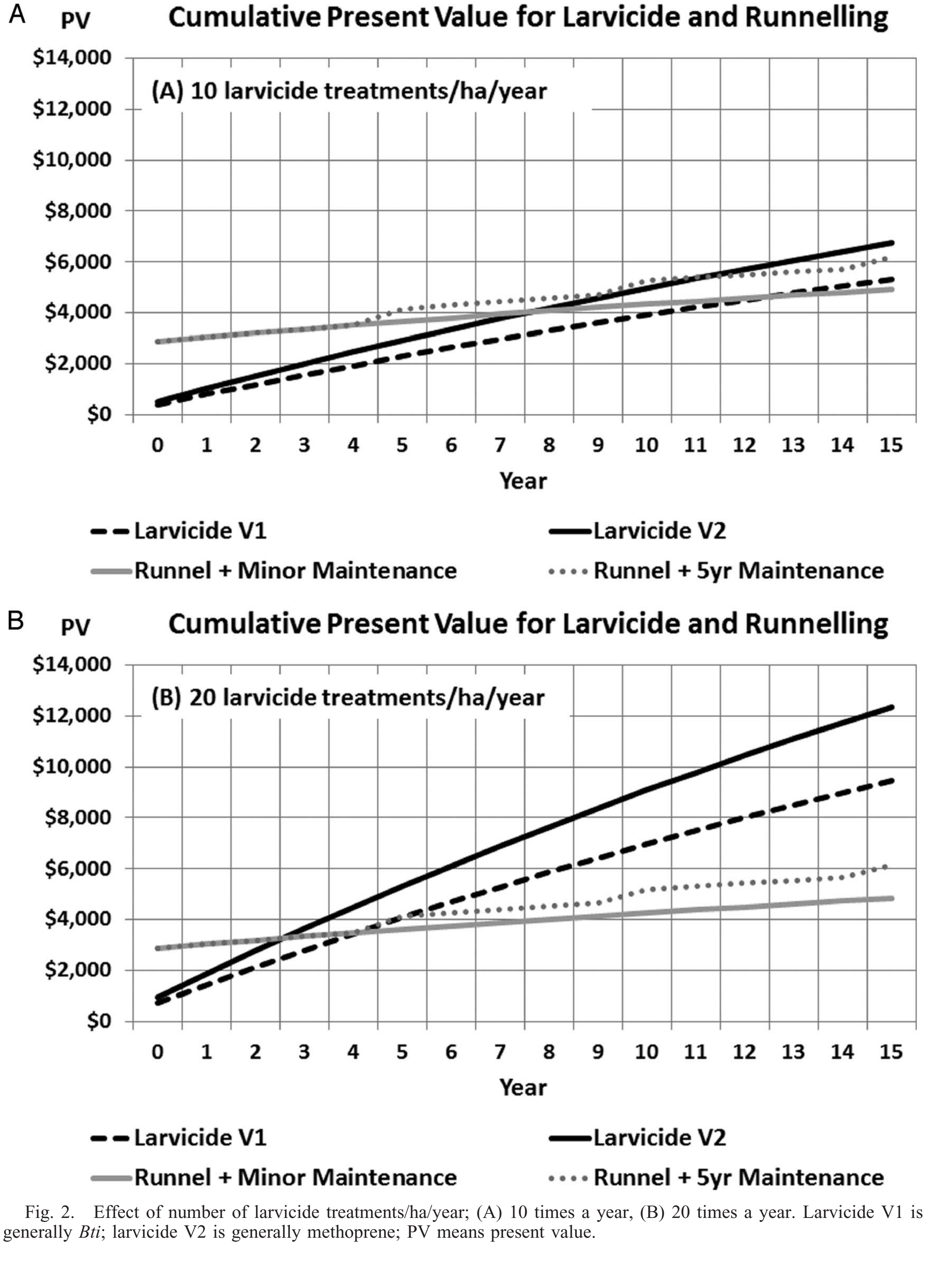

Fig. 2. Effect of number of larvicide treatments/ha/year; (A) 10 times a year, (B) 20 times a year. Larvicide V1 is generally *Bti*; larvicide V2 is generally methoprene; PV means present value.

happen over a selected time frame. That is a no-risk strategy and can be used to support management decisions. Referring to Fig. 1A and 1B, the effect of the higher 7% discount rate, compared to 3%, does not have a significant effect on the time at which the source reduction PV becomes less than that for larviciding. This suggests that the model is not particularly sensitive to changes in the discount rate. This is because all the recurring costs are treated the same, and so the relativities between them will usually mainly respond to the one-off costs, which are generally unchanged.

If management is using the 3% discount rate, as suggested in the literature (Musgrove and Fox-Rushby 2006), in the case where minimal maintenance is needed for source reduction, it is likely that runnelling would be a preferred option. The situation is very different if intensive maintenance is required. If expensive larvicides are used, it will still be a preferred option to runnel the marsh by year 6; however, if the cheaper larvicides are used, then it may not be a useful option until year 11 (Fig. 1A), if PV is the only criterion.

Maintenance can be a significant factor for the total PV for source reduction (in this case runnelling). There may be relatively low ongoing maintenance costs, and this would be the ideal situation. According to Shisler and Shulze (1985) permanent control (Open Marsh Water Management) in many cases required no maintenance over 10 years, and they anticipated 25 years without maintenance or larvicide treatment. This is consistent with the Australian experience, at least for some sites. If properly designed and constructed, they can still be operating more than 20 years after construction (Dale and Knight 2012, Knight and Dale unpublished data). However, if major maintenance is required, such as reconstruction, this may prove less attractive than recurring larvicide applications. It may also indicate that the site was not really suited to modification or that the design was not optimal.

Another consideration is the planning time frame. For example, if the time frame of interest was 5 years, then, with the data used here and shown in Fig. 1A, the PV of source reduction would not warrant using that method under either the minimal or major maintenance scenario, if PV was the only criterion. That is so, even if the more expensive larvicide was being used, because the PV for source reduction would only be less than that for larviciding for just over a year. In general, the longer the time frame, for our data, the more likely it is that source reduction would incur a lower total PV than larviciding. This is consistent with the work of Shisler and Schulze (1981, 1985).

Frequency of larviciding is a significant factor in calculating total PVs. Aerial larviciding is effective, but it needs to be repeated whenever there is a larval hatch that exceeds some threshold. Thresholds vary from agency to agency and are related inter alia to proximity to human settlement. Some agencies conduct aerial larviciding 11 or more times a year, whereas others may do it only 6 times. The actual number varies from year to year, depending on tides, tidal anomalies, and rainfall. Climate change may affect both the areas of mosquito larval habitats and the required frequency of treatments (Dale and Knight 2008). If the frequency is at the lower end (e.g., 6 times compared to 11 times a year) the PV for source reduction is usually considerably higher than that for larviciding. If the number of annual larvicide treatments increases as a result of climate, habitat change or encroachment of human settlement toward mosquito habitats, then the PV of source reduction may compare more favorably with larviciding. That situation is illustrated in Fig. 2B and reflects a real scenario in the 2016–2017 season where there were 20 or more larvicide treatments in some programs, in response to higher than expected tides, but also related to a longer "mosquito season," as temperatures have been warmer than usual and the winter reduction in larvae has been delayed in southeast Queensland.

Limitations

The reliability of the model depends on the information provided. For some mosquito control agencies in our study there was uncertainty about costs and their allocation to either source reduction or to larviciding, and they suggested that it made little difference for each method. As examples, the costs of the mosquito control manager or ancillary personnel such as secretarial assistance, infrastructure that was provided at a higher corporate level, were all difficult to allocate to a specific method. In that situation the advice was to omit such costs, having established, by working some examples, that it did not have a great impact on the comparison. This is because, as the relevant people pointed out, the resources would be used for both larviciding and source reduction. In practice, these are unlikely to be significant issues because the Excel spreadsheets can be populated by data specific to a particular mosquito control program and keeping it simple is an advantage for managers.

Although not strictly a limitation there is a proviso: the tool is only for comparisons and strategic planning. It is not designed to be used directly for budget purposes. What it does do is to provide comparisons using real or estimated data at year 0 and discounting to PV thereafter. It is up to an agency to select and consider making changes to the underlying input variables and to take the model outputs into account in decision making.

Environment

Mosquito control operates in a broader environment, and environmental values need to be taken into account at both a general level and at the program-specific level. At a general level, mosquito control agencies have responsible attitudes to their environmental duties. For the simple tool presented here we have not included social costs and benefits that have impacts on the environment and on human health. To do so is not at all simple and would have complicated the tool for local strategic planning. However, these costs and benefits are of great importance in a broader area than just mosquito control and are the subject of further research.

At the program level, issues that have been noted by some, but not all, programs include concern about the impact of chemicals on the environment. In that case, even if source reduction (runnelling) was not to be the preferred solution based on the analysis, it would be seriously considered. For example, for some mosquito control agencies aerial treatment that involves flying over bat colonies has the potential to create problems if the bats relocate to urban habitats, causing noise and odor issues for residents. Sometimes aerial treatment over migratory bird roosting sites has also been mentioned as disturbing the birds. This can be avoided by timing the aerial treatment for when the birds are foraging at sea. As Shisler and Schulze (1985) remarked, each mosquito control agency has its own factors to consider, and the tool presented here allows some of these to be included for planning purposes.

The relatively simple decision-assisting tool using a widely available workbook (Excel) compared source reduction with larviciding. Although Australian data and estimates were used, the tool can be adapted to other methods and data, simply by replacing the relevant values.

The main findings from applying the tool to the Australian situation were that if larviciding is currently expensive, then source reduction may be a preferred option, even if costly maintenance is needed; if larviciding is currently relatively cheap, then source reduction would be a preferred option, but only if *minimal maintenance* is needed. If *expensive maintenance* is required, then larviciding would be the better option but only if money is the main criterion. Nevertheless, if the frequency of applying larvicides increases, then the relative PV of source reduction is reduced, and that may make it a more attractive option.

There are issues that may, in some circumstances, override apparently effective options shown by a long-term low PV. For example, source reduction may sometimes be considered the preferred option despite the model outcomes. This would be, for example, in situations where there is public concern with the use of larvicides or where there are adverse impacts of aerial treatment on other organisms (e.g., birds or bats). Conversely, public opposition to source reduction may make larviciding a preferred option, even if the longer-term comparison suggests otherwise.

This paper has addressed the gap in comparing source reduction with larviciding identified by Shisler and Schulze (1985). The tool, estimating total PV over the "whole life" of a program, with variables determined by the agency, is a useful guide to optimal decision making. It allows "what if" scenarios to be explored including, but not limited to the following:

What if the inflation rate changes?
What if larvicides have to be applied more often?
What if aerial treatment methods and costs change?
What if methods and costs of source reduction change?

Finally, it is wise to have a *variety of control* methods available in an integrated program and an *evaluation tool* that can be simply applied to compare the various methods will facilitate informed decision making.

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