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Assessing the trade-offs in more nature-friendly mosquito control in the Upper Rhine region

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Recent studies show that the widely used mosquito control agent Bti has more negative effects on nature than previously expected. However, it is not yet clear whether people support a more nature-friendly mosquito control, as such an adaptation could potentially lead to higher nuisance. This study explores this question by assessing the willingness to pay for an adapted mosquito control strategy that reduces the use of Bti, while maintaining nuisance protection within settlements. For this purpose, a Contingent Valuation Study was conducted in the German Upper Rhine Valley. The results show that the majority of the surveyed population attaches a high value to a more nature-friendly mosquito control in terms of willingness to pay and is willing to accept a higher nuisance outside the villages. Policy makers should, thus, foster the development and implementation of such more nature-friendly mosquito control strategies to increase both environmental and societal benefits.

Keywords: mosquito control; nuisance; Bti; contingent valuation; insect decline

1. Introduction

In many regions across the world, the existence of mosquitoes poses a health threat to humans. Consequently, actions are undertaken to reduce, or even eradicate, mosquito populations near human settlements. Such mosquito control has a long history and is currently pursued by a wide variety of means. The reasons for mosquito control are twofold: either because of the diseases they transmit, or because of nuisance, or both. In Europe, the risk of diseases, due to migratory birds, globalization, and climate change, is increasing (Becker 2008; Hernández-Triana *et al.* 2014; Sambri *et al.* 2013), however, the most common reason for large-scale control of mosquitoes is still nuisance (Brühl *et al.* 2020). Although nuisance caused by mosquitoes seems unimportant to human health compared to the transmission of diseases such as Malaria or the West Nile Virus, several studies have highlighted its relevance for households. For example, Halasa *et al.* (2014) showed in their survey that avoiding nuisance caused by biting mosquitoes is of equal importance to the public as neighborhood safety. Dickinson and

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Paskewitz (2012) found in their survey that the control of mosquito nuisance is considered more important than the control of health risks associated with mosquitoes.

Besides these reasons for mosquito control, the perceived benefit to households also depends on the method of control. For a long time, control was based on chemical insecticides. This had negative effects on human health and the environment (Boisvert and Boisvert 2000; Brühl *et al.* 2020) and led to criticism (Coetzee and Koekemoer 2013; Hemingway and Ranson 2000; Van den Berg, Yadav, and Zaim 2015). As early as 1976, the bacterium *Bacillus thuringiensis* subsp. *israelensis* (Bti) was identified as a viable alternative (Goldberg and Margalit 1977). By now, the biological insecticide Bti is used worldwide, as it is considered environmentally friendly due to its alleged low impact on so-called non-target organisms (Becker *et al.* 2010; Boisvert and Boisvert 2000). This is especially important in temperate latitudes, where nuisance mosquito species breed in wetlands, that are recognized as ecologically sensitive areas (Becker 1998). Several studies have shown that the value of control by far exceeds the costs (Bithas *et al.* 2018; Farmer *et al.* 1989; Halasa *et al.* 2014; John, Walsh, and Moore 1992; Mwebaze *et al.* 2018; Von Hirsch and Becker 2009). With respect to Bti, both John, Stoll, and Olson (1987) and Von Hirsch and Becker (2009) were able to show that households' benefits significantly exceed treatment costs. This is not surprising, since further studies have shown that people place a high value on environmentally friendly treatment of mosquitoes (Dickinson and Paskewitz 2012; John, Stoll, and Olson 1987; Westerberg, Lifran, and Olsen 2010).

There has been evidence for some time that, contrary to the initial assumption, Bti has negative effects on non-target organisms (Boisvert and Boisvert 2000). Recent studies now indicate that the effects are greater than previously expected and, therefore, reason for concern. For example, Allgeier, Kästel, *et al.* (2019), Jakob and Poulin (2016), Kästel, Allgeier, and Brühl (2017) and Theissinger *et al.* (2018) demonstrated negative effects on chironomid midges. The negative effects of Bti on chironomids are of particular concern when Bti is used in protected areas (Brühl *et al.* 2020; Lagadic, Roucaute, and Caquet 2014; Schäfer and Lundström 2014). The use of Bti in such areas is not only a problem because of the general decline in insect numbers (BfN (Bundesamt für Naturschutz) 2022), but also because chironomids, besides mosquitoes, are an important food source for many other animals (Allgeier, Friedrich, *et al.* 2019; Armitage, Cranston, and Pinder 1995; DuRant and Hopkins 2008). Several studies have shown that the decline in chironomids can also have negative effects on other species such as amphibians, birds, and dragonflies as food chains are disrupted (Boisvert and Boisvert 2000; Jakob and Poulin 2016; Poulin, Lefebvre, and Paz 2010). From a scientific point of view, the current treatment practice of large scale aerial Bti applications therefore seems outdated and several scientists are calling for the application of Bti to be adapted to these new findings (Boisvert and Boisvert 2000; Brühl *et al.* 2020; Poulin, Lefebvre, and Paz 2010). It remains unclear, however, how people will evaluate the new evidence on the environmental impact of Bti and how they would value adapted mosquito control that better protects nature. The latter is important to understand since, most likely, any adapted mosquito control that forgoes treatment in sensitive areas to protect non-target midges would also come at a cost ultimately borne by private households. The question that needs to be raised is whether the benefits resulting from the protection of nature can outweigh the related costs, both monetary due to higher efforts and lower well-being due to higher nuisance in these areas.

This study attempts to answer this question by assessing private households willingness to pay (WTP) for an adapted mosquito control strategy in the affected areas. This strategy avoids the use of Bti within areas of high ecological value, while maintaining nuisance protection within settlements through the use of small-scale technical mosquito traps. For households, this scenario would lead to an additional benefit compared to the status quo, i.e. nature would be better protected in ecologically sensitive areas. The costs for households are twofold: (1) any adapted and more nature-friendly control would imply higher efforts for within-settlement protection and, consequently higher costs; and (2) the nuisance level outside settlements increases to some extent due to a higher mosquito burden. To determine the net value of such a scenario to the population in the affected areas, a contingent valuation survey (CVM) was conducted in the Upper Rhine Valley of Germany, where intensive mosquito control employing Bti has taken place in the Rhine floodplains for many years.

We expect that the WTP of survey respondents for adapted mosquito control will depend on various socio-demographic factors, but most importantly on people's attitudes towards the environment and mosquitoes, as these two topics directly affect perceived benefits and costs. Several authors have already demonstrated the influence of socio-demographic variables on WTP for mosquito control. Previous studies have shown that gender (Halasa *et al.* 2014), age (Dickinson *et al.* 2016; Farmer *et al.* 1989; Mwebaze *et al.* 2018; Von Hirsch and Becker 2009), income (Dickinson *et al.* 2016; Farmer *et al.* 1989; John, Stoll, and Olson 1987; John, Walsh, and Moore 1992; Mwebaze *et al.* 2018), education (Dickinson *et al.* 2016; Farmer *et al.* 1989; John, Stoll, and Olson 1987), and duration of residence (Farmer *et al.* 1989; Von Hirsch and Becker 2009) have an influence. Several authors assume an influence of place of residence, although this influence has not yet turned out to be significant (Halasa *et al.* 2014; John, Walsh, and Moore 1992; Reiling *et al.* 1989). In terms of respondents' attitudes towards the environment, Dickinson *et al.* (2016), John, Stoll, and Olson (1987), and Ingabire *et al.* (2017) have shown that respondents' concerns about the negative impacts of mosquito control on the environment have an influence on WTP. Regarding the attitude of respondents towards mosquitoes, evidence highlights that sensitivity towards mosquitoes (Dickinson *et al.* 2016; Von Hirsch and Becker 2009), satisfaction with current mosquito control (Farmer *et al.* 1989; Von Hirsch and Becker 2009), implementation of personal mosquito control measures (John, Stoll, and Olson 1987; Reiling *et al.* 1989; Von Hirsch and Becker 2009), and the time people spend outside (Brown, Dickinson, and Paskewitz 2016) have an influence on WTP.

In addition to these already known influences, we assume that acceptance of the described scenario by households depends essentially on the willingness to tolerate more mosquitoes outside settlements. This is the crucial trade-off for households, as here the attitude towards the environment has to be weighed against the attitude towards mosquitoes. Also, we assume that the insight of households to reconsider and develop the current practice plays a significant role. We further assume that the perceptions of mosquitoes depend not only on the amount of time people spend outside (Brown, Dickinson, and Paskewitz 2016), but also on the activities themselves, as these determine where and how people are exposed to mosquitoes.

In order to test these hypotheses and to determine the added value of more nature-friendly mosquito control, a CVM survey with 318 personal interviews was conducted with households in the Upper Rhine region in Germany.

2. Methods

2.1. Mosquito control in the Upper Rhine region

With the aim to determine household preferences for a more nature-friendly mosquito control strategy, a contingent evaluation study was conducted in the Upper Rhine Valley of Rhineland-Palatinate, Germany (Figure 1). The Upper Rhine Valley with its floodplains and wetlands is one of the most species-rich areas in Germany

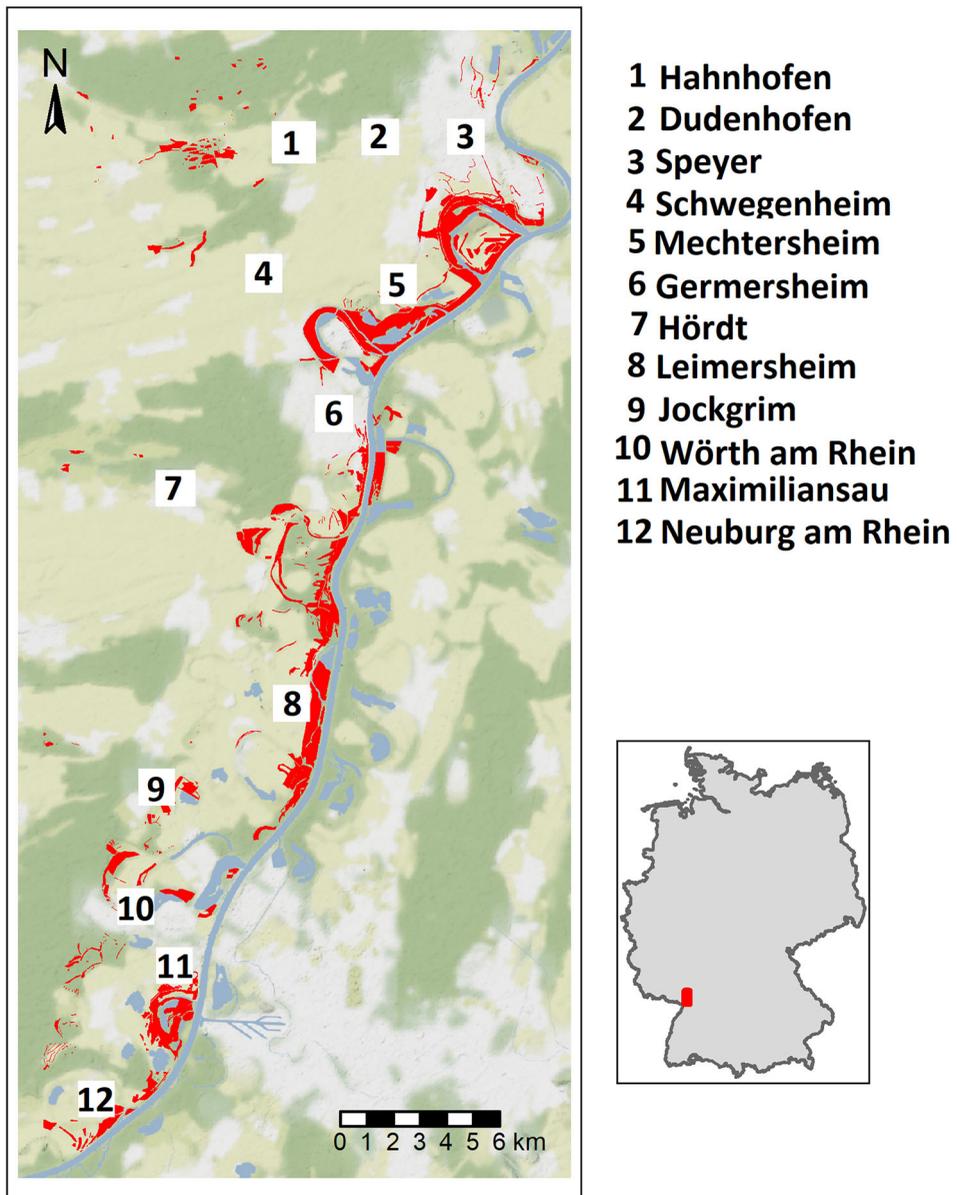


Figure 1. Study area. Numbers indicate areas surveyed; color coding: area treated with Bti (red), water areas (blue), forests (dark green), agricultural areas (light green), settlement areas (grey). Colour online.

(Ackermann *et al.* 2012) and numerous aquatic as well as terrestrial habitats are classified as Natura 2000 sites or national nature protection areas (Naturschutzgebiete, NSG) and are accordingly protected. Each year, there are an average of 5 (1 to 11) flood events in these areas, resulting in large numbers of floodwater mosquitoes (especially *Aedes vexans* > 90%) hatching (Becker, Ludwig, and Su 2018).

Due to the resulting nuisance, mosquito control has been implemented in the temporary wetlands of the Upper Rhine Valley for many years. Since 1976, control has been carried out by the German Mosquito Control Association (Kommunale Aktionsgemeinschaft zur Bekämpfung der Schnakenplage e.V.–KABS). The association is financed by the municipalities and counties in which control is carried out. It now has more than 100 regional member communities (Becker, Ludwig, and Su 2018) with over three million people (Becker *et al.* 2010). Since 1981, control of floodwater mosquitoes has been conducted with formulations of *Bacillus thuringiensis* subsp. *israelensis* (Bti) (Becker, Ludwig, and Su 2018). This involves the treatment of more than 400,000ha by helicopter and by hand an average of five times per year, reducing the mosquito population by more than 90% (Becker, Ludwig, and Su 2018). A large proportion of the treated areas (ca. 90%) are located in protected areas (Brühl *et al.* 2020).

2.1.1. Costs and benefits of mosquito control by Bti

Mosquito control has both benefits and costs for the public, which are shown in Figure 2. On the one hand, the reduction in the mosquito population by more than 90% (Becker, Ludwig, and Su 2018) potentially leads to a decrease in nuisance both within and outside settlement areas. Consequently, a higher quality of life for people

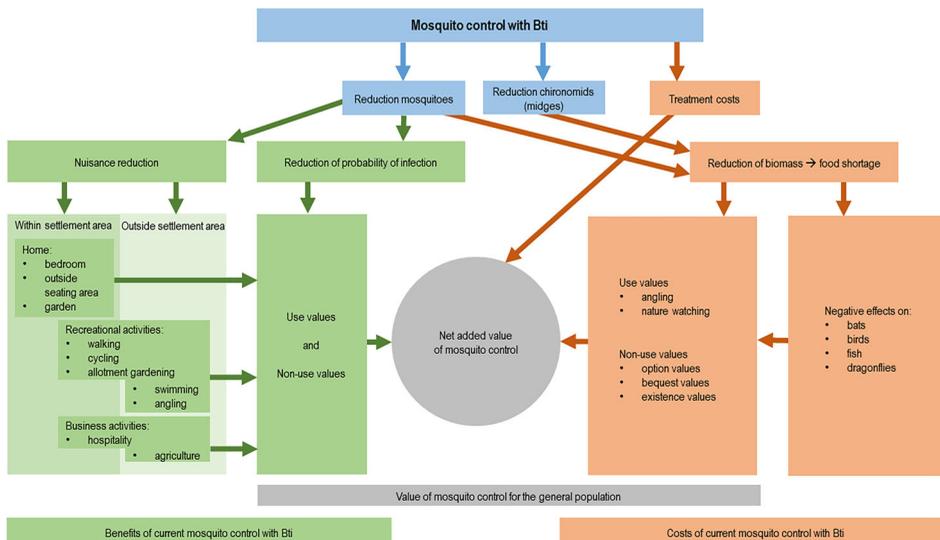


Figure 2. Costs and benefits of mosquito control with Bti. The figure shows the effects of the current mosquito control with Bti. The effects of Bti on mosquitoes and midges are shown in blue, the resulting benefits for the population in green and the costs in red. The net added value of mosquito control for the society is shown in gray. The examples given are only a selection of important effects and do not claim to be exhaustive. Colour online.

in their residence, for example in the garden, outdoor seating or even in bedrooms is expected. They also benefit during recreational activities, such as walking, cycling, allotment gardening, or bathing and fishing, both within and outside settlement areas. In addition, the reduced nuisance can also have a positive effect on certain businesses, such as hospitality and agriculture. And likewise, the reduction in mosquitoes could lead to a further decline in the already low probability of transmitted infections (No infections were detected in the study area; however, infections were recorded in other parts of Germany (RKI 2020, 2021)). The benefits of the described advantages result from the respective use as well as non-use values which people assign to these aspects (Kumar 2010, Pearce, Atkinson, and Mourato 2006). Thus, people who now find fewer mosquitoes in their bedrooms benefit (use value), but so do people who have never had a problem with mosquitoes in their bedrooms, but are happy that there are fewer mosquitoes because others used to suffer (non-use value).

At the same time, mosquito control is also associated with costs for households (Figure 2). The work of KABS is financed by its members. This amounts to about €3.5 million per year for the entire treatment area, which is about 1.3€ per person (KABS 2016). On the other hand, the reduction in mosquitoes leads to a decrease in biomass, which is available as food for other species. In addition, current control with Bti also reduces the abundance of chironomid larvae, which are then also missing as a food source. The impact on the food web is of particular importance because Bti is applied to a large extent in protected areas (Brühl *et al.* 2020). For the local population, there will be fewer animals to observe and fish, as their direct or indirect food source is reduced. On the other hand, it also has the consequence that something is lost to people who attach a value to these animals, but also to mosquitoes and midges, without using them directly. One reason may be that they are happy that these animals exist (existence value), another that they are happy that their children may experience these animals in the future (bequest value) or because they still have the opportunity to see these animals themselves in the future, to catch them or to use them in another way (option value).

The effects shown in Figure 2 are not exhaustive. It is conceivable, for example, that affected animals can no longer fulfill other functions in the ecosystem, leading to further consequences for the ecosystem and the population.

2.1.2. *The trade-off between nuisance reduction and nature protection*

Previous cost-benefit analyses of mosquito control with Bti did not take into account the formerly unknown negative effects on midges and thus underestimated the full costs incurred by mosquito control. A reduction in these costs, however, would inevitably generate other costs. This is because only a reduction in treatment with Bti will lead to better protection of midges; however, a reduction would simultaneously result in more mosquitoes, which would increase public nuisance. This represents a trade-off decision for households (Figure 2). On the one hand, people benefit from a reduction in mosquitoes (Figure 2, green), on the other hand, they benefit from intact nature (Figure 2, red). The key question is whether the lower costs associated with more nature-friendly mosquito control compensates for the lost benefits.

It is also important to consider that costs and benefits are perceived differently depending on the location. Nuisance is likely to be more strongly perceived within settlement areas than outside. And protection of midges is most useful in ecologically

valuable areas. Thus, for the public's cost-benefit trade-off, it is crucial to know where midges will be protected and what the resulting nuisance is.

2.2. *The contingent valuation study*

This study aims at determining people's preferences for a hypothetical more nature-friendly mosquito control scenario using the contingent valuation method (CVM). The CVM is a standardized procedure for determining the value of environmental goods, which can also be used to estimate non-use values (Johnston *et al.* 2017). The idea of the method is to offer a certain environmental good on a hypothetical market to households for purchase and to determine the value of the environmental good on the basis of the households' purchase decisions. The method has been continuously improved due to ongoing criticism (Venkatachalam 2004) and is used in countless studies (e.g. Bishop *et al.* 2017; Carson *et al.* 2003; Carson 2011). For an overview of the method see Alberini and Kahn (2009); Frör (2018); Johnston *et al.* (2017).

The good evaluated in this study is a more environmentally friendly treatment scenario that does not abandon mosquito control by Bti in general, but treatment in ecologically valuable areas. With this scenario, we are following official efforts to reduce biocide use in ecologically valuable areas (Deutscher Bundestag 2019). The reduction in the use of Bti, however, would lead to increased nuisance within and outside settlement areas. In order to maintain the protection of the population within settlements, the scenario foresees the use of small-scale technical mosquito traps. Thus, the scenario ensures that the mosquito burden within settlements remains just as high as it is today, but increases outside settlements. We do not claim that the scenario studied is the ideal and only solution to the problem at hand. It is only one potential option that we use to investigate the added value of a more nature-friendly mosquito control. Further studies must show whether it is practically possible to protect settlements with the help of technical traps.

For the citizens of the respective settlements, the scenario would lead to a higher financial burden, as the technical traps need to be purchased and maintained, leading to one-off and regular costs. This is not vastly different to the current situation in which costs for mosquito control in the German Upper Rhine region are paid by all member municipalities of the KABS via annual municipal contributions. The payment scenario presented to respondents requires households to finance the additional costs incurred to implement the adapted mosquito control in the form of higher municipal fees. Following the strategy of consequential questioning (Carson and Groves 2007), respondents were told that the scenario presented would only be implemented if households were willing to broadly agree to bear the cost. To determine the willingness to pay, a single bounded dichotomous choice (SBDC) format was chosen, in which the respondents are given the choice between the scenario presented, taking into account the associated costs, and the status quo at zero additional cost. The SBDC format was used as it is the only format that provides incentive compatibility and minimizes hypothetical bias (Carson and Groves 2007). A total of five different cost levels (bids) were used (€10, €25, €50, €100, €200), which would have to be paid annually per household and were randomly assigned to the respondents in the sampling process. The bids were tested in advance and determined during the preliminary survey.

2.2.1. Survey mode and strategy

The survey took place in the form of face-to-face interviews with households in 13 villages along the west bank of the Rhine between Speyer and Neuburg am Rhein (Figure 1). A total of 318 individuals were interviewed in September 2017. A complete dataset was available for 266 interviews, which were used for further statistical analysis. The interviews were conducted by trained students of the University of Koblenz-Landau (now RPTU Kaiserslautern-Landau).

Households were selected randomly based on a defined procedure. In a first step, the planned number of interviews was distributed proportionally across the selected localities according to the number of inhabitants. Since the two cities of Speyer and Germersheim have by far the most inhabitants, these two cities were underweighted. In this way, more interviews were conducted in the smaller villages, which can be assumed to be more affected by mosquito control and therefore had a higher importance for the study. In order to control for the influence of the underweighted cities we used an additional explanatory variable. In a second step, a random selection of streets was chosen for all localities. Each street was then assigned its share of the interviews in proportion to the number of inhabitants of the selected streets. In a final step, individual households were selected for an interview via random walk (Häder 2019). An interview lasted an average of 20 min.

2.2.2. Questionnaire development and pretest

The questionnaire and scenario were developed in several steps, as recommended by e.g. Johnston *et al.* (2017). Prior to the survey, two workshops on mosquito control and a first pre-survey were conducted. The first workshop was attended by 18 experts from science, authorities, environmental associations, KABS, and representatives of affected communities. The second workshop had 38 participants from different authorities, nature conservation associations, science, representatives of KABS e.V. and the Federal Environment Agency, specialists for mosquitoes, amphibians and technical mosquito traps and a citizens' initiative from Bavaria that wanted to establish a mosquito control program. Both workshops included presentations and group discussions on the aspirations of inhabitants, the mosquito control program and the potential negative effects. Community representatives and mosquito control operators shared the opinion that inhabitants will not accept higher nuisance. The pre-survey concerning the population's concern about mosquitoes was conducted in 2016 in front of supermarkets in several towns along the Rhine. A total of 293 interviews were carried out for this purpose.

Based on the results of the two workshops and the pre-survey, the main questionnaire and scenario was developed. The questionnaire was then tested again in a field pilot and revised several times. For this purpose, 37 interviews were conducted with randomly selected households in the Upper Rhine region.

2.2.3. Questionnaire and statistical analysis

The final questionnaire (online [supplementary material](#)) includes questions about (a) places where respondents spent time outdoors, (b) perceptions of, and attitudes towards, components of nature, (c) attitudes, knowledge about and satisfaction with current mosquito control, (d) perceived nuisance and protection measures personally

taken, (e) the valuation scenario and the WTP question, (f) attitudinal questions about treatment with Bti and the scenario presented, and (g) demographic information about respondents. To prepare respondents for the specific project scenario, they were presented with background information on current mosquito control, current funding, treatment in conservation areas, and potential impacts on wildlife. This was followed by the specific project and payment scenario description (see Section 2.2). The information given was illustrated by pictures and figures and after each block of information, questions were asked about the information given to ensure that the information had been absorbed.

For the statistical analysis, the function *sbchoice* from the package DCchoice (Aizaki, Nakatani, and Sato 2015) for the software R (version 1.2.5033) was used. Calculation of the WTP was performed using the standard logistic regression procedure (Alberini and Kahn 2009; Carson and Hanemann 2005; Haab and McConnell 2002)¹.

A logistic regression model was chosen for the estimation of the WTP function, as it can be assumed that the scenario could also lead to a negative willingness to pay for some respondents, due to the increased exposure to mosquitoes outside the settlements. The associated confidence intervals are calculated using the Krinsky and Robb procedure (Krinsky and Robb 1986).

A total of three regression models were calculated, which are built sequentially and differ in the number of variables included (Table 1). The aim of the three models was to test the relevance of the different types of variables. Furthermore, it should be checked which effects turn out to be robust and which effects are possibly superimposed by other variables. In order to evaluate the performance of the models, pseudo R^2 , AIC and BIC were calculated (Burnham, Anderson, and Huyvaert 2011; Hensher, Rose, and Greene 2010). The models were constructed as follows: the first model includes only socio-demographic variables, the second model includes environmental attitude variables and mosquito variables, and the third model includes additional variables on the respondents' recreational activities. An overview of the variables used can be found in online supplementary Appendix B.

The socio-demographic variables used are gender (MALE), age (AGE), school education (EDUCATION), place of residence (CITY), duration of residence (DURATION) and income (INCOME and NO_INCOME). The variable EDUCATION describes the highest school-leaving qualification acquired. A distinction is made between (1): no school-leaving qualification or still going to school, (2): lower secondary school leaving certificate (German Hauptschulabschluss), (3): secondary school leaving certificate (German Realschulabschluss) and (4): upper secondary school leaving certificate (German Fachhochschulabschluss or Hochschulreife). The income variable (INCOME) was determined in the questionnaire using a set of income intervals (in €100), with the mean values of these intervals used for the analysis. In order to include the INCOME variable in the regression analysis, the missing values of 102 respondents were imputed by the mean of the sample (35). To account for this procedure, an additional dummy variable (NO_INCOME) was added to indicate whether or not a respondent reported his or her income.

The variables used for respondents' attitudes towards the environment include a variable that captures respondents' desire to protect components of nature (PROTECT). This is a dummy variable that indicates whether respondents felt that any of the following components of nature should be more protected: bees, insects in

Table 1. Results of the regression analysis.

	Variables	Model 1	Model 2	Model 3
Sociodemographics	Bid	-0.01***	-0.02***	-0.02***
	Intercept	0.59	-1.37	-1.22
	MALE	0.60**	0.74**	0.74**
	AGE	0.00	0.01	0.00
	INCOME	0.02**	0.03**	0.03**
	NO_INCOME	-0.74**	-0.60*	-0.69**
	EDUCATION	0.11	-0.01	0.03
	DURATION	-0.01	-0.01	-0.01
Attitudes	CITY	-0.08	-0.07	0.00
	PROTECT		1.54***	1.40**
	RECONSIDER		0.32	0.35
	TOLERATE		1.56***	1.60***
	MEASURES		0.27**	0.21*
Activities	NUISANCE		-0.27*	-0.26*
	SATISFACTION		-0.32	-0.49*
	WALKING			0.01
	CYCLING			0.27*
	GARDENING			-0.54*
	PICNIC			0.16
	CAMP_SWIM			-0.40
FISH_PADD			0.41	
	Pseudo R ²	0.17	0.30	0.33
	log-likelihood	-149	-124	-120
	AIC	316	279	283
	BIC	348	332	358
	Mean	134(109-181)	121(103-151)	124(105-160)
	Median	117(93-152)	112(92-137)	114(96-144)

*Mean statistical significance at 10%.

**Mean statistical significance at 5%.

***Mean statistical significance at 1%.

general, birds, frogs and toads, streams and ponds, and riparian landscapes of rivers. Furthermore, respondents' opinion that there is a need to reconsider and further develop the current practice of Bti use in view of the possible negative effects for nature is taken into account (RECONSIDER). Another variable that links environmental and mosquito attitudes is the question of whether respondents would be willing to accept more mosquitoes outside urban areas in exchange for not treating areas of high natural value with Bti (TOLERATE). Among the variables that tend to describe attitudes toward mosquitoes is one that captures the sum of all measures taken for personal protection against mosquitoes (MEASURES). The measures surveyed are: fly screens and mosquito nets, sprays and ointments, vaporizers, incense, protective clothing, avoiding being outside at dusk, and avoiding the forest or the Rhine river floodplains. Other variables capture the average perceived nuisance in the region over the last 3-4 years (NUISANCE) and the satisfaction with the current mosquito control (SATISFACTION). Regarding recreational behavior, the following activities are considered: Walking (WALKING), cycling (CYCLING), allotment gardening (GARDENING), and picnicking or barbecuing in nature (PICNIC). Since a main factor analysis had shown that the activities camping and swimming and the activities fishing

and paddling were very strongly related, the mean values for these activities were combined in one variable each (CAMP_SWIM and FISH_PADD).

3. Results

The results of the survey show that the sample is largely representative for the population of the surveyed localities. However, there were a few differences. For example, the proportion of people between the ages of 20 and 34 in the sample was too low and the proportion of people between the ages of 65 and 79 was too high. In terms of gender, more women were interviewed, and in terms of education, more people with a higher degree were interviewed. An overview of the distribution of the various groups can be found in Appendix A.

Furthermore, the results show that respondents do not rate the current nuisance as very high (2.23). But 84% of all respondents take measures to protect themselves from mosquitoes. On average, they take 2.23 measures, the most common being sprays and ointments (55%), followed by fly screens and mosquito nets (49%), and protective clothing (35%). In terms of recreational behavior, the results show that most respondents go walking (91%), followed by cycling (83%), camping and swimming (55%), picnicking and barbecuing in nature (35%), fishing and paddling (21%), and using an allotment garden (6%). Further, the results show that while only about 75% knew that their community is part of KABS, almost all respondents knew about mosquito control in their area. It also shows that currently 61% of respondents are very satisfied with the mosquito control in their area. But, almost half of the respondents were not aware that mosquito control also takes place in areas intended for nature protection. However, 90% of respondents felt that parts of nature should be protected more and 36% of respondents fully agreed with the statement that they would accept more mosquitoes outside settlements if areas valuable for nature were no longer treated with Bti. Only 12% of respondents completely disagreed with this statement and only 18% of respondents think that the current practice of Bti use should not be reconsidered and further developed. The mean values of the other variables used in the regression analysis can be found in [online supplementary Appendix B](#).

3.1. WTP for adapted mosquito control

Overall, 60.2% of respondents answered positively to the SBDC question presented (Figure 3). Among them, 82.7% agreed with a price of €10, 85.7% with a price of €25, 57.9% with a price of €50, 43.6% with a price of €100, and 34% with a price of €200. Of the respondents who rejected the price assigned to them, 41% fully agreed with the statement that there should be no increase in mosquito nuisance outside localities. Likewise, 40% fully agreed with the statement that they do not believe that traps in towns will sufficiently reduce mosquito nuisance and 30% fully agreed with the statement that they do not see that the current practice of mosquito control with Bti could have negative impacts on nature and the environment.

The results of the regression models show that in terms of pseudo R^2 , model 3 best fits the data, while model 2 does, according to AIC and BIC (Table 1). Since the significant factors in the three models remain largely the same and the focus of the study is on the factors that explain WTP, all significant factors are discussed in more detail below.

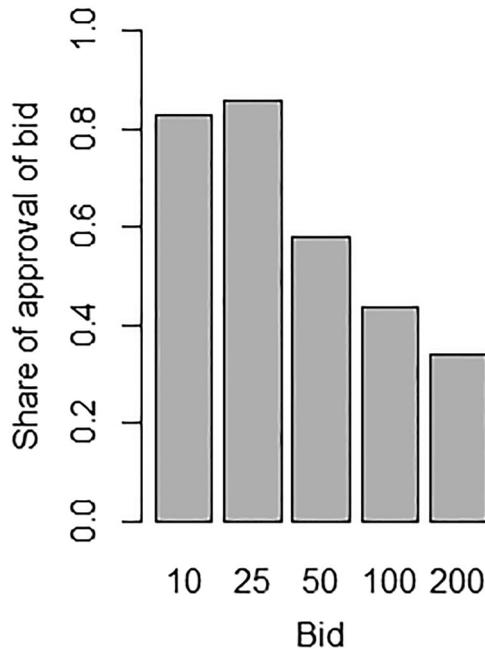


Figure 3. Share of approval of bid.

As expected, the scenario was rejected more often if the associated costs were higher (BID). Regarding the socio-demographic variables, we find that male respondents have a higher WTP than females (MALE), and people with a high income have a higher WTP (INCOME). Respondents who refused to report their income have a lower WTP (NO_INCOME). Respondents' age (AGE), education (EDUCATION), duration of residence (DURATION), and place of residence (CITY) had no effect on WTP. Regarding respondents' attitudes towards the environment, the results show that people who think that nature should be protected more, or who are willing to accept more mosquitoes outside settlements in exchange for not treating areas of high value for nature with Bti, have a higher WTP (TOLERATE). On the other hand, the opinion of respondents that the current practice of Bti use should be reconsidered and further developed with regard to the possible negative effects on nature (RECONSIDER) showed no effect on WTP. Regarding respondents' attitudes towards mosquitoes, results show that WTP increases with the number of personal mosquito protection measures taken (MEASURES), but decreases with the level of perceived nuisance (NUISANCE) and satisfaction with the current mosquito control (SATISFACTION). Furthermore, with regard to recreational activities, people who frequently ride a bicycle have a higher WTP (CYCLING), while people who frequently use an allotment garden have a lower WTP (GARDENING). For the activities walking (WALKING), picnicking (PICNIC), camping and swimming (CAMP_SWIM), as well as fishing and paddling (FISH_PADD) no influence on WTP was observed.

Regarding the WTP of the studied population for an adapted more nature-friendly mosquito control, the results of model 3 show that mean WTP is €124 per household and year, and median WTP is €114, with respective confidence intervals ranging from €105 to €160 and €96 to €144 (Table 1).

The total benefit for the studied scenario is obtained by aggregating the welfare estimates for the entire population of the specific region from which the sample was drawn. Taking into account the calculated mean WTP and the number of households in the study area ($n = 61,789$), this results in an added value of €7,661,836 per year. Using the lower and upper limits of the WTP confidence intervals (Table 1), the total estimated benefits range from €6,487,845 to €9,886,240. When considering the whole area of the Upper Rhine where mosquito control is applied by KABS, the added value would be much higher. For the 1,138,000 households living in this area (Von Hirsch and Becker 2009), the added value would amount to about €141,112,000 per year. Taking into account the lower and upper bounds of the WTP confidence intervals, the added value would range from €119,490,000 to €182,080,000.

4. Discussion

4.1. The WTP for adapted mosquito control and the added value for the population

The results of this contingent valuation study show that the majority of the surveyed population in the surveyed region of the Upper Rhine valley of Germany highly value adapted mosquito control that better protects nature (Table 1) and respects the current nature protection areas. Thereby, the majority of respondents accept a higher level of nuisance outside settled areas, but expect protection to be maintained within settled areas.

The willingness of people to pay for the scenario presented is determined by weighing the individual costs and benefits (Figure 2). In this respect, the results show that the benefits of the scenario, namely better protection of chironomid midges and the animals that depend on them, clearly exceed the costs, namely an increased mosquito burden outside the settled areas. The surplus benefits as measured by WTP still leave room to cover any yet unknown additional monetary costs due to more efforts for adapted control. Since respondents' WTP takes into account both the benefits and costs resulting from the use and non-use values shown in Figure 2, and it is known that people place a high value on nuisance reduction (Dickinson and Paskewitz 2012; Halasa *et al.* 2014), it can be deduced that the value people place on nature protection obtained from the scenario presented exceeds the calculated mean WTP of €124 (net added value). Furthermore, our results suggest that the value of nature for the population is primarily composed of the existence value, bequest value and option value of the respondents, since not so many people fish or actively observe nature in such areas and direct use would also be negatively affected by the increased mosquito burden. This, in turn, shows that non-use values, in particular, have a very high importance for the population compared to use values.

With regard to the added value of mosquito control, Von Hirsch and Becker (2009) have already shown that the population in the Upper Rhine region attaches a high value to it and that this value exceeds the associated costs by a factor of 1.8. The results of this study now indicate that the added value for the population could even be significantly increased by applying more nature-friendly mosquito control as the determined WTP for such a scenario is 10 times higher than what households already contribute to the KABS treatment. However, since in our scenario costs are both monetary (more effort using the traps) and non-monetary (more nuisance outside settlements), an outright benefit-cost ratio cannot be computed. Further, the monetary costs for more nature-friendly mosquito control remain unknown since up to now it has not

been proven that a technical trap-scenario, as presented here, is actually functional in practice. This scenario is used here as a template for any other more nature-friendly mosquito control technique, either existing or to be developed in the future.

4.2. Determinants influencing the WTP

As expected, respondents' WTP is determined by certain socio-demographic factors, as well as attitudes towards the environment and mosquitoes. As for sociodemographic variables, it is surprising to find that men have a higher WTP than women, as Halasa *et al.* (2014) found exactly the opposite effect. The lower WTP of women in this study could be explained by distrust in traps; women were three times more likely to fully agree with the statement that they did not believe that the traps in the localities would sufficiently reduce mosquito nuisance. Further, the results of the study show that, similar to Dickinson *et al.* (2016), Farmer *et al.* (1989), John, Stoll, and Olson (1987), John, Walsh, and Moore (1992), and Mwebaze *et al.* (2018), higher income has a positive effect on WTP. Furthermore, and in accordance with Halasa *et al.* (2014), John, Walsh, and Moore (1992), and Reiling *et al.* (1989), we find no influence of place of residence on WTP for mosquito control. Thus, underweighting of the cities of Speyer and Germersheim in the sampling does not bias the results. But not all expected effects could be confirmed. For example, neither an effect of education (as found by Dickinson *et al.* 2016; Farmer *et al.* 1989; John, Stoll, and Olson 1987), age (Dickinson *et al.* 2016; Farmer *et al.* 1989; Mwebaze *et al.* 2018; Von Hirsch and Becker 2009), nor length of residence (Farmer *et al.* 1989; Von Hirsch and Becker 2009) could be detected in this study.

This study analyzes which attitudes towards the environment and mosquitoes (nuisance) determine WTP for more nature-friendly control. Specifically, it is the desire to improve protection of sensitive habitats and wildlife that leads to higher WTP statements, which is in line with the findings of Dickinson *et al.* (2016), Ingabire *et al.* (2017), and John, Stoll, and Olson (1987). But in our study WTP for more nature-friendly mosquito control is also determined by the degree of acceptance of more mosquito nuisance outside settlements if nature is protected in sensitive areas. This demonstrates that respondents truly evaluate the trade-off between desirable nature protection and mosquito nuisance, which is an indicator for the validity of our survey data.

However, the hypothesis that people who think that current control practices should be reconsidered and further developed will have an impact on WTP could not be confirmed.

Furthermore, we find that, as in John, Stoll, and Olson (1987), Reiling *et al.* (1989), and Von Hirsch and Becker (2009), taking personal mosquito protection measures has an influence on WTP. One explanation for this may be based on people's experience. People who already take multiple measures to protect themselves from mosquitoes may have less of a problem with higher levels of nuisance outside localities and may also be more positive about the use of technological traps. The perceived nuisance was found to have a negative influence on WTP for more nature-friendly mosquito control. This effect is not surprising, since people who perceive themselves to be more disturbed automatically associate higher (emotional) costs with an increase in nuisance outside of localities. Like Farmer *et al.* (1989) and Von Hirsch and Becker (2009), our study finds a significant negative effect of respondents' satisfaction with

the current mosquito control and WTP for an alternative, indicating the tendency to keep the status quo the more it suits them.

As expected, some outdoor activities have an impact on WTP. We find the plausible effect of a decrease in utility due to an increase in mosquito nuisance and a resulting lower WTP only for some activities such as, for example, allotment gardening. No effects, however, were found for most other outdoor activities such as walking, picnicking, camping and swimming, as well as fishing and paddling. We presume that this may be the result of two counteracting effects: people who engage more in these activities experience a higher nuisance when performing those activities; but those people may be the ones with higher general environmental attitudes so that no clear relationship to WTP can be observed. In the case of cycling, we even find a positive relationship. This can be explained by the fact that the activity of cycling in our survey is correlated with both increased perceived nuisance and, at the same time, with the opinion that nature should be more protected in the future.

4.3. Reasons for negative responses to the WTP question

In this CVM study, on average, around 40% of respondents rejected the offered bid. Rejection occurs when the perceived benefit is lower than the offered bid. In this survey 41% of respondents who rejected the bid agreed to the statement that there should be no increase in mosquito nuisance outside settlements. Likewise, 27.5% stated that they could not see any negative impacts from the current Bti treatment. Both statements represent expressions of the benefits respondents perceive to receive or not from the scenario presented and can, thus, be considered valid value expressions. However, also 40% of the respondents who answered “no” to the WTP question stated that they do not trust the technical traps and consequently fear a higher nuisance within settlements, while the scenario description says otherwise. This statement shows that not all respondents trusted the scenario presented. It remains open whether the aforementioned reasons also led the respondents to see no or little benefit in the scenario presented and, accordingly, to reject the bid although they may appreciate the related benefits. But the statements indicate that people’s WTP could have been even higher if all respondents had been given appropriate confidence in the traps. It is important to note, once again, that the scenario presented is hypothetical and was used in this study only to determine the value of more nature-friendly mosquito control. Whether technical traps could be used to protect settlements must first be further investigated. However, the reasons for rejecting the scenario also highlight the potential to increase the benefits of adapted mosquito control to society through awareness raising. In this way, people who recognize the now proven negative environmental effects of Bti treatment and trust alternative solutions may also be motivated to accept an increased nuisance outside settlements.

5. Conclusion

In summary, the results of the study show that the population surveyed attaches a considerable value to a more nature-friendly mosquito control as compared to the current costs of the Bti treatment and large parts of the population in the study area would apparently even accept a higher nuisance level outside the settlements. The results of this study confirm the findings of previous studies (Dickinson and Paskewitz 2012;

John, Stoll, and Olson 1987; Westerberg, Lifran, and Olsen 2010) that have already shown that people value nature-friendly mosquito control. Furthermore, our study finds much higher WTP compared to previous studies (John, Stoll, and Olson 1987; Von Hirsch and Becker 2009).

However, it is questionable whether the respondents would have accepted a higher nuisance within the localities. The results of the study further show that WTP for the scenario presented depends on gender, income, respondents' support that parts of nature should be more protected, willingness to accept more mosquitoes outside settlements, the number of personal mosquito protection measures currently taken, perceived nuisance, satisfaction with current mosquito control, and frequency of cycling and allotment gardening activities.

The results of this study indicate that such an environmentally friendly control strategy could generate a high added value for society. Whether such a scenario should involve the use of technical traps or other solutions is yet to be studied. What is clear, as demonstrated in our study, is that the majority of respondents (67%) want the current Bti application to be reconsidered and mosquito control further developed to be more nature friendly. This wish is in line with the call of numerous researchers for the adaptation of mosquito control to the latest scientific findings (Boisvert and Boisvert 2000, Brühl *et al.* 2020, Poulin, Lefebvre, and Paz 2010). Further, recently the German federal law for the protection of nature was revised to counteract the continuing severe decline in insect biomass in German nature conservation areas (Hallmann *et al.* 2017). The law now explicitly states that large scale biocide applications (and Bti is such a biocide) are prohibited in nature conservation areas (NSG), national parks and other smaller conservation area types. Due to a lack of practical alternatives to the current treatment, state governments issued temporary exemptions from this ban on the grounds of adverse health effects, such as infections caused by mosquito bites. But our study shows that people in the affected regions are both willing to accept higher mosquito nuisance outside of settlements and are willing to pay a considerably higher price for more nature-friendly mosquito control. Consequently, now is the time to work on and promote practical and more nature-friendly alternatives to the current large-scale mosquito control with Bti, even if they come at some higher cost. As shown in our study, this would benefit both nature as well as people.

Note

1. The estimation of WTP is based on the logistic distribution $F_{\eta}(\Delta\bar{v}_h) = (1 - e^{-\Delta\bar{v}_h})^{-1}$ where $F_{\eta}(\cdot)$ is the cumulative distribution of η , $\Delta\bar{v}_h = \bar{v}_h^1 - \bar{v}_h^0 = (\alpha^1 + \beta(I_h - A_h)) - (\alpha^0 + \beta I_h) = \alpha - \beta A_h$ (where $\alpha = \alpha^1 - \alpha^0$) is the difference in indirect utility of household h between utility with the project (superscript 1) while contributing to it monetarily (A_h) and without the project (superscript 0, no monetary contribution). I_h denotes household income. According to random utility theory, indirect utility can be written as a linear combination $\alpha + \beta I_h$ and a random term ε_h . α includes the household's socio-economic and demographic characteristics. We further define $\eta = \varepsilon_h^0 - \varepsilon_h^1$. The probability of accepting the offered bid can be written as $\Pr\{ves_h\} = \Pr\{\eta \leq \Delta\bar{v}_h\} = F_{\eta}(\Delta\bar{v}_h)$. (Maximum)WTP_{*h*} can be defined as A_h when $\Delta\bar{v}_h = 0$ since then the household would be indifferent between situation 1 and 0 despite having to pay A_h . Consequently, $0 = \alpha - \beta WTP_h$ so that $WTP_h = \frac{\alpha}{\beta}$. Further socio-economic or other variables determining WTP can be included by augmenting the utility difference to $\Delta\bar{v}_h = \alpha - \beta A_h + \varphi_j s_{hj}$ where s_{hj} is a vector of J characteristics and φ_j the respective parameter vector. The parameters α and β as well as φ can be estimated using maximum likelihood estimation in R.

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Supplemental data

Supplemental data for this article can be accessed [here](#).

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