Asian tiger mosquito far from home: Assessing the impact of invasive mosquitoes on the French Mediterranean littoral

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Highlights:

- Invasive Asian tiger mosquito both cause nuisance and can transmit serious diseases
- We value these disservices with two stated preferences methods
- The most frequent attitude places the risk of contracting mosquito-borne diseases first
- We identify 3 groups: averse to disease risk, averse to the nuisance, and indifferent
- The main explanatory factors are insecticides and repellents expenditure, housing place and income

Key-words: Invasive Species, Asian Tiger Mosquito, Contingent Valuation Method, Discrete Choice Experiment, Risk and Nuisance Cost

1. Introduction

Although the issue of biological invasions has gained wide recognition both within the scientific community and in the whole society, the definition of what constitutes an invasive species remains debated. To be classified as invasive, a species must first be introduced into a new environment in which it was not previously present; this step can occur independently of human activity, either accidentally or deliberately. Then, it must develop the ability to survive, reproduce, adapt and propagate in this new habitat; which has impacts on the local flora and fauna, and affects the ecosystems (Emerton and Howard, 2008). Biological invasions are a growing problem, due to their increased frequency and the continued expansion of human movements around the world. In a world where the impacts of human activities are pervasive, the specificity of the impacts of invasive species have been questioned (Davis et al., 2011). The difficulty of assessing ecological impacts tend to give more relevance to the evaluation of the consequences on human populations. Although most likely grossly underestimated, the costs linked with invasive insects appear massive and increasing (Bradshaw et al., 2016). They can be divided into direct and indirect costs, depending on whether they result directly from the impacts on the host ecosystem or not. Direct costs include public expenditure on invasion control and costs for the treatment of human and animal pathologies. They also include the effects on other ecosystem services (Evans, 2003). Indirect impacts are not specific to the host ecosystem and relate to public health, effects on private spending, prices and markets, recreational activities and tourism (Emerton and Howard, 2008; Evans, 2003). Controlling invasions is considered a public good, since it benefits the whole community (Perrings et al., 2002; Halasa *et al.*, 2012); this is why it is essential to include control measures in programs aimed at reducing the impacts of invasive species (Leung et al., 2002).

With black and white stripes all over its body and legs, *Aedes albopictus*, commonly known as the Asian Tiger Mosquito (ATM) is easily recognizable. Originally native from the tropical and subtropical area of South-Eastern Asia (Mwebaze et al., 2017), the ATM is currently the most invasive mosquito in the world, recorded in South America, Africa, in the islands in the Pacific and Indian Ocean, and in temperate zones in Europe and North America (Paupy et al., 2009).

The presence of *Aedes albopictus* generates both nuisance, linked to the bites which occur over a wider time range than for native species, and a risk of disease transmission. At this point, it should be pointed out that the perception of the nuisance depends largely on the sensitivity of each individual to the bites. Moreover, the cost of the invasion entails the expenses incurred to monitor and control it and its impacts. The overall cost of a disease such as dengue and chikungunya can be divided into direct costs, including the cost of diagnosis, treatment and prevention of the disease, and indirect costs (Suaya et al., 2007). The latter refers to the economic value lost by households and the society in general because of illness, early mortality of patients and loss of productivity of household members and friends of the patients. Therefore, understanding the population's preferences for the perceived nuisance and the risk related to tiger mosquito-borne diseases may help the public administration in making choices to improve the situation. Most nuisance costs are not directly reflected in market prices, so they cannot be measured directly. Our study therefore consists in constructing of framework that allows analyzing not only the nuisance caused by the ATM, but also the costs of avoiding nuisances and diseases, whereas the measurement of the direct costs of treating the patients will not be addressed here.

In this paper, we use a non-market evaluation method in order to identify the preferences of individuals based on their willingness to pay for the implementation of prevention and control measures. Concretely, our work aims to quantify the impact of nuisance and risk of contracting the diseases transmitted by the ATM, determine their value from the point of view of potentially affected subjects, identify the factors that explain these values, and pinpoint the aspects that characterize the individual preferences regarding nuisance and risk. Few studies have addressed these issues from an economic perspective, particularly in non-tropical contexts. To our knowledge, this is the first economic evaluation of the impact of invasive mosquitoes in France, and the first that uses both contingent valuation (CVM) and discrete choice experiment methods (DCE) in a complementary way. In the following sections, we first examine the literature on the situation of the ATM invasion in France and the few studies that have analyzed the socio-economic impacts of the invasion of this species in comparable contexts. We then present the methods used and, in more detail, the construction of the survey questionnaire, the description of our sample, and we present and analyze the results. The last section discusses the results and their significance, in the light of current literature.

2. Context and motivations

The geographical extension of the ATM out of its indigenous habitat into new areas of its potential range, expanded mainly during the three last decades (Lounibos, 2002), often initiated through the transportation of eggs via the international trade in used tires (Reiter and Sprenger, 1987) and, to a lesser extent, to the importation of lucky bamboos, namely in California (Madon et al., 2002) and the Netherlands (Scholte et al., 2007). The soaring development of international trade during the 20th century enabled the ATM to invade more than 28 countries (Reiter and Sprenger, 1987). Protective measure against spread could be to ban international trade in used tires, but free trade policies make it an implausible solution (Benedict et al., 2007). Although its favorite habitats are rural environments and the proximity to forests (Higa, 2011), its ecological flexibility allows ATMs to evolve and adapt to more urban environments (Paupy et al., 2009). Therefore, the female lays its eggs in both natural water recipients like tree holes and phytotelmes (Tsiodras et al., 2016), and artificial containers such as watering cans or uncovered pools.

As a diurnal species, it bites mostly early in the morning and late in the afternoon, around sunset (Paupy et al., 2009). Monitoring its spread is important from a public health perspective due to its aggressive daytime human-biting behaviour and ability to vector many viruses (Pereira-dos-Santos et al., 2020), including Dengue (La Ruche et al., 2010; Paupy et al, 2009), Chikungunya (Pialoux et al., 2007; Rezza et al., 2007; Peyrefitte et al., 2007; Leroy et al. 2009; Gould et al. 2010), West Nile (Akıner et al, 2019), and Zika (Grard et al., 2014; WHO, 2016). ATM has thus been the source of several chikungunya and dengue outbreaks, in countries sometimes very far from its native area .

In France, *Aedes albopictus* was first detected on the French-Italian border in 2002, according to the Mediterranean mosquito control agency (the Entente Interdépartementale de Démoustication Méditerrannée or EID). The infested part of French territory is divided into regions where mosquito control agencies operate. EID is the main one and covers a large part of the south of the country, a territory on which more than 13 million people live. The EID strategy involves mostly communication campaigns, with active control triggered only in the event of an outbreak after confirmation of indigenous and imported cases, particularly to prevent mosquitoes from developing resistance to the insecticides used to control them.

As described in Table 1, population surveillance, control and protection measures have been put in place as part of the national anti-dissemination plan for chikungunya, dengue and Zika viruses. This plan is implemented each year from May 1st to November 30th by the prefectures, regional health agencies and departmental councils, with 6 alert levels, ranging from 0 to 5 (Septfons et al., 2015).

Table 1. Prevention and control activities according to the different level of severity of the situation

Levels	Descriptions	Typical actions
0	0a. Absence of *Aedes albopictus* 0b. Controlled presence of *Aedes albopictus* from May 1 to November 30	- Entomological watch, setup (without vector control)
1	Implanted and active *Aedes albopictus*	- Entomological surveillance - mosquito control actions
2	Implanted and active *Aedes albopictus* and presence of a confirmed indigenous human case of vector transmission of chikungunya or dengue	- Entomological surveillance - Mosquito control actions
3	Implanted and active *Aedes albopictus* and presence of an outbreak of indigenous human cases (definition of outbreak: at least 2 cases grouped in time and space)	- Entomological surveillance - mosquito control actions
4	Implanted and active *Aedes albopictus* and presence of several outbreaks of indigenous human cases (separate outbreaks with no epidemiological or geographic link between them)	- Entomological surveillance - Mosquito control actions - Epidemiological surveillance
5	Implanted and active *Aedes albopictus* and epidemic 5a. Diffuse distribution of indigenous human cases beyond already individualized outbreaks. 5b. Epidemic over a wider area with a high attack rate that exceeds the epidemiological and entomological surveillance capacities implemented for previous levels and requires an adaptation of the surveillance and action methods.	- Entomological surveillance - Mosquito control actions - Epidemiological surveillance

The ATM invasion generates money costs for French and European municipalities. In France the cost of vector control (VC) amounted to €0.20/cap. on average in 2016 (from data communicated by the EID that covers 82% of the invaded territories), with an upward trend of 5% per year. This cost had been estimated at €0.18/cap./y on average in Italy, in 2011, and €1.5/cap./year in Emilia-Romagna in 2008-2011 (Canali et al., 2017). These costs can rise very rapidly in case of an epidemic. For instance, the cost of reporting a contamination case is empirically estimated by the EID Med at 135 euros. This includes the time spent for the investigation after the phone notification, laboratory costs, interviews, analysis of results, time to set up surveillance, among other actions. As for the cost of health surveys, it includes the cost of training interviewers, the time spent in field for the door-to-door survey, the cost of organizing preparatory meetings and the preparation of regular epidemiological assemblies;

these costs are estimated between €3,120 and €10,800, according to unpublished data from the EID Med. These costs do not include the expenses related to the patients' care, whether hospitalized or not.

Trentini et al. (2018) have developed an original framework they call a cost-utility epidemiological assessment of vector control measures which allows them to extend the socioeconomic analysis of the interventions implemented after the 2007 outbreak in Italy to non-market aspects. They conclude to the cost-effectiveness of these interventions that they estimate to have enabled about 3200 prevented cases, 1450 DALYs averted and €13.5 M saved.

Although the ATM keeps on spreading and gaining more geographical extension, there are few studies assessing the cost of this invasion and quantifying its economic impacts. To value these impacts, non-market valuation methods are used to estimate the costs placed by residents on the nuisance and health risks. Halasa *et al.* (2012) aimed to measure the demand for an area-wide integrated pest management program that will efficiently reduce the nuisance of the ATM in New Jersey. Using a Contingent Valuation Method (CVM), they showed there was a preference for payment via a tax and estimated the WTP at $5.42 per capita per year. However, it should be mentioned that only the nuisance is considered in this study, and the WTP would eventually increase in case of an epidemic outbreak. Also in New Jersey, Halasa *et al.* (2014) found that 54.6% of respondents considered the ATM to be an issue, and its presence deprived 59.5% of the subjects from enjoying their outdoor activities. The authors estimated that the maximum amount residents were ready to pay for an additional hour of outdoor activities without mosquitoes varied between $6.47 and $10.75 respectively for house maintenance and relaxing outside.

The authors of the previous study presented in another article a cost-benefit analysis of the integrated management project implemented between 2009 and 2011 in order to reduce the nuisance caused by the tiger mosquito (Shepard et al. 2014). The program would have recovered 4.45 hours lost from outdoor activities between 2009 and 2011. The study also highlighted the effectiveness of the program when it is implemented in years when rainfall is abundant. In addition, the authors have shown that the progress of the project has favored the development of a less costly and technically more effective strategy which focuses on an intervention in the early spring.

In Australia, Mwebaze *et al.* (2017) conducted a study to measure the WTP to reduce the risk of ATM invasion. Through a CVM, they showed that Australians were ready to pay A$ 67for a decrease in the risk of invasion from 50% to 25%, but their WTP raised to A$90 when the risk reduction was from 50% to 5%. They pointed that the WTP was lower for respondents who were already spending privately on mosquito control, and also that the WTP depends on how the probability of invasion changes.

In Athens Bithas *et al.* (2018) estimated with a Discret Choice Experiment (DCE) the benefits of a mosquito control program that separated the impacts of local mosquitoes and those for which the ATM was responsible. The authors showed that programs to reduce the risk of contracting ATM-borne diseases were more likely to be chosen.

3. Methods

Beyond the cost of patient treatment, most ATM impacts are not directly observable on markets. Non-market impacts can be assessed with methods based on preferences revealed by choices or observable behaviors of agents, or methods based on preferences stated within survey protocols. Among the latter, we have deployed a dual approach: the CVM aims to obtain a willingness to pay (WTP) directly, and the discrete choice experiment (DCE), by asking subjects to express preferences between hypothetical multi-attribute situations, makes it possible to deduce WTP indirectly.

To elicit individual preferences, numerous approaches within the CVM structure exist. We used a dichotomous choice (DC) format, in which a subject does not have to determine the value he thinks suits the considered good or service. The survey provides a bid (€25), which could be accepted by the subject if he is ready to pay that amount or more, or refuse otherwise, assuming that whichever answer he chooses, it is the one that maximizes his utility (Luchini, 2002; Mwebaze et al., 2017). It was followed by two Open-Ended (OE) questions where respondents gave a free-form answer on the maximum amount they would be willing to pay each year for additional communication and control measures to reduce respectively the risk of contracting ATM-borne diseases and the nuisance resulting from its invasion.

3.1. The Discrete Choice Experiment

The DCE method consists of the design and analysis of data based on choices made by the individuals through surveys developed in a hypothetical market context. The designed alternatives form the choice cards, with each alternative defined by attributes varying according to several levels. Usually, experimental designs are used to construct the choice cards in a way that the attributes are not self-correlated (Hoyos, 2010). The cost attribute is typically included to refer to price of the occurring change (Hanley et al., 1998).

The DCE method originates from the combination of Lancaster's theory of value, random utility theory and experimental design (Bithas et al., 2018). According to Lancaster's theory, the global utility of a good can be decomposed into the sum of the utilities of its attributes. This implies that consumers' decisions are determined by the utility they derive from the attributes of a good and from the levels of these attributes, and that they choose the option whose utility is the highest (the most preferred alternative) (Araña and León, 2009; Bithas et al., 2018). The utility that an individual *n* takes from an alternative *i* is expressed:

$$U_{in} = U\,(Z_{in}, S_n)$$

Where Z groups the attributes of the alternative *i* and S the characteristics of the individual *n*. Random utility theory was proposed by Thurstone in 1927 and served as a basis for explaining the dominant choices among pairs of offers. According to Thurstone, although consumers are supposed to choose the alternative they prefer and which copes with their constraints, the chosen option is not necessarily the most preferred one. This is explained by a random component in the utility function of consumers, which is expressed as follows (Adamowicz and Louviere, 1998):

$$\mathrm{U_i} = V_i + \varepsilon_i$$

With U_i the actual utility provided by the alternative i, V_i the observable deterministic part of the utility, and ε_i the random component (unobservable). The deterministic component depends on how much we are able to identify, measure and include as many main factors influencing the decision as possible. It is expressed according to a linear function of the parameters of the dependent variables:

$$V = \beta(X_n)$$

Where β is the vector of the utility coefficients of the attributes and X_n the vector of the dependent variables. Consequently, the probability for an alternative i to be chosen from a set of options C is written as follows:

$$\mathrm{P}(i|C) = P[\,(\beta(X_{in}) + \varepsilon_{in}) > \left(\beta\left(X_{jn}\right) + \varepsilon_{jn}\right), \forall j \in C]$$

3.2. Survey design and administration

The questionnaire should make it possible to collect all the information enabling the preferences of the subjects to be analyzed. It was organized in three sections:

- The first dealt with the general experience of the subjects with mosquitoes. It included questions about the inconvenience related to the ATM, the sensitivity to the nuisance, the possible shortening of the time spent outdoors due to the presence of mosquitoes, the expenditures on repellents and insecticides, and the individuals' assessment on current mosquito control efforts;
- The second dealt with specific questions about the ATM. Respondents were asked if they had a previous knowledge about the ATM, about its ability to transmit certain diseases. We have inserted here a small paragraph on the symptoms of dengue, chikungunya and Zika viruses. DCE choice cards and CVM questions were the main part of this section;
- The last section dealt with the socio-demographic characteristics of the respondents (age, gender, place of residence, family situation, education, income, etc.).

The CVM part included a question in the DC format, asking if the individual's household was willing to pay an additional €25 per year for policy measures that could reduce the likelihood of ATM invasion in the area. If the respondent answered no, we asked him to explain why. This was useful in determining protest responses in the analysis for which we opted for a logit regression model. The OE question came after, and was split into two parts. We asked individuals the maximum amount they were willing to pay annually for enhanced control and prevention measures, which would prevent them from contracting the ATM-related diseases, and mitigate the nuisance caused by the ATM (implicitly, mosquito bites). The data were censored in zero and truncated at €51 (we considered each WTP value greater than twice the offered bid in the DC question as an outlier). We therefore analyzed it using a Tobit model, by considering first the whole data set, and then removing the protest response. In order to distinguish true zeros from protest ones, we considered all respondents who refused to pay for the additional measures for economic reasons, otherwise they were categorized as protest.

For the design of the choice experiment, the first step was to define the attributes. An attribute is relevant when conclusions about individual preferences may be altered if it was neglected (Lancaster, 1966; Hoyos, 2010). We aimed to study all the inconvenience related to the ATM invasion, especially the nuisance caused by its presence and the risk of spreading the diseases it can transmit. With this in mind, we organize focus groups with stakeholders and experts to make sure that the identified attributes were relevant and included all the aspects to be considered. Then, the four attributes were explained to the respondents as follows:

- Nuisance: It increases when a mosquito bites become more frequent, and when the perceived inconvenience due to their presence increases until the individual eventually shortens the time spent outdoor. The three featured levels were: current; medium; and low nuisance levels.
- Risk of contracting diseases: We have described the potential for disease spread through an indicator called "D" (for dissemination), which depends on the number of secondary cases generated from one infected individual. When it takes a value greater than 1, each person who is ill risks contaminating others, and this is how the disease spreads. For instance, in 2014, 11 indigenous cases of chikungunya were recorded in the city of Montpellier. Another epidemic broke out in 2015 in Nimes (a medium-size city located 50 km from Montpellier), the indicator D was expected between 0.5 and 3.2. It was then estimated to be 3.2, which means that, on average, each sick person infects three others. When this indicator takes a value less than 1, the number of people infected decreases naturally because patients do not necessarily transmit the virus they carry. This attribute also takes three values: current; medium; and low levels.

The first 2 attributes represent the impacts related to the invasion of the ATM. Since the forces, pressures and state have been described in the introduction, the following attribute reflects the response to the invasion.

- Actions and strategies of communication and intervention: mosquito surveillance and control include all actions taken to lessen its presence. With regard toATM, these actions consist mainly of communication and prevention campaigns, actual chemical treatments are only used in areas surrounding disease suspected cases. The levels here were: current level of communication; reinforced communication; communication and public intervention.

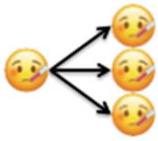
- Cost: It is the amount of money the respondents can afford to pay for improving ATM control actions. It would be included in their electricity bill every two months during the season of mosquito activity, which runs from June to September (a supplement twice a year). Here, 6 levels were proposed, with bids ranging from 0 to €25.

Regarding the nuisance, risk and action attributes, we assumed that the utility increased from one level to the next, that is, the current situation provides the lowest utility. Once our attributes and levels have been identified, we have combined them into an appropriate experience plan. A complete factorial design generates 3 * 3 * 3 * 6 = 162 situations. From these too many possibilities, we determined a reasonable size for an efficient design. The SAS software suggested the conception of 18 choice cards. Next, we used *Ngene* (version 1.1.1) to generate the experimental design for the DCE, which included three options in each choice card, one of which is the status quo. We defined 3 blocks of 6 choice sets, and each block was included in a separate survey, which resulted in three versions of the questionnaire. Figure 1 shows an example of a choice card used in the survey.

Before conducting the surveys, the questionnaire was discussed with colleagues and sent to people with diverse academic profiles, to ensure that the questions were unambiguous, clear and understandable by all. It was then tested with a dozen subjects as a pilot survey.

The survey was implemented in face-to-face interviews by the authors in the city of Montpellier between June and July and 2018, during daytime on weekdays and weekends. We interviewed residents aged 18 and over, to the extent that they kindly agreed to answer our questions. Some 168 people were surveyed and all questionnaires were usable for analysis. Although it is difficult to judge the representativeness of our sample, we strived to randomize the geographic scope of the implementation, surveying all sectors of the city. Each survey lasted approximately 15 to 20 minutes.

Figure 1. Example of a choice card used in the questionnaire

	Option A		Option B		Option C (status quo)
Nuisance	Low nuisance		Current level of nuisance		Current level of nuisance
Risk of contracting diseases	$D \geq 3$ (status quo)		$D < 1$		$D > 3$ (status quo)
Actions and communication strategies	Current level of communication		Communication and intervention	 	Current level of communication
Cost	€20		€5		€0

The most practical and commonly used model in discrete choice analysis is the logit model. It is based on the assumption that the error term ε are independently and identically distributed (IID), which occurs when the unobserved part of the utility of an alternative is not linked to that of another alternative (Train, 2003). Two types of logit models can be used: the conditional logit model (CL) and the multinomial logit model (MNL). The former is used when it is assumed that individual choices depend on the attributes of the alternatives, while the latter is employed when individuals' preferences depend on the characteristics of the individuals themselves (Hoffman and Duncan, 1988). One major assumption on which these models are based, is the property of independence from irrelevant alternatives (IIA), which assumes that the probabilities related to the choice of two alternatives will not be affected by the presence of other alternatives (Bithas et al., 2018). In addition to that, the CL model assumes that the coefficients of the dependent variables are constant, which means that distinct individuals who share the same characteristics will necessarily have the same WTP values and the same preferences (Train, 1998). In other words, individuals' preferences are assumed to be homogeneous (Birol et al., 2006). It will therefore be used firsthand to assess average preferences, while the MNL model will be utilized later on.

However, since individual preferences are heterogeneous, the random-parameter logit model (RPL) takes this into account, providing unbiased estimates of individual preferences and improving their accuracy and reliability (Birol et al., 2006). It could be assimilated to a generalization of the logit model since the estimated coefficients vary randomly (Train, 1998). Prior to using though, one must first determine the parameters for which the distribution will be considered random by the model (Hoyos, 2010). In our study, all level attribute variables except for the cost were randomized. However, the effect of individual characteristics does not appear in the probabilities of choice (Boxall and Adamowicz, 2002).

Explaining the heterogeneity of preferences, requires using the latent class model (LC) that highlights the demographic differences between the groups of respondents (Bithas et al., 2018). Individual choices and behaviors derive not only from the attributes of the concerned good, but also depend on the characteristics of the individuals (Boxall and Adamowicz, 2002). The LC model groups individuals into homogeneous categories of behavior, thus allowing the identification of preferences specific to each class (Bonnieux and Carpentier, 2007). The population is therefore segmented into a finite number of groups of individuals where the membership depends on the socio-economic characteristics of each (Birol et al., 2006).

3.3. Welfare Analysis Model

To analyze the welfare of individuals, we used estimated coefficients to calculate the marginal willingness to pay (MWTP) associated with the attributes levels. The MWTP for a level j is the negative of the ratio of the coefficient related to this level (βj) and that of the monetary attribute (β_{cost}), expressed as follows:

$$WTP_j = -\frac{\beta_j}{\beta_{cost}} \quad (4)$$

Since the levels of the attributes were effect coded, the WTP for the current level of each attribute can be obtained from the negative sum of the WTP of the other levels of this attribute, following:

$$\mathrm{WTP}_{\mathrm{status\ quo}} = \mathrm{WTP}_1 * (-1) + \mathrm{WTP}_2 * (-1) \quad (5)$$

4. Results

4.1. Individual characteristics of the respondents

Among the 168 individuals interviewed, three quarters declared being bothered by mosquito bites or, more rarely, having contracted a mosquito-borne disease. Respondents are moderately sensitive to the nuisance, with a sensitivity level of 3 out of 5 (3 being moderately sensitive and 5 being very sensitive to nuisance). The intolerance to the use of insecticides was also at 3 on average, which means that our sample is rather neutral about it, and the private expenses in insect repellents and insecticides amount to some €12 per year. The presence of mosquitoes led 40% of the respondents to shorten the time devoted to outdoor activities, with an average of 5 hours lost per week. With regard to current mosquito control efforts in the area, the respondents are somewhat satisfied with an average of 3 out of 5. It should be noted that people who are neutral about the efforts made also report a level of satisfaction of 3.

Concerning the questions related to the knowledge of the ATM, 91% of the interviewed persons replied that they had heard of ATM. The fact that it is responsible of the transmission of specific diseases is also widely acknowledged (86%). However, respondents are not satisfied with the current communication campaigns on the control and prevention of ATM populations, with an average level of satisfaction of 2. The dichotomous choice question about the willingness to pay €25 of additional taxes per year to establish measures reducing the probability of invasion receives 66% of positive answers. Among the 58 respondents who refused to pay this amount, 78% were classified as protest answers. Some of them find the current taxes quite high; and others believe that citizens should not have to pay for control and prevention measures. The average WTP for enhanced control measures to prevent ATM-borne diseases and mitigate ATM-related nuisance calculated from the OE question was €20 and €15, respectively.

The socio-demographic characteristics of the sample are summarized in Table 2. Respondents have an average age of 32 years; about 45% of them are men; and more than 80% are residents in Montpellier. The average individual income is about €1200 per month and around €2100 for a household. In terms of education, most individuals obtained a master's degree (31.5%). These characteristics are rather similar to those of the entire Montpellier population and tend to validate the idea that our sample was fairly representative.

Table 2. Descriptive statistics of the surveyed sample

Variable name	Description	Value	Reference value
Age	Age of respondents	32y	36y
Gender	Male = 1; Female = 0	45%	47%
Residency	Place of residency Montpellier = 1; Otherwise = 0	81%	-
Act_short	Outdoor activities shortening Yes = 1; No = 0	40%	-
ATM_know	Ever heard of the ATM Yes = 1; No = 0	91%	-
Satisfaction	Satisfaction level with the current communication campaigns around the ATM • Very unsatisfied = 1 • Unsatisfied = 2 • Neutral = 3 • Satisfied = 4 • Very satisfied = 5	2	-
Hous_type	Apartment = 1 Individual house = 0	77%	85 (lower in the outskirts)
Ext_space	Yes = 1; No = 0	63%	n.a.
Household	Number of individuals in a household (children included)	2.26	1.9
Children	Number of children in a household	0.39	0.97
Expenditures	Expenditures on repellents and insecticides	€12/year	-
Indiv_income		€1200 monthly	n.a.
Hhold_income		€2100 monthly	€1500
Diplomepro	Levels of education	11%	14%
Premiercycle		27%	25%
Diplomeuniv		56%	61%

The reference value is the value for the city of Montpellier (when it makes sense)

4.2. Contingent Valuation results

As explained above, the single-bounded DC question was analyzed using a logistic regression and the model is significant. Table 3 summarizes the estimated coefficients corresponding to the dependent variables. Age and the type of housing are both significantly and negatively associated with the DC response ($p < 0.01$ and $p < 0.05$ respectively), while the age squared variable, residence and expenditures are significantly and positively associated with the choice of response ($p < 0.05$). In addition, people who live in apartments in Montpellier (as opposed to individual houses) and who already spend on repellents and insecticides, often have a positive WTP of additional €25 per year.

Table 3. Estimated logistic regression model for the DC question (CV responses)

Variable	Coefficient
Age	-0.24*** (0.08)
Age2	0.00** (0.00)
Gender	-0.47 (0.44)
Residency	1.14 (0.56)
Expenditures	0.06** (0.02)
Hous_type	-1.78** (0.70)
Ext_space	0.01 (0.43)
Household	-0.25 (0.24)
Children	0.52 (0.41)
Indiv_income	0.00 (0.00)
Hhold_income	0.00 (0.00)
Satisfaction	0.26 (0.17)
ATM_knowledge	-0.42 (0.67)
Act_short	0.66 (0.42)
Diplomepro	-0.23 (1.57)
Premiercycle	-1.69 (1.48)
Diplomeuniv	-1.63 (1.47)
Cons	6.61*** (2.46)
Number of obs	165
Log likelihood	-84.15

Legend: Significant at levels: *10% ** 5% ***1% () Numbers in brackets are standard errors

We used a Tobit regression to analyze the OE question, and compiled the coefficients estimated in Table 4. From the risk related results, the coefficients associated with the individual income and the expenditures are significant (p <0.01) and positively related to a higher WTP both in the whole dataset and when protest responses are discarded. The age and type of home are also significantly and negatively associated with the WTP when the entire sample is considered, while age squared and outdoor activity shortening variables are positively associated to it.

As in the DC question, this suggests that as people age and live in apartments, their WTP to avoid the risk of contracting an ATM-related disease decreases, while older people and people who reduce their outdoor activity time have higher WTP. The sample without the protest response highlights the gender and satisfaction coefficients as significant. The former is negative, meaning that women's WTP is higher than men's. The latter is positive, which means that individuals who are satisfied with current communication efforts are more likely to pay more to contribute to reducing the risk of contracting ATM-related diseases.

With regard to the nuisance aspect of the ATM invasion, the only difference between the whole sample and the one excluding protest responses are the house type coefficients and the number of children in the household, which are statistically significant in the full sample (p <0.01 and p <0.1 respectively). The number of children is positively associated with WTP to reduce ATM-related nuisance. The coefficients related to residence, individual income, expenditures and shortening of outdoor activities are all significant and positively related to WTP, both in the full sample and without protest answers.

4.3. DCE results

The DCE data analysis was run with effect coded variables. With effect coding, for each qualitative attribute level, the variable takes the value 1 when this level is present, takes -1 for the status quo, and 0 otherwise (Bech and Gyrd-Hansen, 2005). The advantage of this method is that there is no correlation between the estimated coefficients of the attributes and the intercept as it is in dummy coding, since the status quo is assigned the value 0 (Adamowicz et al., 1994). Thus, the intercept represents only the utility associated with the reference situation (Bech and Gyrd-Hansen, 2005).

Table 4. Estimated Tobit regression model for the OE question (CV responses)

Variable	WTP for the risk		WTP for the nuisance	
	Whole dataset	Without protest answers	Whole dataset	Without protest answers
Age	-1.19**	-0.4	-0.84	0.19
	(0.46)	(0.4)	(0.51)	(0.46)
Age2	0.01**	0.002	0.007	-0.003
	(0.00)	(0.004)	(0.005)	(0.00)
Gender	-4.57	-4.76*	-4.63	-4.70
	(2.71)	(2.31)	(3.01)	(2.61)
Residency	6.26	4.61	8.73***	6.49*
	(3.38)	(2.9)	(3.76)	(3.29)
Expenditures	0.37***	0.30***	0.42***	0.28**
	(0.12)	(0.1)	(0.13)	(0.11)
Hous_type	-6.78*	-3.81	-8.37***	-4.68
	(3.55)	(3.03)	(3.87)	(3.30)
Ext_space	-2.38	0.57	-1.41	0.91
	(2.68)	(2.28)	(2.94)	(2.56)
Household	0.39	-0.08	-1.75	-2.18
	(1.37)	(1.16)	(1.51)	(1.31)
Children	1.05	0.24	4.19*	3.06
	(2.15)	(1.79)	(2.35)	(1.98)
Indiv_income	0.003**	0.003***	0.004**	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Hhold_income	-0.0004	-0.000	-0.000	-0.00
	(0.00)	(0.000)	(0.001)	(0.00)
Satisfaction	1,005	1.82*	0.55	1.58
	(1.07)	(0.94)	(1.17)	(1.07)
ATM_knowledge	-6.32	-4.97	-10.02	-6.60
	(4.10)	(3.4)	(4.44)	(3.68)
Act_short	4.40*	2.84	6.11**	4.51**
	(2.55)	(2.16)	(2.79)	(2.39)
Diplomepro	0.75	-1.08	-1.22	-2.83
	(6.54)	(5.44)	(7.08)	(5.86)
Premiercycle	0.81	-0.55	-0.77	-1.95
	(6,006)	(4.9)	(6.5)	(5.32)
Diplomeuniv	0.02	-1.99	-4.73	-6.51
	(5.75)	(4.69)	(6.24)	(5.11)
Cons	41.39***	27.44***	34.6***	16.62***
	(10.48)	(8.96)	(11.48)	(10.01)

Legend: Significant at levels: ***1%, ** 5%, *10%; () numbers between brackets are standard errors.

3.3.1. Estimating the coefficients through logit regression models

Conditional and random-parameter logit models

In order to analyze the probability that an individual chooses a given option from a set of alternatives, we start with the CL model then use the RPL. Both models are significant at 1% level, and their estimated coefficients are reported in table 5.

Table 5. Conditional and random-parameter logit models estimation results

Choice	Conditional logit model	Random-parameter logit model	
		Coefficients β	Standard Deviations
BAU[1]	-0.809 ***	-3.531***	3.401***
	(0.238)	(0.773)	(0.536)
Nmedium	0.159	0.375	0.948
	(0.261)	(0.526)	(0.646)
Nlow	0.357***	0.384***	0.077
	(0.095)	(0.105)	(0.333)
Rmedium	0.677***	1,302***	1,308**
	(0.241)	(0.498)	(0.521)
Rlow	1.155***	1.402***	1.214***
	(0.100)	0.165)	(0.209)
Areinforced	0.352	1,247**	-1,277**
	(0.271)	(0.614)	(0.579)
Acominterv	0.335***	0.411***	0.543*
	(0.092)	(0.115)	(0.281)
Cost	-0.041***	-0.048***	-
	(0.004)	(0.005)	
Observations	3024		
Log Likelihood	-835,858	-716,356	

Legend: Significant at levels: ***1%, ** 5%, *10%; () numbers between brackets are standard errors.

In the CL model, the estimated coefficients relative to the BAU and the cost are significant at 1% risk level and negatively associated with the choice. Since we use effects-coded data, the BAU reflects the utility associated with the basic alternative as such, i.e., the factors not described by the attributes considered (Bech and Gyrd-Hansen, 2005). This means that the status quo for all attributes not described in the protocol is rejected. In addition, the probability of choosing an alternative decrease as the cost increases. The other parameters (low nuisance, the medium and low risks, and the communication campaign and intervention)

[1] BAU: Business-As-Usual (status quo)

are significant at the 1% level and positively correlated to the choice. Thus, that when these levels are reached, the probability is higher than the alternative including them is chosen. Moreover, the Hausman test shows that the IIA property is verified.

To identify heterogeneity among the individuals' preferences, we used the RPL model. Similarly, the significant and negative coefficients associated with the BAU and the cost indicate that the utility of the individuals is negatively affected by the presence of the status quo among the alternatives and by an increase in the cost. In terms of heterogeneity, the significant values of the standard deviations show that the preferences for the status quo, for low and medium risk levels, for reinforcing communication and for communication and intervention actions are heterogeneous. Examining the ratios of standard deviations to estimate average coefficients, we find 84% of people prefer a medium-risk situation, 88% opt for a scenario with low risk of disease transmission, 83% choose an alternative with improved communication campaigns, and 77% select situations with communication and intervention actions.

Latent class logit model

The latent class logit model is based on the assumption that membership in a given class depends on the socio-economic characteristics of the individual (Grisolía and Willis, 2012). Assigning individuals into classes and estimating the characteristic coefficients of each class are performed simultaneously (Greene and Hensher, 2003). We have defined three homogeneous classes in terms of preferences, the first one being our reference class, which is used to compare the membership of individuals to one class or another. The first class accounts for 43% of the sample, the second one 11% and the last 46%. Table 6 summarizes the results.

Table 6. Latent Class logit model results

Choice	Class 1 (43% of the sample)	Class 2 (11% of the sample)	Class 3 (46% of the sample)
BAU	-2.31***	0.93	-0.61
	(0.60)	(0.73)	(0.57)
Nmedium	1.09	-0.02	-0.27
	(0.92)	(0.62)	(0.55)
Nlow	0.37***	-0.11	0.28
	(0.13)	(0.54)	(0.18)
Rmedium	14.04	-0.06	1.93***
	(536.45)	(0.60)	(0.58)
Rlow	0.02	0.61	3.49***
	(0.13)	(0.48)	(0.31)
Areinforced	0.70	0.18	2.26***
	(0.93)	(0.73)	(1.08)
Acominter	0.40***	-0.08	0.64***
	(0.12)	(0.55)	(0.20)
Cost	-0.02***	-0.098***	-0.08***
	(0.006)	(0.02)	(0.01)
Observations	1188	324	1458
Log Likelihood	-282.73	-75.25	-208.93

Legend: Significant at levels: ***1%, ** 5%, *10%; () numbers between brackets are standard errors.

Individuals of the first class are characterized by significant preferences for alternatives, including low nuisance and communication on actions. They are also significantly sensitive to the cost and its increase is accompanied by a decline in the utility of individuals. Except for the monetary attribute, no other attribute is statistically significant in the second class. This suggests that the utility of individuals in this class is only affected by the increase in the cost of actions in order to control the ATM invasion. The third class includes individuals for whom medium and low risk, reinforced actions, as well as communication and intervention measures are all positively and significantly associated with the choice of the alternative that includes one of these levels.

The latent class model aims to identify the aspects that distinguish the different classes in our sample. In the second class, we are more likely to find male individuals, rather old people but not the eldest, people who are satisfied with the communication about the ATM, who rather live in apartments, those who do not have a large knowledge about ATM, and do not spend much on repellents and insecticides. The people in the third class are elderly and mostly male, they are mainly Montpellier residents, live in single-family houses, in rather large households, have high individual incomes, are satisfied with the communication about the ATM, but do not do much about it and spend less time outdoor because of its presence. The membership to the first class, which was used as a reference, is determined in comparison to the other two. It is therefore more likely to find women and older respondents in this class, but also people with high household incomes, who spend a lot for private measures of prevention and control of ATM, and who are not satisfied with the way communication on this subject is currently managed.

In general, our sample is composed of three categories of individuals. The first gathers people to whom nuisance, communication and intervention action, status quo and cost uphold a significant importance. The second includes those who are generally indifferent to the presence of the ATM and the resulting nuisance, and who only care about the cost of a possible program implemented to control it. Finally, the third group assembles those primarily affected by the risk of contracting an ATM-related illness, the strategies enforced to control it, and the price to pay for countering them.

3.4. Welfare analysis

In order to calculate the MWTP for the attribute levels, we used equations 4 and 5. Since the cost of the actions in the choice cards was monthly and the payment was to be made twice a year, we multiplied the results by 2 (for the payment of the two summer months) (see Table 7). In the conditional logit model, the respondents express a WTP of more than €17 and €56, respectively, for low nuisance and a low risk of transmission. On the other hand, the random parameters logit model has higher values for these risks and strategies of communication levels. With the latent class model, people sensitive to nuisance (class 1) show a WTP of nearly €20 to have a low nuisance situation, and more than €32 for strategies combining communication and public intervention to control the ATM populations. Class 2 individuals appear indifferent to nuisance and risk, so we consider that they do not express a WTP for any of the aspects taken into consideration. As for the third group, which includes respondents averse to all levels of risk and are interested in every improvement of the actions of prevention and control, they are willing to pay more than €78 for a low risk, and almost €51 to strengthen communication around this topic.

Table 7. WTP for all models

Attribute levels	Conditional logit	Random parameters logit	Latent Class Logit		
			Class 1	Class 2	Class 3
Bau	-39.46	-147.12	-184.88		-
Ncurrent	-17.41	-16	-29.92	-	-
Nmedium	-	-	-		-
Nlow	17.41	16	29.92		-
Rcurrent	-89.36	-112.66	-		-121.99
Rmedium	33.02	54.25	-		43.5
Rlow	56.34	58.41	-		78.49
Acurrent	-1.63	-69.08	-32.64		-65.18
Areinforced	-	51.95	-		50.80
Acominterv	1.63	17.12	32.64		14.38

5. Discussion

In order to study the individual preferences for the control and prevention of the ATM invasion and to facilitate their incorporation into public programs, we chose to implement a dual approach through a CVM and a DCE. First, since our CVM questions did not offer variable bids, this part was only intended to determine which variables are significant for the WTP to reduce the risk and the nuisance caused by the ATM. According to the results of the DC question, an increase in age is more likely to deter people from paying the extra €25 in taxes, however elderly people still choose to pay them. Mwebaze *et al.* (2017) reached the same conclusion with respect to the first part of the results, but not the second when they showed that even older people did not want to pay more for ATM prevention. We also found out that people living in the city of Montpellier and those who spend private expenditures on mosquito control were willing to pay for programs that reduce the probability that ATM will settle in the city. This is consistent with the study by Halasa et al. (2014) who also concluded that the WTPs were positively correlated with residence and spending. Unexpectedly, apartment dwellers (thus having less exterior space) are more likely to pay an extra € 25 compared to those living in single-family homes. An explanation may be that they spend more time in outdoor activities (out of their homes) and are therefore more affected by the inconvenience caused by the ATM.

Considering the whole sample, including protest zeros, the OE question showed that the risk of contracting an ATM-borne disease mattered more for young individuals but also for the elderly, and generally for people who are bothered by the presence of mosquitoes to the point of shortening their time of outdoor activities. This latter result highlights the fact that ATM is an invasive species. Indeed, the outdoor activities included in the survey usually take place when the ATM is the most active. Decreasing the time spent on these activities is thus a change in individual behavior, directly related to the invasion. Moreover, as Mwebaze *et al.* (2017) and Bithas *et al.* (2018) have also found, individual income remains significant whether we analyze the sample with or without protest zeros. Regarding the WTP for the nuisance as a factor of its own, besides the residence in Montpellier, individual income, expenditures against mosquitoes and shortening outdoor activities, the number of children in the household becomes significant and encourage people to pay more for the prevention and control of the ATM. This variable was also found significant by Halasa *et al.* (2014).

Based on the results of the DCE, an overview of the results reveals that the risk of contracting ATM borne diseases outweighs the other attributes, which goes against the result obtained by Dickinson and Paskewitz (2012) about the WTP for the control of mosquitoes responsible for the transmission of West Nile Virus. In this article, homeowners in Madison, Wisconsin, rated the nuisance factor as more important than the disease factor. While in our study, preferences are much more focused on the risk attribute than on the nuisance or the communication campaign. The WTP for the two levels of risk are indeed higher than the other levels in the CL and RPL models. This result is consistent with that advanced by Bithas et al. (2018) who showed in their studies in Athens that the health factor and protection against ATM-borne diseases were a higher priority than the reduction of nuisances. Also in this first analysis of our results, the respondents do not appreciate the current situation of all attributes. Maintaining the status quo is systematically accompanied by a decline in utility. This is revealed through the negative values of the WTP for the current levels of each attribute and for the status quo option (see tables 8 and 9). Although we have not identified any study analyzing the BAU as an alternative of its own, Dickinson and Paskewitz (2012) have shown that homeowners in Madison express a positive value of WTP solely for the nuisance aspect of the mosquitoes. This explicitly means that they are unsatisfied with the current situation and could to some extent be consistent with our findings.

Furthermore, the DCE allows to draw conclusions about each attribute separately. For the risk attribute, the estimated coefficients for the medium and low levels are both significant in the conditional and random parameter logit models. However, the WTPs show that individual preferences are systematically oriented towards the low level. This result is similar to that shown in Australia by Mwebaze et al. (2017) who found that a significant reduction in risk was associated with a higher WTP. And since there is no zero risk, a low level of risk refers to a situation where the epidemic recedes, meaning fewer people infected over time. It is therefore not surprising to note that this level is the one that reaches the highest WTP (€58.42 in the logit with random parameters). This result was itself rather predictable, because the ATM is known as a disease vector to 86% of the sample surveyed, of which at least 77% have already heard of chikungunya. And if the latter is not currently an epidemic, the population is well aware of its effects and its consequences. The priority is therefore to minimize the risk of contracting it. Moreover, if the preference for the low risk level is demonstrated by a difference of €4.16 between the medium and low level in the mixed logit model, it actually reaches €35 for the risk-averse group determined by the latent class model (class 3). The demographic characteristics of this group justify its choices. Indeed, a greater satisfaction with the current communication efforts, the increase in age, of the number of people in a household and especially in the number of children and of individual income are all variables that favor belonging to this group. Although these people do not currently incur any private expenditures to control the invasion of the ATM, the notion of health risk is of great importance to them. It is therefore logical that as people get older, as they start families and have children to care for, they are more likely to pay to reduce the risk of contamination (€78.49, which is 3.9 times the mean WTP to avoid ATM-borne diseases as calculated in the OE question).

Considering the nuisance attribute, the preferences lean towards the lowest level. Individuals described the nuisance caused by the presence of the ATM similarly to that of garbage stacked in the neighborhood. However, for a medium nuisance level, the estimated coefficient for this level of the attribute is never significant. Even the category of people who express an aversion to the nuisance does not react at this level; it is not a situation for which people are willing to pay. An explanation might be that, at a medium level, the inconvenience is not serious enough to result in a change in judgment. The WTP for the low level reaches however €17.41 and €16 respectively in the conditional and random parameters logit models, which is approximately at the mean WTP for the nuisance factor in the OE question (€15). In the latent class model, the nuisance-averse category (class 1) is willing to pay around €30 for this level, twice as much as the latter mean WTP. These choices are logical because these are elderly people who would like to enjoy a few moments outdoors, but the presence of the ATM annoys them to the point of compelling them to shorten the time they wanted to spend outside. Knowing enough about ATM and highly disturbed by its invasion, they are not satisfied with the current communication campaigns and take charge of the fight against mosquitoes through their private expenditures on repellents and insecticides, to the extent that their incomes allow it. To compare with one of the few studies that estimated the WTP for a control program, our values are higher than those of Halasa et al. (2012) ($5.42 per capita per year, which is less than €10 for an average household of 2 people in Montpellier).

Last but not least, all communication efforts do not seem to meet the population’s expectations. As mentioned in the introduction, the current measures to control the ATM consists primarily of awareness and information campaigns, treatment being an exceptional measure limited to the vicinity of suspected cases, especially the indigenous ones. Our survey revealed, however, a general sense of dissatisfaction with these campaigns. It is therefore not surprising that the two levels of improvement in communication campaigns appear significant in the random parameters logit model. The WTP to strengthen communication campaigns about the ATM is in fact 3 times higher than the WTP for actions combining communication and public intervention when heterogeneity is taken into consideration. This difference may refer to the reluctance of a large proportion of our sample to the use of chemical treatments against mosquitoes. It is indeed an argument that has often been mentioned during the discussions with the surveyed individuals. People are much more willing to pay for research purposes on more environment-friendly technologies than for measures that could endanger ecosystems balance and eventually increase mosquito resistance to the insecticides used.

6. Conclusion

In the 1950s, on the French Mediterranean Coast, the issue was clearly stated: with mosquitoes, no development was possible up to 30 km inland. Attracting tourists and promoting economic development was the objective of the elected representatives who created the EID-Méditerranée in 1959. Overall, the objectives of safety, comfort, quality of life and socio-economic development in a broad sense were also ensured by this mission. During these decades, the EID and its partners, namely academic researchers, have developed remarkable expertise, particularly to deal with insecticide resistances developed by mosquitoes. The arrival of new invasive species, vector of disabling diseases, constitutes a new challenge.

Valuation methods based on stated preferences are inevitably confronted with the problem of hypothetical bias (Ajzen et al 2004). We tried to mitigate it through the presentation of the contingent valuation scenario (the respondents were aware of the nuisances and diseases transmitted by the ATM) and also by choosing a familiar payment vehicle (the electricity bill). For the specific case of the DCE, the repetition of the choice cards allows to capture the stability of the responses and limits this bias (Desjeux et al 2005).

For the evaluation of these costs, the previous studies appear dependent regarding their context and the socio-demographic characteristics of the populations concerned by the study. Our ambition was therefore to build an evaluation framework and apply it in the particular case of the city of Montpellier. Using both a CVM and a DCE, the results highlight that the status quo is the least popular scenario because individuals associate it with the weakest well-being.

Our objective was to assess the value attributed to the nuisance and risk of contracting an ATM-borne disease in and around the city of Montpellier, France. Indeed, a better understanding of individual preferences can be of real interest in informing public decisions. For the evaluation of these costs, previous studies remain dependent on their context and on the socio-demographic characteristics of the populations concerned by the study. Our ambition was therefore to build an evaluation framework and implement it in a real case. Using both a CVM and a DCE, the results highlight that the status quo is the least preferred scenario since individuals associate it with the weakest welfare. We also showed that preferences focused more on the risk of ATM-borne diseases than on nuisances caused by its presence and bites. In terms of nuisances, respondents are only willing to pay for the lowest level of this attribute. And when it comes to strategies and actions, there is more willingness to strengthen communication efforts. This attitude seems to refer to a collective consciousness oriented towards the use of more environmentally friendly control measures. Our results also highlight the existence of three categories of people within the sample according to the priority expressed in their preferences. One that expresses an aversion towards health risk, another that cares more about nuisance, and a third that appears indifferent to both attributes. The factors that have the strongest influence on individual choices are expenditures on repellents and insecticides, residence in Montpellier and individual income.

At this point, it is worth noting that the surveys were conducted during the summer, which means that the results reflect preferences marked by a fairly immediate confrontation with the questions asked. The attitude to inconvenience might have been different if the surveys were conducted outside the period when mosquitoes are the most active. Moreover, these conclusions reflect the preferences of a sample established in Montpellier. The results could be quite different in a region where ATM has only recently been detected or, on the contrary, has been installed for a longer period. The extrapolation of our results cannot be done indiscriminately, and must take into account the importance of the invasion, the duration of presence of ATM in the region and all that allows the population to have a better understanding of the issues based on a certain familiarity with the nuisance and health risks associated with its invasion.

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