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Evaluating perceptions of risk in mosquito experts and identifying undocumented pathways for the introduction of invasive mosquito species into Europe

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Abstract. In several reported cases of the entry of invasive mosquito species (IMSs) into Europe, the introduction was associated with a specific pathway of introduction or dispersal. The identification of potential pathways for the introduction of IMSs and evaluations of the importance of the different pathways are key to designing proper surveillance strategies to promptly detect and control introductions in non-infested areas. The main goals of the present study were to identify other, previously undocumented, pathways of introduction into Europe, and to identify mosquito experts' perceptions regarding control measures against IMS introductions via different documented pathways. At the European Mosquito Control Association (EMCA) conference in Montenegro in March 2017, a questionnaire was distributed among meeting participants to collect expert data. Results showed that ground transportation (by cars, trucks, etc.), passive natural dispersal and the shipping of used tyres are perceived as the most likely pathways. Introduction via aircraft did not appear to be well known and was not perceived as probable. This study shows that there were no pathways unknown to European experts that could lead to cryptic introductions into the experts' countries. Furthermore, the findings demonstrated that the perceived efficacy of surveillance and control is key to overcoming the constraints experienced and to supporting the implementation of actions against introductions.

Key words. *Aedes*, action tendencies, European Mosquito Control Association (EMCA), mosquito control, mosquito surveillance, questionnaire.

Introduction

Over the last decades, Europe has witnessed several introductions of exotic mosquito species with invasive potential, here termed 'invasive mosquito species' (IMSs). Examples include the entry of the Asian tiger mosquito [*Aedes albopictus* (Skuse) (Diptera: Culicidae)] into Italy (Sabatini *et al*., 1990), the American rockpool mosquito [*Aedes atropalpus* (Coquillett)] and the yellow fever mosquito [*Aedes aegypti* (L.)] into the Netherlands (Scholte *et al*., 2009; Brown *et al*., 2011), the Asian bush mosquito [*Aedes japonicus* (Theobald)] into Switzerland, Germany, Belgium and the Netherlands (Schaffner *et al*., 2009; Versteirt *et al*., 2009; Ibañez-Justicia *et al*., 2014), and *Aedes koreicus* (Edwards) into Belgium, Italy, European Russia, the Swiss–Italian border, Hungary and Germany (Capelli *et al*., 2011; Versteirt *et al*., 2012; Bezzhonova *et al*., 2014; Suter *et al*.,

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2015; Kurucz *et al*., 2016; Werner *et al*., 2016). The introduction and possible establishment of these IMSs represent a risk to public health due to the ability of some IMSs to transmit vector-borne diseases. Recently, established populations of *Ae. albopictus* have been involved in outbreaks of dengue and Chikungunya in southern France (Gould *et al*., 2010; La Ruche *et al*., 2010; Calba *et al*., 2017), and Chikungunya outbreaks in Italy (Rezza *et al*., 2007; Venturi *et al*., 2017), and established populations of *Ae. aegypti* caused an outbreak of dengue on Madeira island (Portugal) (Sousa *et al*., 2012). It has also been speculated that countries in which *Ae. aegypti* or *Ae. albopictus* mosquitoes are present may represent sites of future Zika virus outbreaks (Jupille *et al*., 2016).

Increasing international trade and international travel are the main drivers of the expansions in the native distributions of several mosquito vector species (Enserink, 2010). The first sighting of *Ae. albopictus* in Europe occurred in Albania and probably resulted from the trade of goods with China (Adhami & Reiter, 1998). However, only when the species was introduced into Italy in 1990 through the import of used airplane tyres from Atlanta (GA, U.S.A.) (Dalla Pozza & Majori, 1992), and following its subsequent spread in Italy, was it considered a threat to public health (Knudsen *et al*., 1996).

In several of these events, the introduction was clearly associated with a specific pathway. Trade in used tyres has been incriminated in the introduction of *Ae. albopictus* into European countries such as France, Belgium, the Netherlands, Croatia, Montenegro and Spain (Dalla Pozza & Majori, 1992; Schaffner & Karch, 2000; Petrić *et al*., 2001; Scholte & Schaffner, 2007; Generalitat de Catalunya, 2008; Scholte *et al*., 2010), as well as *Ae. japonicus* into Belgium (Versteirt *et al*., 2009), and *Ae. atropalpus* and *Ae. aegypti* into the Netherlands (Scholte *et al*., 2010). Trade in ornamental lucky bamboo plants has also been linked to the introduction of *Ae. albopictus* into the Netherlands and Belgium (Scholte *et al*., 2008; Demeulemeester *et al*., 2014). Ground transport from areas heavily infested with *Ae. albopictus* resulted in the spread of this species from Italy into new areas in Europe such as southern France, Germany, the Balkans, the Czech Republic, Spain and Switzerland (Aranda *et al*., 2006; Scholte & Schaffner, 2007; Sebesta *et al*., 2012; Kampen *et al*., 2013).

Identifying all the potential pathways for the introduction of IMSs at the European level and evaluating the respective importance of these different pathways is key to designing a surveillance strategy that will promptly detect and control introductions of IMSs in non-infested areas.

Surveillance and control measures against IMSs are not likely to be implemented if, for instance, experts experience little interest from government organizations. In this event, their belief that taking action will be effective will be reduced. In order to obtain relevant information, it is important to collect the opinions and perceptions of country experts in mosquito surveillance and control. For this purpose, the present study used protection motivation theory (PMT) (Boer & Seydel, 1996), which proposes that the intention to protect oneself (action tendency) depends upon four factors: (a) the perceived severity of a given hazard; (b) the perceived probability of its occurrence, or vulnerability to this hazard; (c) the perceived effectiveness of the preventive behaviour recommended to deal with the hazard (response efficacy), and (d) the individual's level of confidence in his or her ability to undertake the recommended preventive behaviour against the hazard (self-efficacy) (Boer & Seydel, 1996). In addition to these four factors, a fifth factor can be included: the perception of constraints that impede the implementation of preventive behaviour. Perceived constraints are often considered as important predictors of health promotion behaviour (Janz & Becker, 1984) and can be expected to play a role in explaining the action tendencies of the experts consulted to support the implementation measures that would prevent the introduction of IMSs. In other words, even if an expert perceives the introduction of an IMS as a threat, and believes that surveillance and control actions will effectively reduce the threat, perceived constraints may prevent that individual from supporting the implementation of actual actions against the IMS. As well as playing a role in health promotion and disease prevention, PMT has been successfully used to predict people's actions to prevent injury, share in environmental concerns, and to improve public safety (Floyd *et al*., 2000; Westcott *et al*., 2017). Protection motivation theory can be used to influence and predict various behaviours (Boer & Seydel, 1996) and, if appropriately used in the IMS context, could influence attitudes towards supporting the taking of action against the introduction of IMSs to prevent their establishment.

The main goals of the current study were to identify other, previously undocumented, pathways of introduction and dispersal of IMSs in Europe, and to identify experts' perceptions regarding control measures against IMS introductions via different documented pathways. In addition, as well as providing descriptive information on perceptions of the risk for introductions, PMT provides insight into what drives experts' attitudes towards supportive actions against the introduction of IMSs.

Materials and methods

Questionnaire

Data were collected by distributing a questionnaire among experts during the European Mosquito Control Association (EMCA) conference in Bečići, Montenegro (March 2017). The main objectives of the study and instructions for the completion of the questionnaire were introduced during the plenary opening of the conference by the president of the EMCA and by the first author (AI-J). Subsequently, the questionnaire was distributed to all participants. To ensure independent answers, participants were asked to answer all questions without consulting other participants. Completed questionnaires were collected up to the end of the conference. Participants who arrived after the opening of the conference were asked to participate in the study during the openings of conference sessions over the next days.

Introduction pathways identified from the literature were categorized in four main groups: trade in used tyres; import of lucky bamboo plants; passive transport in vehicles (by road, aeroplanes, ships), and natural dispersal. The questionnaire was designed following the methodology of PMT (Boer & Seydel, 1996) taking into account the following factors: (a) the

perceived severity of a threatening event; (b) the perceived probability of the occurrence, or vulnerability, and (c) the efficacy of the recommended preventive behaviour (response efficacy). Self-efficacy (the fourth factor in PMT) was omitted in the present study because this factor measures the individual's level of confidence in his or her own ability to undertake the recommended preventive behaviour; it is considered less relevant to the present study because IMS control measures take place at a collective rather than an individual level. Instead, an additional factor that assessed perceived constraints with respect to the implementation of preventive behaviour was included. This was done because there are many practical issues that may limit the likelihood of an IMS control programme being successful. This factor was expected to play a role in explaining the action tendencies of participants in supporting the implementation of IMS surveillance and control measures.

The questionnaire was divided into several sections. The first section asked for general information about the participant, including his or her name and institution (not obligatory), gender, age, country and region. Nine subsequent questions addressed the knowledge of the participant regarding pathways for the introduction of IMSs. Questions could be answered with any of the responses 'Yes', 'No' and 'Don't know'. Correct answers were awarded 1 point. Incorrect or blank answers scored no points. Thus, a final knowledge index of 0–9 points (on a 10-point scale) was computed. Thirdly, respondents were asked to evaluate four statements on the perceived severity of introductions of IMSs into their respective countries/regions (e.g. 'Introduction of *Aedes albopictus* in my country/region can lead to irreversible establishment and dispersal of this vector species'). Statements were evaluated using a Likert-based scale with five response alternatives (1 = do not agree at all; 2 = do not agree; 3 = neither agree nor disagree; 4 = agree; 5 = fully agree). Next, respondents were asked to evaluate six statements on the perceived vulnerability of their respective countries/regions to the introduction of IMSs via different known pathways (e.g. 'The chance of introduction of *Aedes* invasive species in my country/region with import of used tyres is rather large'). Statements were evaluated using a 5-point Likert scale similar to that used in the evaluation of severity. Then, respondents were asked to evaluate four statements on the perceived response efficacy of measures for the surveillance and control of IMS introductions into their respective countries/regions (e.g. 'Invasive *Aedes* species surveillance and control measures implemented in my country/region lead to accurate evaluation of potential introduction locations for *Aedes* species'). Statements were evaluated using a 5-point Likert-based scale similar to that used to evaluate severity. After the response efficacy items, respondents were asked to evaluate four statements on perceived constraints with respect to the implementation of IMS surveillance in their respective countries/regions (e.g. 'In my country/region, adequate surveillance of invasive *Aedes* species will be difficult to implement because of the lack of interest of the governmental organizations'). Statements were evaluated using a 5-point Likert scale similar to that used for severity. With the aim of collecting more information about the constraints faced by experts in implementing IMS surveillance, participants were asked to write these constraints in this section and to assign a score to each of the constraints experienced. Lastly, participants were asked to respond to six statements evaluating action tendencies regarding the implementation of IMS surveillance and control measures in their respective countries/regions (e.g. 'To what extent do you agree that IMS surveillance needs to be implemented in all countries/regions of Europe?'). These statements were also answered using a 5-point Likert scale.

After the questions and statements on knowledge, perceived severity, perceived vulnerability, perceived response efficacy, perceived constraints and action tendencies, the questionnaire also asked whether participants were aware of other pathways of introduction that had not been reported previously in the literature. Participants were asked to indicate at least one other pathway of introduction in their respective countries/regions. These data are important for detecting new or neglected pathways for the introduction of IMSs in Europe.

The questionnaire is included in the supplementary data (Appendix S1). Correct answers to the knowledge questions are provided in the questionnaire using bold text. Scores across participants on individual questions are provided in Appendix S2.

Data analysis

The internal consistency of the set of items representing a variable was checked and these items were collapsed into a single index after the Cronbach's alpha values (Cronbach, 1951) were verified as being 0.7 or higher. Alpha values were computed for each variable measured in the questionnaire: Knowledge; Severity; Vulnerability; Response efficacy; Constraints, and Action tendencies. This test is used when a tool includes multiple questions or statements that have scaled answers, and when there is a need to determine whether the scale is reliable. Pearson product–moment correlation coefficients were computed and linear regression analyses were conducted to identify relationships among the variables. Variables included in the regression model were those for which items formed a reliable scale (Cronbach's $\alpha > 0.7$), which allowed the results to be combined into one index, and also variables that were significantly correlated with the dependent variable in the Pearson correlation coefficient analysis. Finally, a mediation analysis was performed to explore whether a relationship between an independent variable and a dependent variable runs via a mediating variable (Baron & Kenny, 1986). This means that an independent variable (e.g. perceived constraints) influences a mediating variable (the mediator; e.g. perceived response efficacy), which, in turn, influences the dependent variable (e.g. action tendencies). Therefore, the mediator provides insight into the underlying process of the relationship between the independent and the dependent variable. To formally test for mediation, a bootstrap analysis (Shrout & Bolger, 2002; Preacher & Hayes, 2004) was employed to test the reduction in the direct effect. This approach involves computing 95% confidence intervals (CIs) (5000 bootstrap resamples) around indirect effects; mediation is indicated by CIs that do not include 0. All statistical analyses were performed using SPSS Statistics for Windows Version 17.0 (SPSS, Inc., Chicago, IL, U.S.A.).

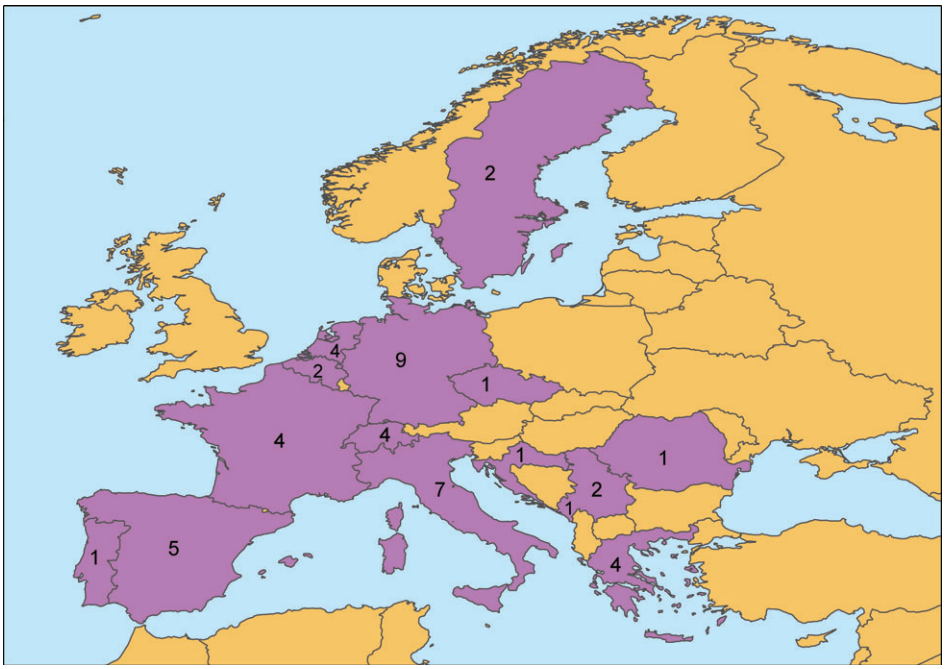

Fig. 1. Countries (in purple) and respective numbers of conference participants completing the study questionnaire. [Colour figure can be viewed at wileyonlinelibrary.com].

Results

Demographic characteristics

In total, 118 participants from 25 countries participated in the EMCA conference in 2017. The countries with the largest delegations were Germany and Greece with 18 (15.3%) and 15 (12.7%) participants, respectively. There were also participants from the non-European countries of the U.S.A., Israel, Thailand and Iran (7/118, 5.9%). Forty-eight participants from 15 European countries filled out the questionnaire. These respondents came from Belgium, Croatia, the Czech Republic, France, Germany, Greece, Italy, Montenegro, the Netherlands, Portugal, Romania, Serbia, Spain, Sweden and Switzerland (Fig. 1). Of these 48 participants, 31 provided information on the name of their organization in the questionnaire. Fifteen participants worked for surveillance agencies, seven for universities, five for control agencies, and four for public health authorities.

As at March 2017, of the 15 European countries represented in responses to the questionnaire, all except Sweden and Portugal had previously reported occurrences of *Ae. albopictus*. These countries were Belgium (not established to date), Croatia, the Czech Republic (not established to date), France (including Corsica), Germany, Greece, Italy (including Sardinia, Sicily, Lampedusa and other islands), Montenegro, the Netherlands (not established to date), Romania, Serbia (not established to date), Spain and Switzerland. Except for records of occurrence on the island of Madeira (Portugal), introductions of *Ae. aegypti* had been reported only in the Netherlands, but the species had not established. Also in the Netherlands and in Italy, *Ae. atropalpus* introductions had been reported without further establishment. Six of the countries represented by respondents to the questionnaire had reported occurrences of *Ae. japonicus*; these included Belgium, Croatia, France, Germany, the Netherlands and Switzerland. Finally, *Ae. koreicus* had been reported in four countries, including Belgium, Germany, Italy and Switzerland.

Of the 48 participants, 33 were male and 14 were female; one participant did not report gender. The average age of respondents was 40.2 years in women (range: 26–53 years), and 44.3 years in men (range: 27–65 years).

Questionnaire results

Knowledge. On a scale of 0–9 points (10-point scale), the mean ± standard deviation (SD) score of all participants was 6.33 ± 1.79. Figure 2 shows total knowledge scores across the 48 participants. Eight participants (16.7%) answered all nine questions correctly.

Figure 3 evaluates responses to each of the nine knowledge questions across all 48 participants. In general, participants had good knowledge of the significance of the import of used tyres (question K1; Fig. 3), the inability of *Ae. aegypti* eggs to survive cold winters (K3), and the association of *Ae. albopictus* with passive transport by road traffic (K5). Overall, 19.0% of all knowledge questions were answered with the 'Don't know' option. Some questions appeared more difficult for the participants because around 30% of responses to these questions used the 'Don't know' option. Overall, 30.0% of participants had difficulty in correctly identifying the only implication (to date) of the introduction of one IMS species (*Ae. albopictus*)

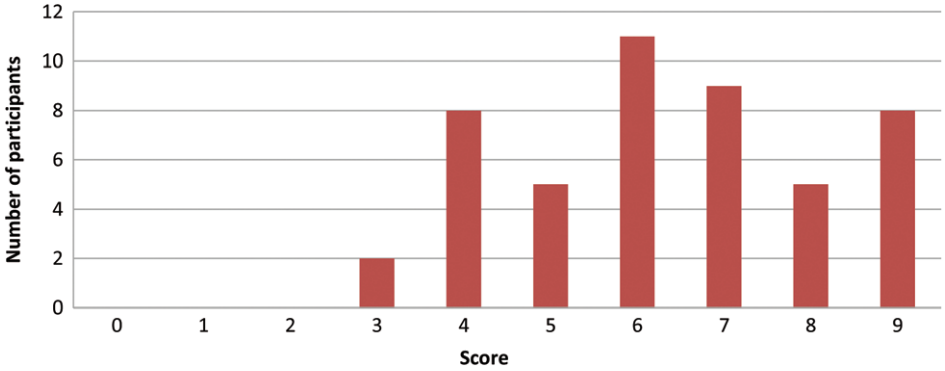

Fig. 2. Knowledge scores of conference participants who completed the study questionnaire. [Colour figure can be viewed at wileyonlinelibrary.com].

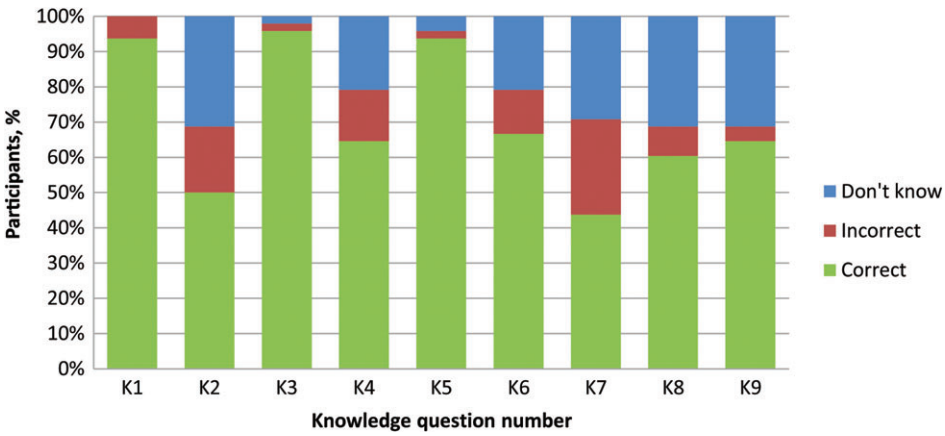

Fig. 3. Evaluation of answers to the nine knowledge-based items on the questionnaire. [Colour figure can be viewed at wileyonlinelibrary.com].

through the import of lucky bamboo plants (K2 and K8). Similarly, participants also showed a lack of knowledge of the absence of *Ae. albopictus* populations in Denmark (K9). Answers to question K7 (absence of evidence of the passive transport of *Ae. albopictus* inside aircraft) showed high rates of both incorrect answers (27.0%) and 'Don't know' options (29.0%).

Severity. The variation in severity responses is presented in Fig. 4. The internal consistency of the scale was low (Cronbach's $\alpha = 0.39$). Therefore, results were not combined into one index. Nonetheless, the median of all severity scores is 5, the maximum score on the scale, indicating agreement on the perceived severity of introductions of IMSs. Introductions of IMSs were perceived to lead to the establishment and dispersal of vector IMSs, to increase the probability of the transmission of vector-borne diseases, and to heighten the risks to human and veterinary health.

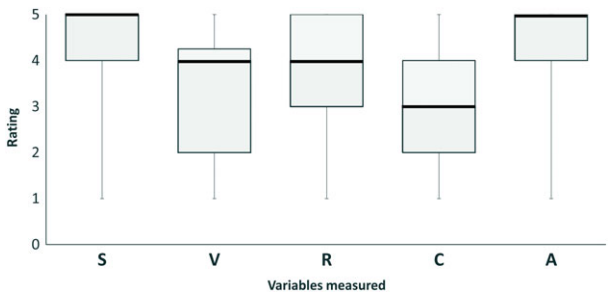

Fig. 4. Likert scale-based ratings of variables measured in the questionnaire. The boxplot represents scores on the different questions per variable measured. The boxes represent the lower and upper quartiles of the values recorded in the questionnaire. The bold horizontal line represents the median of the values. Lower and upper whiskers represent minimum and maximum values, respectively. S, severity; V, vulnerability; R, response efficacy; C, constraints; A, action tendencies. [Colour figure can be viewed at wileyonlinelibrary.com].

Vulnerability. The variation in vulnerability responses is presented in Fig. 4. Similarly to the severity scores, the internal consistency of the scale was relatively low (Cronbach's $\alpha = 0.54$), suggesting that the five pathways of introduction presented were perceived differently in terms of vulnerability. Therefore, the results were not combined into one index. The median scores for vulnerability to the pathways varied from 3 to 4. The median of all vulnerability scores was 4. Participants perceived high vulnerability (median Likert scale score: 4) to passive ground

transport, natural dispersal from neighbouring countries and import through used tyre shipments. Vulnerability to passive transport inside aircraft, with lucky bamboo plants or via maritime ferry traffic was not perceived as particularly high or low (median Likert scale score: 3).

Response efficacy. The variation in answers to items on response efficacy is presented in Fig. 4. The four items formed a reliable scale (Cronbach's $\alpha = 0.78$), which allowed the results to be combined into one index. In general, there was a high perception of the efficacy of case surveillance and control with reference to the 'evaluation of potential introduction locations' and 'early detection of IMS', as well as for 'certainty about IMS presence' (median Likert scale scores: 4). By contrast, participants expressed a much lower perception of the response efficacy of surveillance and control in their countries with reference to the elimination of newly detected IMS foci (median scores: 3).

Constraints. The variation in the constraints responses is presented in Fig. 4. The four items formed a reliable scale (Cronbach's $\alpha = 0.80$), which allowed the results to be combined into a single index. The median score for all constraints answers was 3, a neutral value for participants' perceptions of constraints against the implementation of IMS surveillance in their respective countries. The constraint 'lack of budget' gained higher median values among participants, whereas 'lack of vector surveillance teams' was considered a less important constraint. Other constraints optionally added by participants in their responses to the questionnaire were: lack of coordination among institutions, regional authorities and ministries; lack of unrestricted access to breeding sites; lack of control capacities; lack of universal concern; lack of awareness of local authorities about the importance of source reduction in mosquito control; lack of perception of risk, and lack of communication. The scores for these other perceived constraints were not analysed further in view of the diversity of these data.

Action tendencies. The variation in action tendency responses is presented in Fig. 4. The six items formed a reliable scale (Cronbach's $\alpha = 0.70$), which allowed the separate items to be collapsed into a single index. In general, there was a strong positive attitude towards the implementing of IMS surveillance and control in Europe, and participants agreed on the necessity of investing funds and efforts, including European legislation (median Likert scale score: 5). Participants also tended to agree on the necessity to eradicate *Aedes* IMS in Europe (median Likert scale score: 4).

Other pathways of introduction. Participants reported the following other pathways of introduction: (a) import of plants other than lucky bamboo; (b) import of agricultural products; (c) import of recycled products other than used tyres; (d) import of ornaments [e.g. stone containers (fountains)]; (e) container shipping (inside international freight containers destined for merchant markets); (f) unintended introduction by people using cars, caravans, camper vans, etc.; (g) truck transport by train [e.g. the *Rollende Landstrasse* (RoLa) in Germany]; (h) natural dispersal (e.g. gradual shifts in the areas of Europe in which exotic *Aedes* spp. can live as a result of climate change); (i) travel by entomologists, and (j) introduction by refugees.

Several pathways of introduction mentioned by participants had already been reported in the literature and relate to passive ground transportation of IMSs (e.g. inside freight containers, private vehicles, trucks and trains) or to the natural dispersal of IMSs. Interesting alternative pathways relate to the import of products that have not been reported yet, such as plants other than lucky bamboo, agricultural and recycling products, and outdoor ornaments (e.g. stone fountains). Unexpected pathways perceived by some participants as potentially playing a role in the introduction of *Aedes* IMSs were travel by entomologists and the migration of refugees into European countries.

Table 1. Means, standard deviations (SDs), and Pearson correlations among variables measured on the questionnaire administered during the European Mosquito Control Association (EMCA) conference.

	Mean	SD	R	C
Response efficacy	3.59	0.88		
Constraints	3.18	0.94	**−0.565**	
Action tendencies	4.36	0.49	**0.323**	0.075

Significant correlations ($P < 0.05$) are indicated in bold.

Correlation analysis

Pearson product–moment correlation coefficients were calculated to identify relationships among the computed variables for which Cronbach's alpha results indicated a reliable scale (action tendencies, response efficacy and constraints) (Table 1). A medium positive correlation ($P < 0.05$) was observed between action tendencies with regard to support of the implementation of IMS surveillance and control measures and perceived response efficacy of the surveillance and control of IMS introductions. In other words, if participants felt that surveillance and control programmes were efficacious in their own countries, they tended to support such programmes. The results also show that there is a significant negative correlation ($P < 0.01$) between perceived response efficacy of surveillance and control measures for IMS introductions, and perceived constraints against the implementation of IMS surveillance. In other words, when few constraints are perceived with respect to the implementation of IMS surveillance, participants perceive surveillance and control as more effective.

Linear regression analysis

Linear regression was used to examine the effects of predictor variables perceived Response efficacy and perceived Constraints, on the outcome variable Action tendencies. This analysis sought to examine if these two independent variables

Table 2. Results of the multiple regression analysis of factors affecting the action tendencies of mosquito experts towards supporting the implementation of surveillance and control measures against invasive mosquito species.

Variables	β	95% CI	*t*-statistic
Constraints	0.370∗	0.018–0.362	2.227
Response efficacy	0.530†	0.106–0.473	3.186

CI, confidence interval.
Standardized regression coefficients are reported.
$*P < 0.05$.
$†P < 0.01$.

explain the participants' support for the implementation of IMS surveillance and control measures. Perceived Constraints was included in the model (no correlation with Action tendencies) based on the hypothesis that the more constraints perceived, the less experts will be motivated to support the implementation of surveillance and control. On the contrary, the more surveillance and control are perceived as effective, the more experts will tend to support the implementation of these actions.

The results of the multiple linear regression analysis (Table 2) show that both the perceived response efficacy of surveillance and control measures, as well as the perceived constraints with respect to the implementation of IMS surveillance, significantly affect action tendency in this multivariate regression model. This confirms one of the study's initial hypotheses, which assumed that experts tend to support actions against introductions of IMSs when they perceive IMS surveillance and control as effective against the introductions. By contrast with the absence of a significant correlation in the Pearson product–moment analysis, the perception of constraints against the implementation of these control measures positively affected the tendency to support actions against introductions ($P < 0.05$).

Mediation analysis

The previous results show that no significant correlation was found between the values of perceived constraints and action tendencies ($P > 0.05$). However, there was a negative correlation between perceived constraints and perceived response efficacy ($P < 0.01$), and a positive correlation between perceived response efficacy and action tendencies ($P < 0.05$), pointing to a possible indirect path from perceived constraints to action tendencies via response efficacy. To test for this, a mediation analysis was performed. The results gave a 95% CI of -0.2916 to -0.0343. Based on this result (0 is not included in the 95% CI), the present authors conclude that the mediated effect is indeed significantly different from 0 ($P < 0.05$; indirect effect: -0.15, SE = 0.07), which means that perceived constraints influence action tendencies via perceived response efficacy (Fig. 5). In other words, the perceived efficacy of surveillance and control is key to the European experts overcoming the perceived constraints and supporting actions to implement the surveillance and control of IMSs.

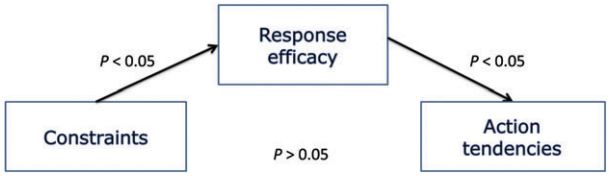

Fig. 5. Representation of mediation analysis results for the measured variables Constraints, Response efficacy and Action tendencies. [Colour figure can be viewed at wileyonlinelibrary.com].

Discussion

This study was designed to investigate if other, previously undocumented, pathways for the introduction of *Aedes* IMSs are present in Europe, to identify experts' perceptions of the risk associated with the different documented pathways, and to investigate what drives experts' attitudes towards supporting actions to prevent and control introductions. The investigation showed that the main pathways have been adequately documented in the literature, and that no other pathways are hidden. Specifically, passive ground transportation (in cars, trucks, etc.) is perceived by experts as the most likely pathway of introduction. The investigation also highlighted the perceived vulnerability to introductions through the natural dispersal of *Aedes* IMSs and through shipments of used tyres within Europe. Introduction via aircraft was not perceived as probable by the participants. Other potential pathways indicated referred to the import of plants (other than lucky bamboo), import of agricultural and recycling products, and import of outdoor ornaments. Finally, the study also demonstrated that the action tendencies of mosquito experts for implementing surveillance and control of IMSs are affected by their perceptions of the efficacy of these programmes and their perceptions of the constraints they encounter.

As the questionnaire was administered during a conference of the EMCA, only a small percentage of participants were public health officers. Most of the participants at the conference who completed the questionnaire were involved in the surveillance and control of mosquitoes, and were often not the final decision makers on issues related to vectors and public health in their countries. In this respect, the measured action tendencies of the experts consulted could be considered as less relevant in view of the profile of the participants. However, their support, advice and reports and the results achieved by implementing surveillance and control measures are key factors on which policymakers can base decisions at regional or national levels, including those on whether surveillance or control are necessary, and if they can be financed and implemented.

In general, if participants feel that surveillance and control programmes are effective, they tend to support them and to experience fewer constraints with respect to the implementation of these measures. A higher perception of the efficacy of surveillance and control measures against IMS introductions was associated with a stronger inclination to support such actions. Furthermore, the perceived efficacy of surveillance and control was negatively associated with participants' perceptions of constraints against the implementation of these measures.

The questionnaire was designed in such a way that all relevant pathways were mentioned repeatedly, allowing the participant to think about the risk for pathways of IMS introduction. The present authors consider that if the participant had knowledge of other relevant pathways in his or her country, he or she would have recorded this at the end of the questionnaire. Of the 'other' pathways of introduction mentioned by participants, several have been suspected to introduce IMSs into or across Europe (e.g. natural dispersal, passive ground transport). Other pathways mentioned need to be evaluated for their contributions to introductions because, to date, they have not been implicated in the introduction or movement of IMSs. For example, import of plants or plant material was pointed out as a possible pathway. In 2017, *Ae. albopictus* was found inside a flower auction house in the Netherlands [Nederlandse Voedsel- en Warenautoriteit (NVWA), 2017]. Transport and trade of lawn ornaments, plant pots and a wide variety of stone or concrete basins may serve as means of spreading eggs and larvae of *Ae. japonicus* in the U.S.A. (Kaufman & Fonseca, 2014). To date, this pathway has only been suspected as the route of introduction to the French Riviera of *Ae. albopictus* from China in stone fountains (ECDC, 2012). An unexpected potential pathway mentioned in the questionnaire was the migration of refugees to European countries. The present group believes that as the only possible way for this route of introduction to succeed depends on the presence of eggs in a refugee's belongings, the introduction of an IMS via this pathway is very unlikely. Nonetheless, the introduction of mosquito-borne diseases (e.g. malaria) has been associated with the migration of refugees (Andriopoulos *et al*., 2013), and this may be why the respective participant indicated this pathway.

Among the documented pathways, passive ground transport (in cars, trucks, caravans, trains, etc.) was perceived as the most important mode of introduction of *Aedes* IMSs in participants' countries. This is indeed an important pathway of introduction, and also of dispersal across highly infested regions for *Ae. albopictus* in southern Europe and neighbouring regions. In this way, this species has colonized southern France from Italy and is extending its range northwards via the main highways. In 2015 it was detected in Strasbourg (France) (B. Mathieu, personal communication, 2018). In Switzerland, it became evident that the European motorway E35 is a key route of invasion into northern Europe (Flacio *et al*., 2016). Findings at service stations along various main motorways in southern Germany also indicated repeated introductions of *Ae. albopictus* into Germany (Becker *et al*., 2013). Unintended movements of IMSs by private ground vehicles have been confirmed in Catalonia (Spain) after a study on main roads in 2016 (Eritja *et al*., 2017). In European regions that are further from established populations (e.g. Belgium, the Netherlands), introductions through private vehicles may be considered less likely because mosquitoes may escape the transporting vehicle during stops made before these countries are reached.

The natural dispersal of IMSs is also considered a probable mode of introduction of IMSs into the survey participants' countries. The adult flight range of *Ae. albopictus* is approximately 200 m (ECDC, 2012; Medlock *et al*., 2015), which implies that adults of this species remain in the immediate surroundings of the breeding sites from which they emerged. Field studies in dengue-affected areas confirmed a wider dispersal range of adults of at least 800 m within a 6-day period (Honorio *et al*., 2003), making natural dispersal in European areas that are climatically suitable more likely. A species that demonstrates an example of the natural spread of a mosquito species in Western Europe is *Ae. japonicus*. This species exploits a wider diversity of potential breeding sites than *Ae. albopictus* (artificial and natural) (Medlock *et al*., 2015), and has expanded its distribution range from colonized areas in Europe.

Trade in used tyres has been confirmed as the route of many first introductions of IMSs into European countries, and remains a source of IMS movement within and between European countries. This pathway was well known to the respondent experts, although some participants did not agree on this potential pathway in their regions. This may be because this type of trade is of low importance in some countries or because of the way used tyres are stored (indoors or outdoors) at used-tyre facilities.

Most of the participants did not agree or disagree on the likelihood of the introduction of IMSs by aircraft. Combined with the high percentage of incorrect and 'Don't know' answers in the questions evaluating knowledge on this pathway of introduction, this signals some level of uncertainty around this topic or may indicate that this pathway is not subjected to adequate surveillance in most of the countries represented in the study. In Europe, there is recent evidence of introductions of *Ae. aegypti* at Schiphol Airport (Ibañez-Justicia *et al*., 2017). Further, because of the increase in international travel and trade, air travel may be considered one of the most efficient methods of transporting IMSs over large distances as mosquitoes may follow their human hosts into aircraft unnoticed (Gratz *et al*., 2000).

Introductions of IMSs with lucky bamboo plants or via maritime ferry transport were perceived as less probable by the study participants. Nonetheless, both pathways have been important in introducing *Ae. albopictus* into European regions. For instance, since 2010 *Ae. albopictus* specimens have been found annually during monitoring at lucky bamboo importing companies in the Netherlands. One reason why the likelihood of introductions with lucky bamboo plants was perceived as low may refer to the low volume of this product imported (or even no import of this product at all) into the various participants' countries. The present authors do not know the volumes of lucky bamboo plants imported into countries in Europe. Similarly, participants from countries such as Germany and Belgium, without short-distance maritime ferry transport to regions with established IMS populations in the Mediterranean Sea, may perceive the risk for introductions through their harbours via this pathway as lower. Maritime ferry transport has been implicated as the most likely route of introductions of *Ae. albopictus* into Sicily and the Tyrrhenian islands from mainland Italian harbours (Di Luca *et al*., 2017; Toma *et al*., 2017).

The observed relationship between the perceived effectiveness of surveillance and control measures, perceptions of constraints to the implementing of these measures, and the action tendencies of experts is relevant for their implementation in Europe. Regression analyses demonstrated that the perceived efficacy of the surveillance and control of IMSs is key to experts overcoming such constraints and supporting the implementation of actions

against introductions of IMSs. As the results show with relation to perceived severity, the introduction, establishment and spread of IMSs in Europe are considered by experts to cause severe negative consequences, and the implementation of surveillance and control is seen by the mosquito experts consulted as effective against these introductions. One important recommendation to promote IMS surveillance and control measures is to increase the perceived effectiveness of the surveillance and control of IMSs by promoting and increasing the visibility of these activities. Investments in risk-based surveillance, research into new effective techniques of IMS detection and control, and the publication of IMS research in specialist journals will engender the support of actions against undesired IMS introductions in Europe.

Among the principal constraints, lack of budget is the most common, but other relevant constraints were lack of coordination and communication among institutions, and difficulty in gaining access to breeding sites for control purposes. In contexts in which an *Aedes* IMS has been recently detected, the combination of these constraints may threaten the effective implementation of control measures. Furthermore, mosquito surveillance is perceived as important to the collection of information about the presence of *Aedes* IMSs, but not in terms of supporting the elimination of newly detected foci at an early stage.

The climatological and geographical differences among countries may explain the variability in answers obtained on the perceived severity of introductions of IMSs. For example, the seriousness of the establishment of IMSs and the probability of transmission of associated vector-borne diseases were perceived as low in countries such as Sweden. In general, answers to these questions indicated the opinions and concerns of the experts about the problem of introductions of IMSs.

The present study shows that there are no pathways of introduction of *Aedes* IMSs unknown to experts, which may lead to cryptic introductions into the experts' countries. Passive ground transport was perceived as the most important pathway for introducing IMSs across European regions, and introduction via aircraft was not perceived as probable by the participants, which raises the question of whether this pathway is subject to adequate surveillance in European regions. Additionally, the removal of apparent constraints against the implementation of surveillance and control programmes, and the resulting high levels of perceived efficacy of surveillance and control programmes are key to enabling European mosquito experts to support the implementation of actions against IMSs. Furthermore, the present group strongly argues that the constraints perceived by experts must be considered and preferably diminished because perceptions of constraints lower levels of response efficacy, which, in turn, lower the tendencies of experts to support the implementation of actions against IMSs. Finally, the present authors recommend that the pathways and origins of new IMS findings be investigated and reported in journals that specialize in reporting on mosquito surveillance.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Questionnaire on the perception of risk for the introduction of invasive *Aedes* species distributed among meeting participants at the European Mosquito Control Association (EMCA) conference, March 2017, Montenegro.

Appendix S2. Scores on individual questions.

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