Advancing insect vector biology research: a community survey for future directions, research applications and infrastructure requirements.

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Abstract

Background: Vector-borne pathogens impact public health and economies worldwide. It has long been recognized that research on arthropod vectors such as mosquitoes, ticks, sandflies and midges which transmit parasites and arboviruses to humans and economically important animals is crucial for development of new control measures that target transmission by the vector. While insecticides are an important part of this arsenal, appearance of resistance mechanisms is an increasing issue. Novel tools for genetic manipulation of vectors, use of *Wolbachia* endosymbiotic bacteria and other biological control mechanisms to prevent pathogen transmission have led to promising new intervention strategies. This has increased interest in vector biology and genetics as well as vector-pathogen interactions. Vector research is therefore at a crucial juncture, and strategic decisions on future research directions and research infrastructures will benefit from community input.

Methodology/Principal Findings: A survey initiated by the European Horizon2020 INFRAVEC-2 consortium set out to canvass priorities in the vector biology research community and to determine key issues that should be addressed for researchers to efficiently study vectors, vector-pathogen interactions, as well as access the structures and services that allow such work to be carried out.

Conclusions/Significance: We summarize the key findings of the survey which in particular reflect priorities in European countries, and which will be of use to stakeholders that include researchers, government, and research organizations.

Author Summary

Research on arthropod vectors that transmit so-called arboviruses or parasites, such as mosquitoes, ticks, sandflies and midges is important for the development of control measures that target transmission of these pathogens. Important developments in this research area, for example vector genome sequencing, genome manipulation and use of transmission-blocking endosymbionts such as *Wolbachia* have increased interest in vector biology. As such, strategic decisions on research directions as well as research infrastructures will benefit from community input. A survey initiated by the European Horizon2020 INFRAVEC-2 consortium set out to investigate priorities in the vector biology research community as well as key issues that impact on research, and access to the structures and services that allow such studies to be carried out. Here we summarize the key findings of this survey, which in particular reflect priorities in European countries. The survey data will be of use to decision makers such as governments and research organizations, but also researchers and others in the field.

Introduction

Vector-borne diseases such as those transmitted by mosquitoes have a major impact on human and animal health. Among the many examples, malaria (caused by *Plasmodium* parasites) and dengue (caused by four serotypes of dengue virus, *Flaviviridae*) stand out as major diseases that affect populations worldwide, but new threats such chikungunya virus (*Togaviridae*) and more recently Zika virus (*Flaviviridae*) have emerged [1-4]. Both known and emerging pathogens put huge pressure on communities and public health systems. Vaccine development against key threats to human health such as dengue virus and *Plasmodium* parasites may offer tools against transmission and disease, and progress is encouraging [5-8]. However, issues such as pathogen strain variation and vaccine or drug production/distribution costs will remain as challenges [9], and even with vaccines vector control will be a crucial part of a multivalent arsenal. Although drugs against malaria parasites are on the market, availability, administration and resistance are problematic [10-12]. Drugs targeting dengue virus are in the development stages [13-16]. In the case of chikungunya virus vaccine candidates and drugs are now in development [17]. Only veterinary vaccines are currently in use for the animal pathogen Rift Valley fever virus (*Bunyaviridae*) and efforts to produce human vaccines are urgently needed [18, 19].

Many ongoing efforts to control vector-borne diseases rely on control measures that target mosquitoes including control of larval breeding sites, use of insecticides, use of bed nets (often used in combination with insecticides) (see for example, [20-25]). These efforts have been successful when implemented consistently, although issues such as insecticide resistance, changes in vector behavior, and difficulties with

99 breeding site control (see for example [26-35]) require that research in vector
100 biology and control is continuously developed and strengthened. Technological
101 developments over the last decade are transforming modern vector research. These
102 include: vector genome sequences, high-throughput genomics, transcriptomics, and
103 population genetics with results in public databases [36], improved methods for
104 genetic manipulation of arthropods (that have led to field trials) [37-43], studies on
105 the influence of the mosquito midgut microbiome on pathogen transmission [44-46],
106 studies on the impact of the insect-specific viruses on arbovirus transmission [47,
107 48], and the use of *Wolbachia* endosymbiotic bacteria that prevent pathogen
108 transmission [37, 49-52]. Nonetheless the opportunity to access and make best use
109 of ongoing research can be difficult, given the specialized knowledge, costs and
110 infrastructures required.
111
112 The European Union (EU) has identified access to specialized Research
113 Infrastructures (RIs) as a key to producing high quality science. RIs are defined as
114 "Tools for science….RIs offer **unique research services** to users from different
115 countries, attract young people to science, and help to shape scientific
116 communities….. RIs may be '**single-sited**' (a single resource at a single location),
117 '**distributed**' (a network of distributed resources), or '**virtual**' (the service is provided
118 electronically)" [53]. Such RIs can be research facilities, resources and related
119 services. Within the Framework Programmes (FP) of the EU, Research Infrastructure
120 projects support the improvement of key high-level facilities for research, and allow
121 access to the facilities by researchers in Europe and eligible member states. A wide
122 range of research disciplines have been targeted by RI projects, including physics,

123 information science, earth science and medicine. One such Research Infrastructure
124 project under EU FP7 was Infravec, which focused on developing and providing
125 research resources for insect vector biology from 2009-2014. Infravec, which was
126 constituted as an EC Starting Community under FP7, obtained the opportunity to
127 renew the project as an Advanced Community (AC) called INFRAVEC-2 under the
128 Horizon 2020 framework. Research Infrastructure projects are not research
129 networks, but rather are tasked to identify the key unique and rare research
130 infrastructures necessary for a research community, and organize them so that
131 researchers at institutes lacking the Research Infrastructures can access the facilities
132 in order to expand the scope of their research. Thus, Research Infrastructures are
133 exceptional facilities that permit experiments that could not routinely be done
134 without this structure. Use of Research Infrastructure facilities by external
135 researchers is provided as so-called “Transnational Access” (TNA), with access costs
136 reimbursed by the Research Infrastructure project, thus provided at no cost to the
137 end-user.
138
139 Conditions have changed since the inception of the FP7 Infravec project, including
140 the emergence and transmission of arboviruses in Europe and elsewhere, as well as
141 widening the project scope to include vector-borne diseases of economically
142 important animals and the most recently developed innovative technologies.
143 Collecting information about the current and perceived future infrastructure needs
144 of the vector biology research community and other stakeholders is an important
145 step to ensure that the services offered via Transnational Access reflect actual needs
146 of the advanced community. Here we present the findings of a survey of scientists

147 and associated stakeholders in the field of vector biology or fields that are linked to
148 vector biology such as pathogen studies, which will help to define priorities and
149 requirements within INFRAVEC-2 but should also be of interest to governments,
150 research organizations and researchers in the field. Participation numbers suggest
151 that in particular European research priorities are reflected in the results, but the
152 data can inform stakeholders worldwide.
153

154 **Materials and Methods**

155 **Survey structure**. A questionnaire (S1 Table) was sent to organizational email lists
156 (European Society for Vector Ecology; the journal Pathogens and Global Health;
157 National Center of Expertise in Vectors (CNEV, France); CIRM-Italian Malaria
158 Network; FP7 Infravec mail list; International Meeting on Arboviruses and their
159 Vectors mail list; BioInsectes; EU/DEVCO MEDILABSECURE network), as well as to
160 other lists owned by the authors. The questionnaire was sent as a URL link to the
161 online form along with an explanatory note to scientists in the vector biology field
162 and associated stakeholders. The questionnaire request was spontaneously
163 retransmitted by an unknown number of recipients to organizational and other lists.
164

165 Briefly, the cover note explained the aims of the INFRAVEC-2 community, followed
166 by a series of questions. The key areas covered by the survey are as follows: 1)
167 vectors and vector-borne pathogens studied by survey participants, 2) research area
168 (with several responses allowed), 3) infrastructures available at the respondents
169 home institution including those for vector and animal research, 4) ease of access to
170 vector research facilities outside the survey participants' home institution, 5)

171 infrastructures that participants would use, offered by the facilities at no cost to
172 user, 6) identification of research priorities over the next 5-10 years, and 7)
173 additional feedback. The survey was carried out from October to November 2015.
174 Respondents were given the opportunity to provide their name and institution,
175 although this was not required for completion of the questionnaire. However, all
176 respondents (n=211) identified themselves, indicating that repeat voting or vote
177 stuffing is not a concern for interpretation of the results. All results shown here are
178 anonymized, and no survey participant details published.
179

180 **Results and Discussion**

181 In total 211 responses were obtained (see S2 Table). Approximately 88% of
182 respondents were from countries across Europe, with France, and then the UK
183 providing the highest numbers of responses. This suggests that the results reflect a
184 good overview of current priorities in European vector biology and vector research
185 areas. Below we summarize and analyze the data obtained in the survey.
186

187 **Research areas: arthropods and pathogens relevant to survey participants.**

188 Our goal was to obtain an overview of the research areas and work of survey
189 participants, which are thus likely to guide their future research needs (S1 Table,
190 Survey Questionnaire). First, respondents indicated vectors relevant to their
191 research as major or minor area of interest (Table 1). *Aedes* species mosquitoes were
192 the top field, followed by *Anopheles* and *Culex* species. The strong interest in aedine
193 species may reflect the emergence of arboviruses such as chikungunya transmitted
194 by *Ae. aegypti* and *Ae. albopictus* as well as the expansion of the latter species in

195 Europe (and other areas) and acting as arbovirus vector [54-60]. Despite their
196 importance in the European context as major vectors of pathogens, comparatively
197 little research is carried out on ticks and *Culicoides* midges. This suggests that the
198 European vector biology community presently lacks sufficient opportunities and
199 resources for research on these vectors. Among the category "Other", comments by
200 participants indicated phlebotomines/sand flies as a key area, with tsetse flies, fleas,
201 triatomines and tabanids/horse flies also mentioned.
202
203 **Table 1. Research areas and interests of the survey participants**. Numbers of
204 responses are indicated as Major or Minor depending on vector listed, or in the
205 category "Other" which incorporates other vectors not specifically listed (selection of
206 responses shown).

Arthropod	**Major**	**Minor**
Aedes spec.	102	38
Culex spec.	66	46
Anopheles spec.	79	42
Culicoides spec.	24	32
Ticks	55	44
Other	42	49
Vectors mentioned under "Other" (selection of most mentioned): phlebotomines/sandflies (33), fleas (13), tsetse flies (7), triatomines (4), tabanids/horse flies (6)		

207
208 We also quantified the major and minor interests of survey participants (Table 2).
209 There was a notably strong indication of research interests in arboviruses, mainly
210 affecting humans but also livestock pathogens as well. These research interests and
211 activities are likely due to the emergence and importance of arboviruses such as
212 chikungunya, Zika, Schmallenberg and bluetongue [2, 55, 61-63]. Given the
213 historically important role of malaria research also in Europe, the overall importance

214 in the vector field is not surprising. Of note was the impact of tick-borne pathogens
215 in the category "Other" and this is worth mentioning especially with the impact of
216 Lyme disease across Europe and North America [64] and surge in interest in
217 Crimean-Congo hemorrhagic fever virus [65, 66].
218
219 **Table 2. Pathogens relevant to the survey participants.** Numbers of responses are
220 indicated as Major or Minor depending on pathogen category listed, or in the
221 category "Other" which incorporates other pathogens not specifically listed
222 (selection of responses shown).

Pathogen Category	Major	Minor
Arboviruses, human	96	40
Arboviruses, livestock	44	45
Plasmodium spec.	66	31
Other	68	28
Pathogens mentioned under "Other" (selection of most mentioned): *Leishmania* (15), trypanosomes (8), tick-borne pathogens (23).		

223
224 To describe their activities in more detail, we collected further data on the research
225 areas of interest to the survey participants (Table 3). In general vector biology
226 describes the research of over half of the participants, however this is a very broad
227 term. Vector ecology, behavior and control were also commonly reported. Of note,
228 genetic modification and vector immunity remain relatively small fields despite
229 important advances in these areas. Interest may increase with better tools and
230 access to new resources such as strains and facilities. The survey data showed that
231 studies of pathogens either directly or within the context of host-pathogen or
232 vector-pathogen interactions are a key area of research. This needs to be

emphasized as it integrates disciplines such as virology, parasitology, cell biology, microbiology and genetics into the vector field. Similarly, surveillance, diagnostics and epidemiology were important areas and this (alongside vector control, behavior and ecology) was an indication of the applied character of many activities in the field of vector-borne diseases.

Table 3. Details of research areas relevant to survey participants. Numbers of responses are shown by research area, or in the category "Other" which incorporates fields not specifically listed (selection of responses shown).

Research area	Response counts	Research area	Response counts
Vector biology	119	Host-pathogen interactions	102
Vector genetics/genomics	68	Vector-pathogen interactions	116
Vector immunity	32	Epidemiology	99
Vector behavior	77	Surveillance	96
Vector ecology	117	Diagnostics	69
Vector control	98	Other	29
Genetically modified arthropods	20	Other: evolution/population genetics, insecticide etc. (few precise indications given).	
Pathogen biology	88		
Genetically modified pathogens	28		

Assessment of currently available facilities

Knowledge of availability and/or ease of access to research infrastructures is a key factor in future planning of research activities. Survey participants were therefore asked to indicate their current organization's current capabilities. As shown in Table 4, survey participants indicated a certain level of capacity to provide vectors but also material across the community. Moreover facilities for biosafety level (BSL) 2 and 3

experiments with vectors, animals and pathogens are available in several places. The concept of Research Infrastructure can be extended to reagent provision and has been successfully established by FP7 Infravec and the European Virus Archive (http://www.european-virus-archive.com). This indicates an existing infrastructure base that can be developed and made available for research on vectors and pathogens on a wider basis (for example those who do not have immediate access to BSL 3 level insectaries but would require experiments to be carried out in such facilities) through communities such as INFRAVEC-2.

Table 4. Research infrastructures and resources available to survey participants. Various types of structures relevant to vector and pathogen research are indicated.

Available facilities and resources	Response counts
Furnish vectors to external users	74
Furnish BSL2/BSL3 infected vectors/extracts to external users	32
BSL2 containment: arthropod infections	91
BSL3 containment: arthropod infections	60
Pathogen work in cell culture	128
BSL2 or BSL3 containment: small animal work	83
BSL2 or BSL3 containment: large animal work	27

Assessment of infrastructure and service requirements

When survey participants were asked to indicate how many had requested access to insectaries at BSL2 or 3 in other institutions, in total 62 positive responses were received. However out of these, 18 responses indicated that access could not be granted in a timely manner. This suggests that inability to consistently access secure insectary facilities comprises a systematic weakness that impedes research on vector-pathogen interactions and may also explain the weaker interest in vector immunity studies, for example. The relevant secure insectary facilities exist in Europe

(Table 4), and thus a mutualized network of insectaries at BSL2 and 3 could resolve access limitations and promote elevated levels of vector research under BSL2 and 3 conditions.

Access needs, or provision of infected vectors or extracts from infected vectors were assessed and participants were asked to indicate which pathogens or facilities/services would be of interest in the context of INRFAVEC-2 where these are free of cost (or the requirement for collaboration) for the end user (Table 5). Although the questions below were originally aimed at potential European users all answers were taken into account. Survey data show that in particular services and structures for arbovirus research would likely generate strong demand. Again this may be due to the surge in research in this field described above. Similarly, BSL2 and 3 studies on infected vectors and insecticides as well as behavior scored highly. Regarding technologies novel for the field, functional siRNA screens and imaging of vectors did not score particularly high but this demand may increase in the future, particularly if facilities were available for access.

Table 5. Infrastructure services (vector infection and vector-pathogen interactions) for the vector research community. Survey participants responded whether the services listed here (vector infection and vector-pathogen interactions) to study vector infections and vector-pathogen interactions, would be of use if offered free of cost. Response counts are grouped into Likely, Not likely or Possible use of the infrastructure/service.

Infrastructure/service: Vector infection and vector-pathogen interactions	**Likely**	**Not likely**	**Possible**
Arboviruses	90	46	31
Plasmodium falciparum	36	77	33
Infected vector & insecticide studies	83	38	50
Behavioral studies with infected vectors	64	50	42
In vivo imaging with infected vectors	48	58	41
Functional siRNA screens of vector cells	35	68	36
Other needs	21	39	15
Category "Other needs" included various *Plasmodium* species, *Leishmania*, tsetse flies etc.			

293

294 Vector genetics and genomics (see www.vectorbase.org, [36]) but also studies of
295 vector microbiomes (given their influence on mosquito infection with arboviruses
296 and parasites [44-46, 67]) are expanding fields. These research areas have strongly
297 benefited from high-throughput sequencing techniques and bioinformatics. Survey
298 participants were enthusiastic about developing insect vector-oriented
299 infrastructures, services and expertise in high throughput genomics and
300 bioinformatics, especially transcriptional profiling and genome and population
301 analysis (Table 6).

302

303 **Table 6. Infrastructure services (vector genomics and bioinformatics) for the vector**
304 **research community.** Survey participants responded whether the services listed
305 here (vector genomics and bioinformatics), would be of use if offered free of cost.
306 Response counts are grouped into Likely, Not likely or Possible use of the
307 infrastructure/service.

Infrastructure/service: Vector genomics and bioinformatics	**Likely**	**Not likely**	**Possible**
Transcriptional profiling	75	42	53
Genome or population analysis	72	43	54
Bacterial microbiome profiling	45	63	41
Population or focused SNP genotyping	39	63	48
Other needs	10	41	8
Category “Other needs” included proteomics, metabolomics.			

The era of genomics has brought about much needed information on vector genomes (see for example [68-70]). Genetic manipulation of genomes in basic biological studies of gene/sequence structure and function, and applications based on genome manipulation (see for example [71-73]) are useful tools to maximize the value of this information, and for example CRISPR/Cas9-mediated genome manipulation is an important technical advance also for the vector field [74, 75]. We therefore asked survey participants about their interest in applying genome editing technologies within their work. As shown in Table 7, there was particularly strong interest in genetic manipulation of aedine mosquitoes. *Culicoides* midges seemed at present a less popular subject, probably at least in part because the community is small as mentioned above, as well as that the technologies have not yet been applied to this system or general issues with establishing colonies of important midge vector species. Among the category “Other”, ticks stood out.

Table 7. Infrastructure services (vector genome editing) for the vector research community. Survey participants responded whether vector genome editing would be of use if offered free of cost. Response counts are grouped into Likely, Not likely or Possible use of the infrastructure/service.

Infrastructure/service: Vector genome editing	**Likely**	**Not likely**	**Possible**
Anopheles spec.	35	71	44
Aedes spec.	60	60	33
Culicoides spec.	20	85	17
Other	27	53	7
"Other" included ticks (17), phlebotomines (5), *Culex* spec. and tsetse flies (both 4).			

Studies on vectors (infected, uninfected or genetically modified) often include components that analyze behavior and ecology. A further section of this survey therefore focused on a number of specific potential requirements in this area. As indicated in Table 8, the interest to work in field sites in endemic countries if access could be provided, as well as standardized behavioral assays and bioassays for vectors generated strong positive responses. This suggested a need for these in the vector research community. Positive responses for large cage studies (controlled indoors or semi-controlled outdoors) were also strong considering that such applications are very specialized, and the facilities are rare. However, this illustrates the potential contribution of a Research Infrastructure project, because community mutualization of rare infrastructures can allow access to state of the art facilities for researchers with occasional needs. In the future, the possibility to access such facilities may become stronger as more genetically modified vectors will be assessed in pre-release assays. Few positive responses for electrophysiology experiments

were obtained, suggesting that there is no major need for additional facilities beyond what is already in place.

Table 8. Infrastructure services (vector ecology and behavior) for the vector research community. Survey participants responded whether specific services or infrastructures to study vector ecology and behavior, would be of use if offered free of cost. Response counts are grouped into Likely, Not likely or Possible use of the infrastructure/service.

Infrastructure/service: Vector ecology and behavior	**Likely**	**Not likely**	**Possible**
Facilitated work at endemic country field sites	96	39	43
Electrophysiology	14	99	23
Standardized vector behavioral assays & bioassays	65	52	52
Large cage studies (controlled large indoor insectary)	64	61	46
Large cage studies (semi-controlled outdoor large cages)	46	77	40
Other needs	7	44	3
Very few responses to “Other needs” given, for example cage trials in Europe.			

Survey participants were also asked about their requirements for more specific vector-related data and research resources such as reference genomes, specific cell lines and mosquito strains (Table 9). Results indicated that in particular, a bank of standard vector colonies would be of interest to the community. Easily accessible quality-controlled vector colonies available from a European repository could be an important influence promoting comparability and reproducibility of experimental

359 infection and other results across laboratories. Similarly vector systematics and
360 collections generated high interest. However, the practices of systematics may be at
361 a juncture, because the technological capacity will soon be available to whole-
362 genome sequence large numbers of unidentified individuals of a putative vector
363 clade, and cluster them bioinformatically to determine phylogenetic relatedness.
364 These results will need to be compared to existing collections, including voucher
365 specimens. Perhaps surprisingly, new reference and cloned vector cell lines did not
366 score highly but these may be of interest to smaller research areas such as virologists
367 who carry out particular types of studies. Cell lines may be of less interest in malaria
368 vector research where the biology is not consistent with simple cell models of
369 *Plasmodium*-mosquito interaction. Despite high interest in *Wolbachia* to block
370 pathogen transmission [51], generation of novel trans-infected vector strains was
371 also not a priority. Finally, a small number of responses under "Other needs"
372 mentioned the importance of training.
373
374 **Table 9. Infrastructure services (vector biology resources) for the vector research**
375 **community.** Survey participants responded whether specific resources for vector
376 biology, would be of use if offered free of cost. Response counts are grouped into
377 Likely, Not likely or Possible use of the infrastructure/service.
378
379
380
381
382

Infrastructure/service: Vector biology resources	**Likely**	**Not likely**	**Possible**
Bank of standard vector reference strains (genome & RNA sequenced)	85	34	54
Colonization of novel vector strains & species	76	45	53
Production of new reference vector cell lines (genome & RNA sequenced)	38	74	38
Production of cloned vector cell lines	39	75	37
Production of microbiome-free mosquitoes	28	82	40
Wolbachia-transinfected vector strains	23	76	52
Vector systematics and collections	62	52	55
Other needs	5	44	3
Very few responses to “Other needs” given, mainly mentioning training needs.			

Our survey specifically addressed training needs, community networking and communication. As shown in Table 10, all suggestions - training in vector BSL2 and 3 methods, training in bioinformatics and genomics and scientific communication by conferencing - were positively received by the survey participants. Clearly these are areas of need that should be developed as a real requirement within the vector research field.

394 **Table 10. Infrastructure services (training and networking activities) for the vector**
395 **research community.** Survey participants responded whether specific services or
396 infrastructures in the areas of training and networking activities, would be of use if
397 offered free of cost. Response counts are grouped into Likely, Not likely or Possible
398 use of the infrastructure/service.
399

Infrastructure/service: Training and networking activities	**Likely**	**Not likely**	**Possible**
Training in BSL2 and 3 vector infection and study techniques	96	30	51
Training in bioinformatics and genomic analysis	107	25	53
Conferencing	102	16	59
Other needs	8	32	7
Very few responses to "Other needs" given; one example: training of field workers and students in field identification.			

400

401 Survey participants were also asked to give their opinions in a text field on research
402 priorities for vector biology over the next 5-10 years. Answers varied but some key
403 areas were identified: 1) Vector interactions with hosts and pathogens, including
404 vector competence and transmission; 2) Insecticide resistance and novel
405 insecticides; 3) Ecology and behavior, including of infected vectors, introduction of
406 vectors etc.; 4) Vector control, novel control measures and surveillance; 5) Vaccines,
407 including anti-vector vaccines; 6) Modelling; 7) Vector genomics/genetics and
408 bioinformatics. Although no survey can be complete, the data presented here yields
409 a valuable picture of the needs and requirements in disease vector biology,
410 especially of European scientists. We thus expect this study to be relevant to

411 stakeholders such as governments, research councils and organizations but also
412 researchers as priorities for future activities such as those planned by INFRAVEC-2
413 are determined.

414

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418

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708 **Supporting information legends**

709 **S1 Table.** The INFRAVEC-2 Survey Questionnaire, as sent out to participants. A brief
710 description of the INRFAVEC-2 community is given, and the aims of the
711 questionnaire explained.

712 **S2 Table.** Responses to the INFRAVEC-2 and participation numbers by country, split
713 by continent.

Supporting information S1 Table.
The INFRAVEC-2 Survey Questionnaire, as sent out to participants. A brief description of the INRFAVEC-2 community is given, and the aims of the questionnaire explained.

HORIZON 2020 INFRAVEC-2 Questionnaire

Introduction

A consortium of European institutions based in the former FP7/INFRAVEC project is responding to the new H2020 call “Integrating Activities for Advanced Communities” of the European Research Infrastructures (RI) Programme under the item “Research Infrastructures for the control of vector-borne diseases”. The primary purpose of an “integrated infrastructure” is to provide the EU scientific community with access to its network of RI facilities and services, without charge to the end user, at the state-of-the art premises of participating institutions. Access to the specialized RI enables European researchers and SME to carry out experiments beyond their current capacities.

Building upon the major achievements of FP7/INFRAVEC in forging a European Starting Community of insect vector RI, we worked with EC representatives to generate the current H2020 call for an Advanced Community (AC). With strong commitment obtained from collaborating institutions hosting top-level specialized EU facilities for vector-borne disease (including Institut Pasteur FR, Imperial College UK, Centre de Recerca en Sanitat Animal (IRTA-CReSA) ES, Wageningen University NL, University of Glasgow UK, Institut de Recherche pour le Développement (IRD)-Montpellier FR, Polo d'Innovazione di Genomica, Genetica e Biologia (Polo GGB) IT, Pirbright Institute UK, Max-Planck-Institut für Infektionsbiologie DE, Radboud University Medical Center NL, and EMBL European Bioinformatics Institute DE), the group, chaired by K. Vernick (Institut Pasteur), has been invited to organize the AC.

The RI consortium will provide enabling infrastructures and support for research on disease vectors and their pathogens. We have listed possible RI and services within the following questionnaire, and we would like to solicit as wide as possible feedback from potential users in order to understand the major needs of the vector biology community. Your particular requirements and feedback will have strong impact on how the project will be structured, as this “integrated infrastructure” needs to be tightly tailored to, and inspired by real community needs. Please, take a minute to fill in a short questionnaire (~15 min) that will help us mobilize necessary resources for the future of our community.

Please feel free to forward this email to relevant colleagues. The primary target audience is EU insect vector researchers and SME, but we welcome replies from outside the EU as well. All individual replies and identity information will be kept confidential. Questions can be addressed to email: infravec-survey@pasteur.fr

Please complete this form as soon as you can. The survey will close November 25th 2015.

Thank you for your collaboration.

Q1. Please provide your name and contact details.

Title

.....

First name

.....

Last name

Position

Organization

Country

Email (optional)
Providing an email address is optional, but will permit us to keep you informed about the consortium; contact information will not be shared with other parties.

Q2. Please identify the arthropod vectors and/or vector borne pathogens that you research

Select all that apply

	MAJOR	Minor
Aedes	◯	◯
Culex	◯	◯
Anopheles	◯	◯
Culicoides	◯	◯
Ticks	◯	◯
Other	◯	◯

If other other area
Please specify below

Select all that apply

	MAJOR	minor
Arboviruses (human)	◯	◯
Arboviruses (livestock)	◯	◯
Plasmodium	◯	◯
Other	◯	◯

If other other area
Please specify below

Q3. Please select the most relevant areas that describe your research interests from the list below

Select all that apply

- [ ] Vector biology
- [ ] Vector genetics/genomics
- [ ] Vector immunity
- [ ] Vector behavior
- [ ] Vector ecology
- [ ] Vector control
- [ ] Genetically modified arthropods

- [ ] Pathogen biology
- [ ] Genetically modified pathogens

- [ ] Host-pathogen interactions
- [ ] Vector-pathogen interactions
- [ ] Epidemiology
- [ ] Surveillance
- [ ] Diagnostics
- [ ] Other

If other
Please specify below

Q4. Does your organization have infrastructure facilities described by the list below?

Select all that apply

- [ ] To rear arthropod vectors
- [ ] To furnish vectors as a provider to external users
- [ ] To infect arthropods in BSL-2 containment
- [ ] To infect arthropods in BSL-3 containment
- [ ] To work with pathogens using in vitro cell cultures
- [ ] To infect small animals under BSL-2 or 3 containment
- [ ] To infect large animals under BSL-2 or 3 containment
- [ ] To furnish BSL-2 or -3 infected vectors or extracts to external users

Q5. Have you ever tried to access BSL-2 or 3 vector research facilities based at organizations other than your own?

- ◯ Yes
- ◯ No
- ◯ Not applicable

a. If yes, did the facility have sufficient capacity to accommodate your request in a timely manner?

- ◯ Yes
- ◯ No

Q6. Which infrastructure services offered to European users would you be likely to use, with user access costs paid by a Horizon 2020 Research Infrastructure consortium (i.e., at no charge to the end-user). Items provided as user access or custom service, which does not require scientific collaboration with the providing facility.

a. VECTOR INFECTION AND VECTOR-PATHOGEN INTERACTIONS. Access to BSL-2 or 3 secure insectary facilities for infection of vectors, or provision of infected vectors or extracts custom-generated by such a facility. Vectors infected by the following pathogens, and for the following research purposes (select all that apply).

	Likely	Possible	Not likely
1. Arboviruses	☐	☐	☐
2. Plasmodium falciparum	☐	☐	☐
3. Infected vectors and insecticide studies	☐	☐	☐
4. Behavioral studies with infected vectors (e.g., odorant/host choice)	☐	☐	☐
5. In vivo imaging of infected vectors (e.g., confocal, spinning disk)	☐	☐	☐
6. siRNA functional screening of vector cell lines	☐	☐	☐
7. Other needs	☐	☐	☐

If other needs--please specify below

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Q6. Which infrastructure services offered to European users would you be likely to use, with user access costs paid by a Horizon 2020 Research Infrastructure consortium (i.e., at no charge to the end-user). Items provided as user access or custom service, which does not require scientific collaboration with the providing facility.

b. VECTOR GENOMICS AND BIOINFORMATICS. High-throughput genomic services. If desired, with upstream bioinformatic design advice and downstream bioinformatic analysis (select all that apply)

	Likely	Possible	Not likely
1. Transcriptional profiling by Illumina RNA-seq			
2. Genome or population analysis by Illumina DNA sequencing			
3. Bacterial microbiome profiling by 16S rRNA amplicon deep sequencing			
4. Population or focused SNPgenotyping (e.g., Sequenom)			
5. Other needs			

If other needs--please specify below

Q6. Which infrastructure services offered to European users would you be likely to use, with user access costs paid by a Horizon 2020 Research Infrastructure consortium (i.e., at no charge to the end-user). Items provided as user access or custom service, which does not require scientific collaboration with the providing facility.

c. VECTOR GENOME EDITING. Provision of custom genetic modification of your requested target gene or sequence using CRISPR or other technology in vectors (select all that apply). Could also include phenotyping the mutation effect by pathogen challenge under (a) above.

	Likely	Possible	Not likely	
1. Anopheles				
2. Aedes				
3. Culicoides				
4. Other needs				

If other needs--please specify below

Q6. Which infrastructure services offered to European users would you be likely to use, with user access costs paid by a Horizon 2020 Research Infrastructure consortium (i.e., at no charge to the end-user). Items provided as user access or custom service, which does not require scientific collaboration with the providing facility.

d. VECTOR ECOLOGY AND BEHAVIOR. Provision of access to facilities or custom-performed assays (select all that apply). Could also include pathogen infection of vectors under (a) above.

	Likely	Possible	Not likely
1. Facilitated work at endemic country field sites, Africa, Asia, S. America (population & epidemiology studies)			
2. Electrophysiology / EAG			
3. Standardized vector behavioral tests & bioassays (e.g. odorant, host choice)			
4a. Large-cage studies (e.g. behavior, fitness,reproduction, test of modified genetic strains) in completely controlled indoor large insectary			
4b. Large-cage studies (e.g. behavior, fitness,reproduction, test of modified genetic strains) in semi-controlled outdoor large cages (Africa)			
5. Other needs			

If other needs--please specify below

Q6. Which infrastructure services offered to European users would you be likely to use, with user access costs paid by a Horizon 2020 Research Infrastructure consortium (i.e., at no charge to the end-user). Items provided as user access or custom service, which does not require scientific collaboration with the providing facility.

e. VECTOR BIOLOGY RESOURCES. Provision of vector research resources by request (select all that apply).

	Likely	Possible	Not likely
1. Bank of standard vector reference strains (genome & RNA sequenced)	⬭	⬭	⬭
2. Colonization of novel vector strains and species	⬭	⬭	⬭
3. Production of new reference vector cell lines (genome & RNA sequenced)	⬭	⬭	⬭
4. Production of cloned vector cell lines	⬭	⬭	⬭
5. Production of microbiome-free mosquitoes	⬭	⬭	⬭
6. Wolbachia transinfected vector strains	⬭	⬭	⬭
7. Vector systematics and collections	⬭	⬭	⬭
8. Other needs	⬭	⬭	⬭

If other needs--please specify below

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Q6. Which infrastructure services offered to European users would you be likely to use, with user access costs paid by a Horizon 2020 Research Infrastructure consortium (i.e., at no charge to the end-user). Items provided as user access or custom service, which does not require scientific collaboration with the providing facility.

f. TRAINING AND NETWORKING ACTIVITIES. Promotion of expertise using standardized, comparable practices, scientific exchange.

	Likely	Possible	Not likely
1. Training in BSL-2 and 3 vector infection and study techniques	⬭	⬭	⬭
2. Training in bioinformatics and genomic analysis	⬭	⬭	⬭
3. Conferencing	⬭	⬭	⬭
4. Other needs	⬭	⬭	⬭

If other needs--please specify below

Q7. In your opinion, what are the top research priorities (up to 5) in vector biology and/or vector borne disease that need to be addressed in the next 5-10 yrs in the European research context?

1.

2.

3.

4.

5.

Thank you for participating!

Please use the space provided below to send us any additional feedback on this survey.

Supporting Information S2 Table.

Responses to the INFRAVEC-2 and participation numbers by country, split by continent.

	Participants/country
Europe	
Albania	2
Austria	2
Belgium	4
Bosnia-Herzegovina	1
Bulgaria	2
Croatia	1
Czech Republic	3
Denmark	1
Estonia	2
Finland	1
France	56
Germany	11
Greece	3
Hungary	1
Italy	15
Kosovo	1
Latvia	1
Luxembourg	2
Moldova	1
Macedonia	2
Montenegro	1
Portugal	8
Romania	2
Serbia	4
Slovakia	2
Slovenia	2
Spain	15
Sweden	4
Switzerland	3
The Netherlands	4
UK	28
Asia	
Armenia	1
Burkina Faso	2
Cambodia	1
Israel	2
Palestine	2
Singapore	1
Turkey	3
Africa	
Algeria	1
Cameroon	1
Egypt	1
Morocco	2
South Africa	1

Australia	
Australia	1
North America	
USA	7