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30 **Abstract**

31 Faced with the increased frequency of zoonotic spillover in recent decades, emerging vector-
32 borne diseases from non-human primates pose a significant threat to global public health.
33 Understanding transmission dynamics driven by arthropod vectors between wildlife
34 populations is critical for surveillance, modelling and mitigation. Elevated canopy-level
35 sampling is a valuable approach for elucidating vector behaviour and sylvatic transmission.
36 However, this is underutilized in many regions due to the logistical and mechanical
37 challenges of re-purposing ground-based trapping for the forest canopy. We review methods
38 of canopy-level entomological surveillance, present case studies and identify opportunities to
39 integrate new technologies. Paired with robust experimental design, canopy-level trapping
40 can complement existing surveillance of emerging zoonotic diseases and provide critical
41 insights into the role of vectors driving spillover risks.

42

43

44 **Surveillance for vector-borne diseases with non-human primate hosts**

45 Many vector-borne diseases (VBDs) originated in **non-human primates (NHPs**, see
46 **Glossary)**. Diseases, such as malaria, yellow fever and other arboviral diseases, often include
47 **sylvatic disease cycles** involving wildlife in natural forest habitats [1]. In the natural habitats
48 of NHPs, **zoophilic, acrodendrophilic** (canopy-dwelling) **mosquitoes** transmit the pathogens
49 between wildlife hosts [2]. Human populations can become infected if they encroach into
50 NHP habitats or when infected zoophilic **bridge vectors** transmit pathogens from wildlife to
51 humans, with VBD infections spreading rapidly if they can be transmitted by competent,
52 **anthropophilic mosquito** species [3]. This results in spillover into human populations and
53 potential transitions from a sylvatic disease cycle to an endemic human transmission cycle [4]
54 (See **Figure 1**).

55 **[Insert Figure 1]**

56 NHP reservoirs are a barrier to VBD elimination due to the risk of repeated spillover and
57 pathogen maintenance in sylvatic transmission cycles. The emergence of dengue as a global
58 health burden demonstrates the shift from a sylvatic cycle to a human-endemic cycle due to
59 ecological disturbance and subsequent adaptation to nonzoonotic transmission [5].

60 Characterised by infrequent but large epidemics from 1780 – 1940 [6], the large-scale habitat
61 degradation in the Pacific and South-East Asia theatres during World War II created optimal
62 conditions for increased transmission in urban areas maintained by anthropophilic vector
63 species with repeated spillover events mediated by bridge vectors [7].

64 Applying traditional control measures for nonzoonotic VBD diseases to diseases with
65 sylvatic cycles, has rarely succeeded given the complexity of transmission. Standard vector-
66 borne disease control measures, such as insecticide treated nets, vaccine drives and rapid
67 detection and treatment of cases, target nonzoonotic transmission and do not prevent spillover
68 from wildlife. Wildlife reservoirs have become increasingly critical in areas where

69 nonzoonotic disease transmission has been eliminated, such as zoonotic malaria outbreaks in
70 otherwise malaria free areas of Malaysia and Brazil [8]. Due to the complexity of sylvatic
71 transmission cycles, there remain key research gaps on how to design and implement
72 **zoonotic and vector-borne disease** surveillance [9].

73

74 For diseases with sylvatic cycles, surveillance systems are needed to monitor pathogen
75 transmission between wildlife populations. Arboreal **zoophilic mosquitoes** act as vectors for
76 a number of sylvatic zoonotic pathogens, including *Plasmodium* sp., West Nile virus, yellow
77 fever virus (YFV) and Rift Valley fever virus [10]. Data on the abundance, biting preferences,
78 vectoral capacity and circulating pathogens in these vector species is essential to understand
79 the epidemiology of these pathogens. Despite advances in genetic methods, which have led to
80 increased use of **xenosurveillance** to noninvasively detect circulating pathogens from vector
81 bloodmeals [11], data on pathogen epidemiology circulating between canopy dwelling
82 wildlife remain limited [12]. Targeted mosquito trapping has identified the vector species for
83 sylvatic pathogens including Rift Valley fever, dengue and yellow fever and malaria [6, 13].
84 Additionally, vector trapping data provide insights into spatial and temporal patterns of vector
85 occurrence, vector community composition, blood feeding preferences, and niche specificity.
86 Evaluation of mosquito trapping methods has primarily focused on design for terrestrial
87 usage, creating a paucity of research on transmission cycles in the forest canopy.

88

89 Here, we review existing methods of entomological surveillance at canopy level, assess
90 specific canopy-level trapping requirements and identify opportunities to develop canopy-
91 level trapping tools for surveillance of sylvatic disease cycles. We examine case studies of
92 canopy-level trapping tools used for monitoring zoonotic malaria in Malaysian Borneo and
93 zoonotic malaria and arboviruses in Brazil. Placing canopy-level trapping in the broader

94 framework of developing policy for effective surveillance and control strategies for zoonotic
95 diseases, we discuss applications and future priorities.

96

97 **Entomological trapping methods**

98 Entomological trapping methods for research and operational use have been extensively
99 developed to catch mosquitoes across all stages of their life cycle, with context-dependent
100 efficacy for different methods [14]. Host-seeking adult mosquitoes are commonly surveyed
101 using traps that may incorporate live animals or human volunteers as attractants. For
102 anthropophilic mosquito vectors, the gold standard remains **Human Landing Catch (HLC)**
103 [15-17], which requires human volunteers to collect landing mosquitoes. Other traps utilise
104 attractants such as carbon dioxide, odour, heat and light of different wavelengths to attract
105 mosquitoes [18, 19]. Alternatively, traps that target egg-laying behaviour include oviposition
106 traps, which use small containers containing water to attract egg-laying mosquitoes and a
107 substrate to collect eggs, and gravid traps, which similarly use water to attract gravid
108 mosquitoes and methods such as sticky glue boards or oil to capture adult mosquitoes [20,
109 21]. As these traps target blood fed mosquitoes, there is a higher probability of detecting
110 infections.

111

112 **Human landing catches in the canopy**

113 However, using these entomological methods at canopy levels creates new logistical
114 challenges (see **Figure 2**). First, there needs to be method of deployment to access the
115 canopy. For HLCs or other human-baited traps, this may require using certified tree climbers
116 or creating fixed platforms for people to access. Research by Hendy *et al.* [22] evaluated the
117 efficacy of volunteers using hand-nets to collect approaching mosquitoes from platforms in
118 Manaus, Brazil, and observed a decreasing mosquito species richness with altitude, and the

119 presence of flavivirus vectors at all elevations. However, developing these platforms requires
120 substantial investment in infrastructure that is not easily moveable. Alternatively, trained tree
121 climbers were used to collect zoonotic malaria vectors at canopy level in Malaysian Borneo
122 [23]. These human-baited methods allow people to record detailed data on when mosquitoes
123 were collected to better characterise vector bionomics. However, both of these methods
124 expose people to health and safety risks due to the need to climb trees and potential exposure
125 to pathogens . Moreover, the use of humans and other species not typically found at canopy
126 level as bait may alter the distribution and behaviour of vector and wildlife communities and
127 therefore abundance estimates from human-baited traps may not be representative of vectors
128 biting NHPs. While some vector species may be generalists, studies have identified vector
129 species with much stronger attraction towards NHP odours compared to humans or other
130 animals [24].

131 **[Insert Figure 2]**

132 **Animal-baited traps in the canopy**

133 The ideal method of surveillance to understand sylvatic cycles is to use traps baited with the
134 natural wildlife host, although this is biased towards vectors and pathogens associated with
135 the chosen animals. For example, when using monkey-baited traps, *Anopheles cracens* (a
136 *Plasmodium knowlesi* vector found in the forests of peninsular Malaysia) prefers feeding on
137 NHP species at the canopy level, and on humans at the ground level[25]. This identified
138 potential biases in ground-based studies that have perhaps erroneously reported higher biting
139 behaviour for humans, with important ramifications for understanding vectorial capacity [8,
140 26]. Alternatively, early studies used CDC traps baited with non-host animals to examine
141 vertical stratification and biting behaviours of *Culex* and *Anopheles* mosquitoes in Brazil
142 [27]. Despite the utility of these methods, animal-baited traps are rarely implemented in

143 canopy level due to the expense, logistical challenges and ethics requirements around the use
144 of NHPs and other animals in research.

145

146 **Case study: Canopy-level entomological surveillance in Brazil: insights and operational**
147 **use**

148 YFV is a vector-borne sylvatic disease that has a complex transmission cycle, and has a long
149 history as a zoonotic disease with recurrent epidemics in rural regions of Africa and South
150 America [28]. Recently re-emerging in Minas Gerais and São Paulo states in Brazil in 2016,
151 in the most significant epidemic in over 70 years [29], YFV provides an interesting example
152 of the application of surveillance strategies. As an arbovirus, control strategies for YFV,
153 involve vector control measures for populations with high habitat specificity, with distinct
154 mosquito species transmitting the virus in the three independent epidemiological cycles;
155 jungle, savannah and urban cycles in Africa, and a sylvatic cycle in Brazil [30]. Historically,
156 the YFV urban transmission cycle has been interrupted by aggressive control of *Ae. aegypti*
157 vector populations, although these are often not economically feasible and are unable to
158 control *Haemagogus* spp. and *Sabethes* spp. Vectors involved in enzootic transmission in
159 forested landscapes in Brazil. The development of a highly successful vaccination program
160 against YFV in the 1930s in Africa, foreshadowed these problems of sylvatic disease
161 transmission [31].

162

163 Canopy-level entomological trapping deployed in São Paulo State successfully sampled
164 sylvatic YFV vectors [32, 33]. Canopy-mounted platforms in the Atlantic Forest Biome were
165 used to support a variety of entomological sampling methods that observed higher overall
166 species diversity and higher YFV vector richness in the canopy. As a result of the successful
167 demonstration of the importance of canopy-level surveillance, the São Paulo State Secretary

168 of Health integrated canopy surveillance of YFV vectors into the Institutional Development
169 Plan In Research and Technology for Vector Surveillance and Control [34].

170 **[Insert Figure 3]**

171 Mosquito specimens of epidemiological importance to YFV transmission, particularly
172 *Haemagogus* spp. and *Sabethes* spp., were predominantly captured at a canopy height of 6–8
173 meters, compared to ground-level collections, in the Cantareira State Park within the
174 Brazilian Atlantic Forest biome (**Figure 3A**)[32]. These collections took place in two areas
175 between 10:00 a.m. and 3:00 p.m., using hand-held nets with mobile human bait and CDC-
176 type automatic traps equipped with volatile chemical baits (dry ice and/or BG-Lure[®]
177 attractant). Platforms installed at 6–8 meters allowed simultaneous canopy and ground-level
178 net collections in each area. A total of eight traps were deployed – four at ground level and
179 four in the canopy – positioned 100 meters to the north, south, east, and west of the platform,
180 which served as the central reference point. Although more mosquito specimens were
181 captured on the ground (n=2,855) than in the canopy (n=715), the canopy exhibited greater
182 species diversity and evenness, as well as lower species dominance, regardless of the
183 collection method used (**Figure 3B**)[32].

184

185 In the Adolpho Ducke Forest Reserve, Manaus, located more than 2,500 km from Cantareira
186 State Park in São Paulo, Brazil, researchers observed a similar pattern of vertical stratification
187 in *Haemagogus* spp. and *Sabethes* spp. (**Figure 3C**) [22, 35]. BG-2 traps, baited with CO₂
188 (dry ice) and BG-Lure (synthetic attractant), were deployed at heights of 0, 5, 10, and 15
189 meters across three sites, each approximately 500 meters from the forest edge. Although
190 *Haemagogus* spp. and *Sabethes* spp. were less frequently found at ground level compared to
191 5, 10, or 15 meters, their occurrence at ground level may increase when temperatures are
192 higher and relative humidity is lower—a condition more common at forest edges [35].

193 Furthermore, the study found no significant effect of trap height on the vertical stratification
194 of mosquito community diversity, as measured by the Shannon-Wiener Diversity Index.
195 However, a stronger effect was observed at two of the three sites sampled (**Figure 3D**).

196

197 These studies used canopy collections at heights significantly lower than the actual canopy
198 height of tropical rainforests [22, 35]. In Cantareira State Park, an Atlantic rainforest habitat
199 in Brazil, trees can reach heights of 20-25 meters, far exceeding the sampling heights of 6-8
200 meters [32]. In the Adolpho Ducke Forest Reserve, canopy height ranges from 30 to 35
201 meters, with emergent trees reaching up to 50 meters [35]. Thus, sampling at a maximum
202 height of 15 meters introduces a clear limitation in vertical space coverage, potentially
203 biasing results toward lower strata; this could be addressed through other deployment
204 methods. Other researchers have addressed this challenge by documenting insect fauna
205 variability using 6-meter Gressitt-style Malaise traps placed along a vertical canopy gradient
206 (0-32 meters at 8-meter intervals) on a metal tower in a tropical forest north of Manaus, in the
207 Central Amazon, Brazil [36-38]. Certain fly families (Diptera) typically exhibit a two-peak
208 pattern, particularly those that exploit very different resources—such as blood-feeding flies
209 like mosquitoes (Culicidae) and biting midges (Ceratopogonidae). Mosquitoes were most
210 frequently found at ground level (40%), with a secondary peak at 24 meters (20%), and at
211 least 1% occurring at 32 meters.

212

213 Following a severe outbreak of a sylvatic arbovirus, which was unknown at the time but has
214 since been identified as the Rocio Virus, in southeastern São Paulo, Brazil, several studies on
215 mosquito ecology and systematics were conducted in the Ribeira River Valley, employing
216 various methods commonly used at the time [39]. CDC traps baited with pigeon (*Columba*
217 *livia*) and rodent (*Rattus norvegicus*) were used to collect mosquitoes at both ground and

218 canopy levels within the forest and edges and at ground level in open areas [27]. For each
219 baited trap in the forest environment, simultaneous collections were conducted without bait.
220 Mosquito species associated with arboviral spillover from wildlife to humans, including those
221 from the *Culex* (Melanoconion) subgenus—particularly *Cx. sacchettae*—were prominently
222 captured using CDC traps baited with pigeons or rodents. This method allowed researchers to
223 identify *Cx. sacchettae* as a species associated with ecotones at ground level, indicating its
224 potential to transmit pathogens to humans if infected with the relevant pathogen. Together,
225 this exemplifies a systematic approach for evaluating canopy-level trapping methods and the
226 importance of monitoring across a vertical gradient.

227 **[End of case study]**

228

229 **Use of mosquito traps in the canopy**

230 These significant ethical and logistical considerations of live baited traps [40], have resulted
231 in the development of alternative trap models that use a combination of synthetic attractants
232 to catch adult mosquitoes, and are easily transportable. Example traps include the Centers for
233 Disease Control Light Trap (CDC-LT; BioQuip Products, Rancho Dominguez, California,
234 USA; <http://www.bioquip.com>), BioGents Sentinel-2 and BioGents Pro traps (BioGents AG,
235 Regensburg, Germany <https://eu.biogents.com>), and the Mosquito Magnet (MosquitoMagnet,
236 Lititz, Pennsylvania, USA; <http://www.mosquitomagnet.com>), alongside a variety of
237 variations in attractants and models used. These traps show variable efficacy targeting
238 different mosquito genera in different settings and may not be directly comparable to HLCs
239 or NHP baited traps [41-44]. However, there is limited data available to validate these
240 methods for elevated canopy trapping. Whilst comparative efficacy studies of ground-based
241 trap models are well represented geographically, very few studies have used elevated canopy
242 trap designs to systematically compare trap efficacy against traps baited with the natural

243 reservoirs. For example, at ground level, traps such as the CDC-LT have been observed to be
244 more effective in sampling community richness and abundances [18], whilst traps such as the
245 BG-2 have been shown to be more effective at sampling target species such as *Aedes*
246 *albopictus*, *Ae. aegypti* and *Culex pipiens* [45], however both trap types show significant
247 variation in efficacy across different contexts [46-48].

248

249 **Deployment of mosquito traps in the canopy**

250 Deploying traps in the canopy is significantly more logistically feasible than using traps with
251 humans or NHPs, which may require either platforms or scaffold towers to be constructed.
252 Previous studies have used ropes or other methods to lift traps into the canopy [49]. However,
253 depending on the trap type, weight and attractants used, there may be a need to construct
254 different delivery systems. For example, if traps rely on large batteries or carbon dioxide
255 tanks as attractants, these need to be either lifted with the trap or connected from ground-
256 level. Additionally, common methods such as using a sling shot to throw a rope, may be
257 difficult to deploy if there are complex vegetation structures or, at very high heights. Sling
258 shot methods deploying ropes require field staff to be able to access the target location and
259 may pose safety considerations, particularly if weights are used to deploy lines. Moreover,
260 traps may be difficult to raise and lower without pulley systems and limit the ability to check
261 hourly collections. Traps may be structurally damaged by wildlife such as NHPs and other
262 arboreal vertebrates. Ants and other insects may also enter the traps and may predate
263 mosquito catches; sticky substances are commonly applied to ropes to avoid this.

264

265 Among the few studies completed globally, significant vector community stratification has
266 already been observed [27]. Hendy *et al.* [35] suspended BG-2 traps at intervals in the canopy
267 of central Brazil to examine community composition of potential ZIKV vectors, and noted a

268 positive correlation of two flavivirus mosquito vectors with increasing height above ground,
269 and niche conditions including relative humidity and temperature. The use of Malaise traps
270 suspended on specially constructed scaffold towers confirmed vertical stratification and
271 higher diversity of *Diptera* communities in the forest canopy [38]. Alternatively, some studies
272 have shown no differences in vector behaviour vertically. In Evangelista *et al.* [50] mosquito
273 vectors were collected using Nasco Aspirators [51], Shannon Traps and CDC-LTs which were
274 suspended at regular intervals in the canopy of conservation forests in São Paulo, following
275 which blood meal analysis was conducted on visibly engorged specimens to determine
276 relationships between vertical niches and biting behaviours. The study observed strong
277 vertical abundance stratification in species such as *Culex nigripalpus* and *Anopheles cruzii*
278 which showed no biting preference for hosts in this vegetation level and therefore concluded
279 that biting was opportunistic and host preference was not constrained by height but rather
280 host abundance. For studies aiming to assess vertical stratification of vector communities,
281 there is a need to pair ground-based and canopy-level sampling to assess potential biases due
282 to traps attracting mosquitoes from different heights.

283

284 **Case Study: drone deployment of canopy-level entomological traps in Sabah, Malaysia.**

285 In Sabah, Malaysia, deforestation has led to the emergence and transmission *Plasmodium*
286 *knowlesi*, a zoonotic malaria mostly involving macaques [53]. Studies suggest macaque
287 parasite prevalence is spatially heterogeneous and sylvatic cycles between macaques are
288 driving spillover risks [see 54 for a review]. However, vector sampling in the majority of
289 these studies was conducted near the ground. Deploying canopy-level mosquito traps poses
290 significant challenges in tropical forest environments. However, drones seem to have the
291 potential to deploy traps more efficiently and better target specific locations [52]. Pilot
292 studies using drones to deploy mosquito traps were conducted across a gradient of forest

293 types in the Lower Kinabatangan Wildlife Sanctuary in Sabah, Malaysia (**Figure 4**) (Taylor,
294 S, MEng Thesis, University of Glasgow, 2024; Chan, J.H, BSc Thesis, University of
295 Glasgow, 2024).

296 **[Insert Figure 4]**

297 The BG-2 and Mosquito Magnet traps were used in these studies and deployed in the canopy
298 at a height of ~15m. Traps deployed in the canopy required extensive design modifications
299 (see **Figure 4**) to ensure effective functioning, including a ‘slingshot’ method of deployment,
300 piping of CO₂ to the trap, and major structural modifications. Within this site, there were
301 considerable practical constraints. For example, traps and equipment may attract macaques,
302 orangutans and other animals, requiring extra steps to prevent damage. This may include
303 setting traps inside sturdy mesh cages (**Figure 4C**). Suspended traps are also more vulnerable
304 to weather conditions and may require sturdy fixation to tree branches, covering electrical
305 connections with waterproof tape and preventing accumulation of rain.

306

307 To enable more precise vertical deployment, drones were used to insert ropes at canopy level.
308 Unlike the sling shot approach, the drones can navigate around branches to the desired altitude
309 and location [52]. However, to deploy an entire trap, such as the BG-2 with CO₂ tank and power
310 supply, the drone would require an approximate payload capacity of 5 kg and be prohibitively
311 large to operate within forests. In this study, a miniature, tethered drone (DJI Tello) used to
312 insert a rope at canopy level for precise vertical deployment of the traps (**Figure 5**)

313 **[Insert Figure 5]**

314 The drone measures 10cm diagonally, weighs 87g and has a front-facing camera, enabling first-
315 person-view controls through a smartphone app or computer API. For the initial phase of the
316 line insertion in **Figure 5A-C**, the drone manoeuvres around a target branch. Once the target
317 branch is cleared, the drone shuts down causing it to get caught by the tether (fishing line in

318 red). For the final trap deployment, the initial fishing line tether (red line) was retracted until
319 the rope (blue line) could be anchored to the ground, as illustrated in **Figure 5D-E**. Finally, the
320 trap was hoisted into the canopy using the rope (**Figure 5F**). **Figure 5G-J** demonstrate the
321 drone-based approach for the deployment of mosquito traps.

322

323 The difficulties associated with deploying traps with sufficient efficacy in suitable locations
324 accessible by drones with high maximum payloads, are barriers that must be overcome to
325 ensure scalability of surveillance strategies. There is significant international interest in
326 developing sampling arrays that can be deployed in the canopy by drones, as demonstrated by
327 the XPrize Foundation [55]. Drones offer opportunities to deploy traps in very high or
328 inaccessible canopy environments, where slingshots and other ground-based methods would
329 be unlikely to reach.

330

331 Additionally, the known *P. knowlesi* vector, *An. latens* was detected in the canopy at two
332 sites, but not on the ground. While further studies need to be conducted to understand the full
333 vector bionomics in the region, the identification of *P. knowlesi* vectors only at canopy level
334 highlights the need to consider these environments in future vector surveillance programmes.

335

336 **[End of case study]**

337

338 **Integration of canopy-level surveillance with xenosurveillance**

339 As well as trapping host-seeking mosquitoes, combining canopy trapping methods with blood
340 meal analysis will enable more accurate understanding of pathogens circulating in NHP
341 populations as well as the importance of NHPs, humans and other species in sustaining
342 vector populations and driving transmission dynamics [56]. For example, canopy traps have

343 been used for xenosurveillance of carrion flies biting different mammalian species to identify
344 circulating pathogens in wildlife. Furthermore, mosquito vector species often rest on foliage
345 after taking blood meals, analysis of which provides key insights into biting preferences and
346 the importance of different wildlife and human populations in sustaining vector populations
347 [41]. Limited studies have attempted to use resting traps to sample canopy dwelling
348 mosquitoes. Canopy-level deployment of resting traps in Malaysian Borneo collected blood-
349 fed *Aedes* and *Culex* mosquitoes but no *Anopheles* species [57]. Other studies have used
350 backpack aspirators on fixed canopy platforms to collect mosquitoes from surrounding
351 foliage [51]. Conventional methods, such as backpack aspiration, are unlikely to be feasible
352 in the canopy without specialised equipment and tree climbers or fixed platforms and will not
353 be able to survey wide areas. There is an acute need to develop more effective methods of
354 trapping blood fed vectors in the canopy.

355

356 **Concluding remarks**

357 To design vector surveillance for zoonotic diseases, a detailed understanding of sylvatic
358 disease cycles is required. Methods of effective canopy trapping to monitor canopy-dwelling
359 vector species are therefore essential for two reasons. Firstly, examining vertical community
360 stratification in the forest canopy may provide insight into the risk factors associated with
361 zoonotic spillover events and quantify the role of wildlife reservoirs and intermediate hosts.
362 Secondly, recently blood-fed mosquitoes may reside in the canopy, which are essential in
363 determining biting preferences and infection rates using blood meal analysis and
364 xenosurveillance. Existing ground-based trapping methods remain significantly taxa and
365 location specific and need to be further validated for canopy levels. Moreover, effective
366 canopy trapping methods that do not pose significant health and safety concerns such as HLC

367 or monkey-baited traps, remain severely under-developed, given the technological and
368 logistical challenges of mounting traps in the canopy (see **Outstanding Questions**).

369

370 Deploying the BG-2 and Mosquito Magnets at canopy-level in Sabah, Malaysia, proved
371 extremely challenging, with considerations including safety, and preserving functionality of
372 the traps warranting significant modifications to the original trap design. Moreover,
373 deploying canopy trapping methods during longitudinal surveys poses an even greater
374 challenge. For long-term fixed location sampling, building permanent canopy towers is likely
375 to be the most effective method. However, if entomological surveys need to be conducted
376 across a wider area or in less accessible regions, surveys are still predominantly reliant on
377 manual methods of deployment. Accessing branches at suitable heights by the manual sling-
378 shot method was a challenge and constrained to edge-habitats with degraded canopies.
379 Drones can improve placement of the trap at desired canopy heights and enable deployment
380 of traps in locations that are otherwise. However, the cost of developing or purchasing a
381 drone capable of either carrying a 5kg payload or a rope is a significant consideration and
382 may require experienced pilots. With advances in artificial intelligence and drone navigation
383 methods, there is a need to further develop and optimise drones which can navigate forest
384 environments [[58](#), [59](#)].

385

386 Available methods primarily rely on modifying existing mosquito trap protocols and design,
387 many of which display variable efficacy dependent on habitat type and composition of
388 mosquito communities. Further research is therefore essential to refine canopy traps and
389 compare with natural reservoirs. Designing a canopy-level trap that is both effective and
390 robust will require two considerations. The first is developing deployable, effective trapping
391 methods that maximises multi-taxa efficacy or catching of specific target species and the

392 second is developing a reliable and accurate deployment protocol. Given the growing
393 importance of sylvatic disease cycles in an environment of rapid anthropogenic disturbance,
394 enhancing canopy level surveillance is essential in developing integrated zoonotic disease
395 surveillance programmes and, more broadly, in applications of One Health policy [60].

396

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404

405 **Declaration of interests**

406 The authors declare no competing interests.

407

408 **Captions:**

409

410 **Figure 1: Infographic depicting generalised cycles of zoonotic and vector-borne disease**
411 **transmission in Malaysian Borneo**, illustrating the role of zoophagous vectors maintaining
412 enzootic sylvatic disease transmission between NHPs (L), bridge vectors that transmit
413 pathogens across prey categories (C) and anthropophagous vectors that maintain transmission
414 in human transmission cycles.

415 **Figure 2: Published case studies of trap deployment.** Study aims are listed in the first
416 column of the table and linked to key study parameters (first row), including site & study
417 design, trap type and deployment type thereby displaying the variation in survey designs due
418 to the range of data types and study aims. See references [22, 23, 35, 50, 61-63]

419 **Figure 3: Comparison of canopy versus ground collections in urban parks in the**
420 **metropolitan region of São Paulo and the Amazonian city of Manaus, Brazil.** (A)
421 Comparison of capture frequencies for *Haemagogus* and *Sabethes* in canopy versus ground
422 collections using CDC traps and nets in São Paulo. (B) Comparison of diversity among

423 mosquito species in canopy versus ground collections in São Paulo. (C) Comparison of
424 capture frequencies for *Haemagogus* and *Sabethes* in canopy versus ground collections using
425 BG-sentinel traps in Manaus. (D) Comparison of diversity among mosquito species in canopy
426 versus ground collections in Manaus.

427

428 **Figure 4: Preparation and deployment of suspended BG-Sentinel 2 and Mosquito**
429 **Magnet traps in Sabah, Malaysia.** (A) Map of LKWS with sampling sites shown for the
430 Mosquito Magnet. (B) Suspended Mosquito Magnet trap at 10m with electrical wire and CO₂
431 tubing (L). (C) Mesh and plastic tubing cage to protect traps from interference by Macaque
432 troops. (D) Plastic tubing, CO₂ source, electrical wire and battery pack used for BG-Sentinel
433 2 trap protocol.

434 **Figure 5: Concept of slingshot drone for canopy-level trap deployment.** Tether attached
435 to drone is shown in red and the rope for trap deployment in blue. The arrows indicate the
436 direction reeling in and out of the corresponding lines. (A-B) Tethered drone navigates
437 around canopy. (C-E) Rope is attached and released in the canopy. (F) Trap is deployed using
438 the rope. (G-H) Initial experimental demonstration for low branches corresponding to steps
439 (B) and (E). (I-J) Deployment of mosquito trap shown in magnified picture using the rope
440 (blue line). See references (Taylor, S, 2024; Chan, J.H, 2024) [64-66].

441

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573

574 Glossary

575 **Acrodendrophilic mosquito:** Species of mosquito which reside primarily in the forest
576 canopy.

577 **Anthropophilic mosquito:** Referring to species of mosquito that exhibit a feeding preference
578 for humans over other wildlife.

579 **Bridge vector:** Species of vector that are capable of transmitting pathogens between humans
580 and wildlife; 'bridging' different transmission cycles.

581 **Human Landing Catch (HLC):** A technique of entomological trapping used in the context
582 of anthropophilic vectors, in which human volunteers are used as bait to attract
583 hematophagous vector species.

584 **Non-human primates (NHPs):** The taxonomic group of mammals known as primates,
585 which may include both simians and prosimians.

586 **Sylvatic disease cycle:** refers to the stage of a pathogen transmission cycle between wild
587 animals and vectors.

588 **Xenosurveillance:** A disease surveillance technique that involves the genomic analysis of
589 hematophagous (blood-feeding) vector species to confirm the presence or absence of
590 pathogen DNA/RNA.

591 **Zoonotic disease:** refers to diseases that are transmitted from wildlife to humans.

592 **Zoophilic mosquito:** Referring to species of mosquito that exhibit a feeding preference for
593 wildlife rather than humans.

594