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1 The impact of industrial activities on vector-borne disease transmission

2
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14 15 **ABSTRACT**

16 Industrial activities have produced profound changes in the natural environment, including the
17 removal of trees, fragmentation of habitats, and creation of larval breeding sites, that have allowed
18 the vectors of disease to thrive. These may be coupled with significant changes to demographics that
19 can potentially increase contact between pathogens, vectors and people, and see a shift of parasites
20 and susceptible populations between low and high endemic areas. Indeed, where vector-borne
21 diseases and industrial activities meet, large numbers of potentially immunologically naïve people may
22 be exposed to infection and many lack the knowledge and means to protect themselves. Such areas
23 are typically associated with inadequate health care, thus allowing industrial development and
24 production sites to become important foci of transmission. The altered local vector ecologies, and the
25 changes in disease dynamics that they affect, create challenges for under-resourced health care and
26 vector-control systems.

27 28 *Keywords:*

29 Industrial activity; mining; malaria; vector-borne disease risk.

30 31 **1. Introduction**

32 Industrial activities have an important role in the history and development of human settlements, and
33 can contribute considerably to the economies of resource-endowed countries. However, mining,
34 logging, oil and gas, and other extractive industries can also impose significant negative health
35 externalities and burdens associated with elevated incidence of vector-borne diseases (Saha et al.,
36 2011; Santos et al., 2009; Andrade et al., 1995). In Colombia, for example, alluvial gold mining using
37 simple tools and other rudimentary methods is traditionally a single-person operation for extracting
38 ore, and is typically associated with low malaria risk, whereas large open-pit mining is associated with
39 a higher malaria incidence (Castellanos et al., 2016). Overall, the Amazon River Basin accounted for
40 92.5% of malaria cases in the Americas in 2014 (Pan American Health Organization, 2014), with cases
41 mostly being reported in areas of recent human encroachment, new agricultural settlements, and
42 open-cast mining sites (Taulil, 1986; Camargo et al., 1994; Sanchez et al., 2017; Recht et al., 2017).

43
44 The associations between malaria and mining are multi-factoral, and result from (i) environmental
45 changes that affect malaria transmission ecology and epidemiology, (ii) increased human movement

46 between malaria transmission zones, and (iii) various direct and indirect economic and demographic
47 factors linked to mining activities (Confalonieri et al., 2014; Bauch et al., 2015; Andrade et al., 1995;
48 Veeken, 1993; Soe et al., 2017). Firstly, mining methods can create ideal aquatic ecological niches for
49 vector anopheline mosquitoes to propagate and survive (Fernando et al., 2016). Mining activities also
50 ensure a greater number of repeated contacts between human reservoirs of disease pathogens and
51 the mosquito vector (Silbergeld et al., 2002). Over time, the unsteady pattern of human migration,
52 and the highly variable ecological changes associated with mining activities, may be replaced by a
53 more organized infrastructure through the process of urbanization and the development of greater
54 community cohesion. At this point, pathogen/vector exposure to humans is reduced, and more stable,
55 low levels of transmission and rates of malaria infection result (de Castro et al., 2006). This outcome
56 is similar to trends seen in agricultural settlements: recently arrived settlers, usually located closer to
57 the deforestation imprints of side roads, may be more exposed to malaria because of their proximity
58 to the forest fringes where larvae are dense, but as deforestation progresses, transmission decreases
59 (Barros and Honório, 2015).

60

61 The development of formal industrial activities such as large mine sites has the potential to greatly
62 affect the socioeconomic profile of previously isolated, less populated rural districts (Kitula, 2006;
63 Obiri et al., 2016; Wilson et al., 2015). In addition to an open pit mine and processing plant, an entire
64 infrastructure base may be created that can include an airstrip, multiple access roads, maintenance
65 and administrative facilities, and new residential settlements for the workforce and their families.
66 Moreover, as a result there are direct and indirect ecological, social, economic, and health impacts on
67 the surrounding communities (Knoblauch et al., 2017; Attuquayefio et al., 2017; Jacobi et al., 2011;
68 Richards and VanWey, 2015; Hilson and Laing, 2017; Gibb and O'Leary, 2014; Bauch et al., 2015;
69 Arrifano et al., 2018,).

70

71 Examples of primary vectors of malaria include *Anopheles darlingi* in South America (Hiwat and Bretas,
72 2011; Ahumada et al., 2016; Pimenta et al., 2015), *An. arabiensis*, *An. funestus*, and *An. gambiae* in
73 Africa (Sinka et al., 2012; Lobo et al., 2015), and *An. fluviatilis* in south Asia (Sinka et al., 2011; Sahu et
74 al., 2017). The *Anopheles dirus* complex, *An. maculatus* group, *An. minimus*, *An. balabacensis*, and *An.*
75 *sundaicus* complex represent important vectors in the South-East Asia region (Tainchum, et al., 2015;
76 Kwansomboon et al., 2017, Rahman et al., 1997), while some members of the *An. punctulatus* group
77 are efficient vectors in the southwest Pacific area (Cooper et al., 2009, Beeb et al., 2015). *Aedes*
78 *aegypti* and *Ae. albopictus*, the primary vectors of important arboviruses including dengue,
79 chikungunya, Zika, and yellow fever, are found widely in tropical and sub-tropical regions (Kraemer et
80 al., 2015; Ducheyne et al, 2018, Weetman et al., 2018). In some countries, the distributions of these
81 species overlap with rich mineral deposits of marketable metals (IBRAM, 2012).

82

83 Herein, we consider the large resource and extractive industries that contribute significantly to the
84 developing economies in tropical and subtropical areas of the world that also face major challenges
85 with vector-borne diseases. The environmental and demographic impact of these activities on the
86 occurrence and distribution of vector-borne diseases is discussed.

87

88 **2. Methods**

89 A literature search was performed using archives of published biomedical and life sciences journal
90 literature available through PubMed (MEDLINE) and Web of Science. Search terms included: "African

91 trypanosomiasis AND industrial activity” OR “African trypanosomiasis AND mining” OR “Chagas AND
92 industrial activity” OR “Chagas AND mining” OR “Chikungunya AND industrial activity” OR
93 “Chikungunya AND mining” OR “Dengue AND industrial activity” OR “Dengue AND mining” OR
94 “Japanese encephalitis AND industrial activity” OR “Japanese encephalitis AND mining” OR
95 “Leishmaniasis AND industrial activity” OR “Leishmaniasis AND mining” OR “Lymphatic filariasis AND
96 industrial activity” OR “Lymphatic filariasis AND industrial activity” OR “Lymphatic filariasis AND
97 mining” OR “Lymphatic filariasis AND mining” OR “Malaria AND industrial activity” OR “Malaria AND
98 mining” OR “Rift Valley fever AND industrial activity” OR “Rift Valley fever AND mining” OR “Sleeping
99 sickness AND industrial activity” OR “Sleeping sickness AND mining” OR “Vector-borne disease AND
100 industrial activity” OR “Vector-borne disease AND mining” OR “Yellow fever AND industrial activity”
101 OR “Yellow fever AND mining” OR “Zika AND industrial activity” OR “Zika AND mining”. These searches
102 were made without restrictions on languages or publication dates. Active searches were made in June-
103 July 2017. Additional resources were subsequently accessed to strengthen the narrative and provide
104 contextual information to the findings of the literature search.

105

106 **3. Results**

107

108 *3.1. Literature search*

109 The literature search returned 785 potential references. Of these, 164 were selected for further review
110 based on the reference titles, and 31 of these have been cited herein.

111

112 *3.2. Impact of industrial activities on malaria transmission*

113 There is strong evidence for a link between industrial activities and transmission of malaria, and
114 important examples of these associations have sufficient and reliable background (pre-development)
115 disease information to derive an assessment of impact. In Colombia, one third of reported malaria
116 cases are from active mining areas, and undocumented population migration combined with
117 substantial under-reporting and self-treatment in areas with illegal mining activity suggest that official
118 statistics are likely to significantly underestimate the true burden of disease (Castellanos et al., 2016).
119 Furthermore, mining activity plays an important role in the maintenance of focal and regional malaria
120 transmission, and could be an important obstacle to its elimination (Castellanos et al., 2016; Recht et
121 al., 2017). There are mining-related communities living in close proximity to mine sites, and workers
122 in these sites often demonstrate an ignorance of health promotion and disease prevention methods
123 against mosquito vectors, as has been reported in other countries (Knoblauch et al., 2014; Mazigo et
124 al., 2010; Potter et al., 2016). Whilst malaria declined in Colombia from approximately 117,000 cases
125 in 2010 to around 60,000 in 2013, including an overall reduction in malaria cases in most active mining
126 areas, the mining districts of San Martin de Loba, Costa Pacifica Sur and north-eastern parts of
127 Antioquia reported an increase in the Annual Parasite Incidence (API = cases per 1,000 exposed) by
128 more than 50% over a 5-year period (Castellanos et al., 2016).

129

130 Associations between mining and malaria have also been found in Peru, where transmission in Madre
131 de Dios in the southern Peruvian Amazon basin is unstable, geographically heterogeneous, and
132 strongly associated with illegal gold mining. Health facilities located in areas of intense illegal gold
133 mining reported 30-fold more cases than those in non-mining areas, although adjustments for
134 population size were not possible due to the intense migration in these area (Sanchez et al., 2017).
135 Further north in French Guiana, malaria outbreaks have been reported in soldiers and military police

136 returning from illegal gold mining sites in remote rainforest areas (Pommier de Santi et al., 2016a;
137 Pommier de Santi et al., 2016b). Between 1985 and 1996, a statistically significant association was
138 found between the amount of gold extracted and malaria incidence in Mato Grosso, Brazil, i.e. for
139 every increment of 100 kg of gold extracted, models predict that the API in mining areas increased by
140 0.31 (Duarte and Fontes, 2002). At present, malaria infections among miners in Brazil constitute
141 approximately 6% of the country's total cases, 3% in Colombia, and a remarkable 47% in Venezuela
142 (Recht et al., 2017).

143

144 3.3. Association of industrial activities with the transmission of other diseases

145 Industrial activities, often associated with dramatic environmental modifications, deforestation and
146 human migration and movement, are not just linked with malaria but other diseases transmitted by
147 insect vectors, including leishmaniasis in Suriname and Brazil (Dourado et al., 1989; van der Meide et
148 al., 2008). In the state of Pará, Brazil, the forest areas around the Capiranga bauxite mining base in
149 Juruti have shown heavy occurrence of the sand fly vectors capable for transmitting the protozoan
150 agents causing diffuse cutaneous and mucocutaneous leishmaniasis (Garcez et al., 2009). The principal
151 vector of mucocutaneous leishmaniasis, *Lutzomyia (Psychodopygus) complexa* has daytime feeding
152 habits, an unusual behaviour among Amazonian phlebotomines, which increase the risk of human
153 exposure to infection (Garcez et al., 2009). An array of *Leishmania* vector-reservoir relationships,
154 which includes up to eight phlebotomine species, has been described in Serra do Navio, a historic
155 mining area in the Guiana Shield of northern Brazil (Almeida de Souza et al., 2017).

156

157 In parts of Queensland Australia, gold miners are vulnerable to dengue fever because the immature
158 stages of the primary vector, *Ae. aegypti*, can be found abundantly in abandoned flooded mine shafts,
159 making adults available for the transmission of disease (Russell et al., 1996; Eisler 2003). By contrast,
160 occupational exposure associations with Rift Valley fever in Africa, transmitted by several mosquito
161 species including *Aedes* species, are related to livestock and forestry work exclusive of industrial
162 activities (Olaleye et al., 1996; LaBeaud et al., 2015).

163

164 *Culex quinquefasciatus* is prevalent in tropical and sub-tropical areas (Samy et al., 2016), and is
165 identified as the major vector of the filarial nematode, *Wuchereria bancrofti*, in parts of South
166 America, Africa, and Asia (Brito et al., 1997; Kramer et al., 2008; Chandra et al., 2007). It frequently
167 breeds in drains, ditches, and other peri-domestic habitats that hold water and organic material long
168 enough for the development of larvae to the adult stage (Prakash et al., 1998; Noori et al., 2015). In a
169 district of West Bengal, India, the numbers of *Cx. quinquefasciatus* were found to be significantly
170 higher in colliery areas than in non-colliery areas, and were determined to be a major reason for the
171 higher prevalence of bancroftian filariasis in that area (Adhikari and Haldar, 1995). This supported
172 earlier findings of *Culex fatigans* in undergrounds pits of a coalmine in India (Dutta, 1977). However,
173 whilst the infection rate and infectivity rate were also found to be higher in the colliery areas, other
174 factors such as exposure of the hosts to coal might impact the pathogenesis of the disease (Adhikari
175 and Haldar, 1995).

176

177 *Culex* mosquitoes include competent vectors of West Nile virus (WNV) and St Louis encephalitis in
178 North America, Rift Valley fever in Africa, and Japanese encephalitis in Southeast Asia (Brualt, 2009;
179 Turell, 2009; Sang et al., 2010; Pearce et al., 2018). Studies in the United States have indicated that
180 WNV incidence increases with urbanization and agriculture, which may result from the habitats used

181 and commensal nature of two important vector species, *Cx. pipiens*, and *Cx. Tarsalis* (Kilpatrick, 2011).
182 Consistent with this, mosquitoes collected from tyres along an urbanisation gradient in South America
183 revealed *Cx. quinquefasciatus* to be more frequent at the urban end (Cardo et al., 2018). In this
184 context, it is clear how anthropogenic alterations that affect the availability of breeding sites and other
185 features of local ecology can have impacts on communities of insects of medical importance (Abella-
186 Medrano et al., 2015).

187

188 3.4. Environmental changes that affect vector ecology

189 Vector-borne diseases are amongst the infectious diseases with the strongest links to land use since
190 vector ecology is closely affected by the environment (Patz et al., 2004; Zahouli et al., 2017; Young et
191 al., 2017; Sheela et al., 2017). Important aspects of a vector population, such as species diversity and
192 population densities, can be governed by environmental parameters (Petrić et al., 2014; Bashar et al.,
193 2016, Betekov et al., 2010; Confalonieri and Neto, 2012). As environmental conditions change, either
194 through slow natural processes or accelerated by human activities, opportunities arise for important
195 changes in species biodiversity and abundance that can influence a shift in the epidemiological
196 dynamics of transmission and disease risk (Eisen et al., 2008; Ferraguti et al., 2016; Chang et al., 1997;
197 Chinery, 1984; Steiger et al., 2016).

198

199 For example, a shift in species composition resulting from industrial activity has been reported in
200 north-eastern Amazonia, where the initial construction of roads in forest areas created large tracts of
201 partially shaded, unpolluted water that is a suitable breeding site for *An. darlingi*, a primary malaria
202 vector. The subsequent clearing of forest and eventual polluting of water sources made these sites
203 less suitable for these mosquitoes, whereas the creation of stagnant pools for agricultural use
204 attracted other vector species (Conn et al., 2002). This example of land use change allowed a species
205 previously of minor importance, *An. marajoara*, to become the principal malaria vector in Macapá,
206 Amapá state, Brazil.

207

208 Sri Lanka has now been declared a malaria-free country (Wijesundere and Ramasamy, 2017), but
209 historically transmission of malaria was reported when conditions were conducive for the breeding of
210 the primary vector, *An. culicifacies* (Abeyasinghe et al., 2012). This species breeds in clean stagnant or
211 slow moving waters, and typically thrives in the dry zone, where pools of water collect during the rainy
212 season (Amerasinghe, 1999). Larvae were observed in the water-containing shallow hand-dug gem
213 pits in the Elahera area, in the north central part of the country (Yapabandara and Curtis, 2004). The
214 mining sites were expected to be closed following excavation activities, but many licensed pits were
215 left unfilled, and other pits dug without permits. These pits were documented reaching a density of
216 247-370 per hectare (Yapabandara and Curtis, 2004). In addition to providing a suitable habitat for *An.*
217 *culicifacies*, they are also used for the propagation of *An. subpictus* and *An. varuna*, and their creation
218 may have also contributed to the emergence of these species as significant malaria vectors.
219 (Yapabandara and Curtis, 2004; Yapabandara, et al., 2001). In the Kaluganga mining area, a dry zone
220 of central Sri Lanka, mosquito larval surveys indicated that water-filled gem pits contributed 60% of
221 larvae of the three vector species mentioned (Yapabandara and Curtis 2004). These species show
222 variability in their preferences for feeding and resting, so activities that allow them to thrive have
223 potential impacts on the selection of vector control methods (Rawlings and Curtis, 1982; Yapabandara
224 and Curtis, 2004). Subspecies of these vectors have also demonstrated variability in longevity,

225 susceptibility to parasite infection, and resistance to insecticides (Surendran et al., 2006; Surendran
226 et al., 2012).

227

228 This historical example highlights the important links between industrial activities, mosquitoes, and
229 malaria, and the need to mitigate these effects. Environmental modifications that included the filling
230 of abandoned gem and quarry pits, and spot checks carried out in areas not covered by sentinel site
231 monitoring, were both parts of an integrated vector control programme that led to the elimination of
232 malaria in Sri Lanka, which has experienced no indigenous cases since 2012 (World Health
233 Organization, 2017). Nonetheless, larval sampling from active and abandoned quarry pits from
234 February 2012-June 2013 revealed the presence of *An. culicifacies* and other competent malaria
235 vectors, suggesting that there is potential for future epidemics.

236

237 The biting activities of *An. culicifacies*, *An. subpictus* and *An. varuna* have been reported to be between
238 18:00-23:00 hours, with peak biting activity between 19:00-20:00 and a small peak in the early
239 morning hours between 03:00-05:00. (Yapabandara and Curtis, 2004). However, different species can
240 show differences in peak biting time depending on location and season. In South America, *An. darlingi*
241 has been reported with unimodal, bimodal and even trimodal evening biting peaks, and it has been
242 suggested that these behaviours represent an adaptation to anthropophagy (Rosa-Freitas et al, 1992).
243 Consistent with this, *An. darlingi* activity in the Sifontes region in southern Venezuela has been found
244 to peak during the night (with two minor peaks at 23.00-00.00 and 03.00-04.00), aligning with the
245 night-time activity of gold mine workers (Moreno et al., 2007). Further, there are differences between
246 species with regards to a preference to feed inside or outside human structures, and whether they
247 take blood meals primarily from human or other animal sources. Differences in biting habits, within
248 the same species or amongst several species, have consequences for vector control, as the use of
249 insecticide-treated nets and indoor residual spraying will be less effective against those mosquitoes
250 that display more outdoor and early evening biting activity. Coupled with this, changes in species
251 composition can change the dynamics of disease transmission based on differences in vector
252 competence and capacity to transmit; e.g., some species are more susceptible to propagating malaria
253 parasites, and others are more refractory (Beerntsen et al., 2000). It is, therefore, important to
254 understand the mosaic of different locally-important vectors and their interactions with human
255 populations, and to recognise that changes in land use may lead to changes in species composition
256 and a consequent change in transmission risk (Conn et al., 2002).

257

258 Key environmental changes linked to mining that may significantly influence vector-borne disease
259 transmission, positively or negatively, include: (i) creation of larval habitats, (ii) removal of trees
260 (shading), and (iii) fragmentation of habitats, each of which can produce changes in mosquito
261 populations.

262

263 3.4.1. Creation of larval habitats

264 The excavation of minerals directly creates open pits to access ore, and other disturbances of
265 surrounding ground to support these activities (e.g., road building, drainage), also create depressions
266 which are liable to fill with rainwater. Other industrial activities, such as construction or creation of
267 borrow pits, can similarly produce human-made aquatic habitats that are permanent or temporary.
268 These can become important larval habitats for some malaria vector species (Conde et al., 2015;
269 Soleimani-Ahmadi et al., 2013; Mereta et al., 2013). Freshly excavated pits, in particular, have been

270 found to contain abundant immature *An. gambiae* s.l. in Ethiopia, and *An. culicifacies* in South India
271 (Russell and Rao 1942; Kiszewski et al., 2014).

272

273 Industrial scale gold mining activities in Niolam (Lihir) Island in Papua New Guinea offer a model for
274 the types of problems associated with human changes to tropical environments (Ebsworth et al.,
275 2001). Before mining activities began, entomological surveys suggested that *An. farauti* s.l. was the
276 most important vector of malaria and lymphatic filariasis (*Wuchereria bancrofti*), and largely
277 responsible for the intense, year-round transmission of both diseases on the island; *Anopheles*
278 *punctulatus*, on the other hand, was only recorded in small numbers (Bockarie et al., 1994; Ebsworth
279 et al., 2001). The construction of the gold mine, port, processing plant, roads, and worker housing in
280 the area were associated with significant environmental changes and, interestingly, a change in the
281 relative abundance and distribution of the primary malaria vectors. Subsequent entomological surveys
282 revealed that *An. punctulatus* was widespread and abundant (Bockarie et al., 1994). This is significant
283 as *An. punctulatus* is regarded a more efficient malaria vector species than members in the *An. farauti*
284 complex (Beebe et al., 2013). The most common sites for *An. punctulatus* immature stages were small
285 temporary, sunlit pools, commonly formed along the edges of poorly drained sections of dirt roads.
286 The rarest larval habitats were the more permanent ecotypes such as lake edges and natural wetlands
287 (Ebsworth et al., 2001). A mine-funded, integrated vector control intervention began in 2004 that led
288 to a substantial reduction of both *P. vivax* and *P. falciparum* infections in the mining-impacted areas
289 (Mitjà, et al., 2013).

290

291 3.4.2. Removal of trees

292 The removal of trees (thus shading) and disturbed earth movement associated with mining activities
293 allows pools of rainwater to form that are suitable aquatic habitats for certain species of mosquitoes
294 (Silbergeld et al., 2002). The deforestation of primary or secondary forest has been directly associated
295 with increased mosquito population densities and biting in the Peruvian Amazon: Human biting rates
296 measured at sites selected for primary vegetation type and controlled for human presence found that
297 the predominant malaria vector, *An. darlingi*, had biting densities more than 200 times greater than
298 attack rates in areas that remained predominantly forested (Vittor et al., 2006). Moreover, sampled
299 aquatic sites with immature *An. darlingi* had an average of 24% forest cover compared with 41% for
300 sites without *An. darlingi*, indicating that deforestation and associated ecologic alterations in this area
301 increased *An. darlingi* breeding, and by consequence changed the malaria dynamics of the affected
302 region (Vittor et al., 2009). Similarly, a study of villages in the Lower Caura river basin in Venezuela
303 found that the relative abundance of *Anopheles* mosquitoes was greatest in the village with the least
304 native forest cover (Rubio-Palis et al., 2013).

305

306 There is evidence from Brazil that deforestation has coincided with increases in malaria: after
307 adjusting for access to care, health district size, and spatial trends, Olson and co-workers showed that
308 a 4.3% change in deforestation in Mâncio Lima, Acre State from August 1997 through August 2000
309 was associated with a 48% increase of malaria incidence, which the authors linked with the habitat
310 preference of *An. darlingi* (Olson et al., 2010). Whilst deforestation may increase vector-borne disease
311 transmission by providing the more open, sunlit breeding sites preferred by *An. darlingi* vectors, as
312 well as some members in the *An. gambiae* complex in Africa and of the *An. punctulatus* group in the
313 southwest Pacific (Sinka et al., 2010; Cooper et al., 2002), care must be taken in finding patterns
314 because of the unique settings in which these changes take place, and because each species may

315 respond differently. In parts of Southeast Asia for example, deforestation may lead to *reductions* of
316 *An. dirus* and *An. balabacensis* densities because of a loss of the shaded breeding sites preferred by
317 these species (Yasuoka and Levins, 2007).

318
319 The effects of habitat alteration on anopheline mosquito distribution, and their impact on disease
320 transmission, can be complex and difficult to predict. Indeed, a systematic review of the relationship
321 between forest cover and malaria failed to find overwhelming evidence supporting a consistent
322 relationship between deforestation and malaria (Tucker Lima et al., 2017). During the construction of
323 the Jirau hydroelectric dam in Porto Velho, Brazil, human landing catch data indicated a decrease in
324 anopheline species diversity and altering species composition during the first stage of annual flooding,
325 after which species diversity returned to levels observed during the pre-flood stage, despite the
326 permanent change to the ecosystem that the dam introduced (Rodrigues et al., 2017). The continual
327 monitoring of vectors during the operational phase of such projects is therefore important for public
328 health.

329
330 *3.4.3. Fragmentation of habitats*
331 Habitat fragmentation alters the composition of host species in an environment, and could have an
332 impact on disease transmission if vectors are released from predator control or if there is a change in
333 the availability of hosts on which to feed (Kruess and Tschardt, 1994; Patz et al., 2004). For example,
334 smaller fragments of habitat are less able to support top predator species, and this can result in an
335 abundance of their prey species. If these prey species are reservoirs of infectious disease, the habitat
336 fragmentation could impact disease transmission, as has been reported with the fragmentation of
337 North American forests resulting in the increased incidence of cutaneous and visceral leishmaniasis
338 by peri-domesticated sand flies due to an increase in the number of fox reservoirs (Desjeux, 2001).
339 Equally, if some hosts are more efficient reservoirs of disease than others, habitat fragmentation
340 leading to changes in local species diversity could allow for increases or decreases in the chance of
341 vectors becoming infected, as has been described for Lyme disease spirochete infection of ticks:
342 nymphal infection prevalence is dramatically reduced by the presence of hosts of low reservoir
343 competence (Schmidt and Ostfeld, 2001).

344
345 In addition to changing the availability of host species, activities that create forest fringe areas can
346 provide favourable breeding conditions (moist soil areas) for sand fly vectors of leishmaniasis
347 (Azevedo et al., 2011; Feliciangeli, 2004) and various species in the leucosphyrus group of malaria
348 vectors that have a strong proclivity for forested and forest-fringe environments (Sallum et al., 2005).
349 In a frontier settlement of Rorainópolis, in the northern Brazilian Amazon, deforestation has created
350 the unique forest fringe ecosystems that have become hotspots for larvae. Sampling of these areas
351 has revealed a positivity rate of over 80% for *An. darlingi* larvae, and they are considered highly focal
352 determinants of malaria transmission (Barros and Honório, 2015).

353
354 Forest fragmentation can create a distinct community of species that changes along the edge-to-
355 interior gradient: some species increase in abundance, while others decrease (Yahner et al., 1989),
356 and this phenomenon has been observed in mosquito vectors. A reduction in anopheline species
357 diversity has been demonstrated following forest fragmentation resulting from human activities in
358 northern Thailand (Overgaard et al., 2013). If those species that become predominant are competent
359 vectors of disease and have access to suitable hosts (i.e. humans), the environmental changes could

360 favour pathogen transmission (Ferraguti, et al., 2016). Unfortunately, there is a lack of empirical
361 studies demonstrating these outcomes.

362

363 There is evidence that habitat fragmentation can affect adaptive genetic variation (Fraser et al., 2014),
364 and it can affect non-adaptive variation through reductions in population size or increased population
365 isolation, which are expected to increase the influence of genetic drift, the stochastic change in allele
366 frequencies over time (Johnson and Munshi-South, 2017). Large genic differences have recently been
367 detected in allopatric populations of *Ae. aegypti* (Dickson et al., 2017), and the form that preferentially
368 feeds on humans, and resides near human population centres, is known to be more efficient in
369 transmitting disease than that which lives in forested habitats (Sylla et al., 2009). There is considerable
370 variation among other populations of *Ae. aegypti* in their ecology, behaviour and vector capacity
371 (Crawford et al., 2017). An interesting question for the future is whether habitat fragmentation has
372 the potential to ultimately lead to evolutionary change in disease vectors, and their capacity for
373 disease transmission.

374

375 *3.5. Economic and demographic changes*

376 Together with changes in natural habitats, mining is associated with substantial economic and
377 demographic changes that (i) increase contact between pathogens, vectors and humans, (ii) shift
378 parasites and susceptible human populations between low and high endemic areas, (iii) create
379 vulnerable populations experiencing poor living conditions, and (iv) are typically associated with
380 inadequate health care to deal effectively with vector-borne infections (Potter et al., 2015; Silbergeld
381 et al., 2002; Veecken, 1993; Douine et al., 2017; Recht et al., 2017). For example, the construction of
382 roads into and around mining sites allows previously difficult or inaccessible regions to be settled by
383 an influx of people (Kleinschroth and Healey, 2017). Mining and other industrial activities are also
384 accompanied by expansion of more densely populated environments and can involve the increase of
385 foreign as well as large indigenous workforces (Richards and VanWey, 2015; Coderre-Proulx et al.,
386 2016).

387

388 *3.5.1. Increased contact between humans and vectors*

389 Engagement of populations in mining activities can increase occupation-related exposure of humans
390 to disease vectors (Cotter et al., 2013). Occupational exposure to vector-borne diseases was
391 documented as early as the 1850s during the construction of the Panama Railroad, when an estimated
392 12,000 workers died due to vector-borne diseases (malaria and yellow fever) from 1850 to 1855
393 (McCullough, 1977). More recently, an analysis of factors associated with malaria in Juruena, Matto
394 Grosso, Brazil, in 2005 found that infection prevalence was higher in individuals working in mining
395 activities than observed for house workers (Ferreira et al., 2012), indicating that mining activities place
396 workers at greater risk of contracting malaria. In the Americas as a whole, 60% of malaria cases
397 occurred in men in 2014, and younger men are more at risk of malaria infection, consistent with the
398 period of life in which individuals are exposed to the highest densities of vectors because of their work
399 (Barbieri et al., 2005; Ferreira et al., 2012; Pan American Health Organization, 2014).

400

401 *3.5.2. Migration of workers into and out of mining regions*

402 The migration of workers to mining and other industrial sites is well documented and has important
403 consequences for transmission of diseases of many kinds, including vector-borne and sexually-
404 contracted diseases. Malaria infection risk can be described along three main axes: (i) vulnerability,

405 (ii) exposure, and (iii) access (Guyant et al., 2015). Migrants may be more biologically vulnerable than
406 indigenous populations in malaria endemic areas because of a lack of naturally-acquired immunity
407 developed from previous infections. For instance, in Juruena malaria prevalence in a mining
408 settlement was 56% greater in individuals coming from non-endemic areas than in those that
409 originated from malaria endemic areas (Ferreira et al., 2012). Indeed, it was the 'transient non-
410 immune' population during the Pailin gem rush of the 1950s and 60s that was thought to fuel the
411 emergence of chloroquine resistance in Western Cambodia (Verdrager, 1986). Additionally, having
412 lower immunity, migrants from non-endemic areas are particularly vulnerable to malaria because they
413 have little or inadequate knowledge about the disease and its prevention (Wangroongsarb et al.,
414 2011). Furthermore, migrants are less likely to be aware of existing health services than are local or
415 long-term residents. Lastly, migrants may be more exposed when sleeping or working at night in areas
416 suitable for transmission, and may not take bed nets with them when they cross borders (Prothero,
417 2002; Malaria Consortium, 2013; Peeters Grietens, 2015).

418

419 Access to (or lack of) health services and outreach is the third risk element. The lack of administrative
420 registration among the majority of internal migrants in Cambodia resulted in most households (66.7%)
421 having never received an insecticide bed net from the National Malaria Control Programme (NMCP),
422 and a majority (76.3%) of internal migrants reporting never having received a bed net from the NMCP
423 in their home province. Access to malaria services is especially difficult for people who are either
424 defined as illegal migrants or working in an illegal trade who may prefer to avoid contact with
425 government services (Singhanetra-Renard, 1993).

426

427 One of the consequences of the migratory nature of mine workforces, formal or informal, is the
428 difficulty of disease surveillance for measuring disease burden. Active case detection implemented by
429 the Brazilian government has been credited with a dramatic reduction in malaria incidence in Mato
430 Grosso from 96.1 to 2.7 cases per 1,000 inhabitants from 1992 to 2002 (Ferreira et al., 2012). Case
431 monitoring can be interrupted or complicated by migration and periodic movement of mine workers,
432 i.e., those who may be missed completely or who may be labelled as imported cases elsewhere.

433

434 The second mechanism by which migration linked to mining can increase vector-borne disease
435 transmission is the movement of pathogens into non-endemic areas, for instance through migration
436 of workers out of mining regions. In Colombia, mining populations include individuals that have
437 migrated from areas that are not malaria endemic. Those that then travel back to their places of origin
438 pose a serious risk of introducing infections within a naïve population (Castellanos et al., 2016). An
439 infection tracing study found that over 1,000 cases of malaria, occurring as far away as Rio de Janeiro
440 (approximately 1,700 km), could be linked to gold mining activities in the Tapajós region of Pará. The
441 nature of mining as an episodic occupation that often involves regular movement (e.g., work rotations)
442 contributes to dispersal of disease (Silbergeld et al., 2002). In the particular case of drug resistant
443 strains of malaria, it is believed that mefloquine-resistant *P. falciparum* spread from Borai on the Thai-
444 Cambodia border to Mae Sot on the Thai-Myanmar border by infected Burmese gem miners returning
445 by bus from the ruby mines of Cambodia (Wongsrichanalai et al., 2001). Concerns have also been
446 raised about the spread of antimalarial drug resistance in the Guiana Shield, where resistance to
447 artemisinin in Suriname has been linked with gold miners travelling from French Guiana (Pommier de
448 Santi et al., 2016c).

449

450 3.5.3. *Urbanisation, inadequate housing and lack of planning*

451 When large tracts of land are devegetated and extensively modified by human activities, the process
452 of urbanisation is associated with both the importation of non-native species and the creation of
453 favourable habitats suitable for their establishment (McKinney, 2006). The extent to which a niche
454 opportunity arises for vectors may be site- and species-specific, but have important consequences for
455 disease transmission. For example, expanded urbanization might increase malaria transmission in
456 parts of Asia where *An. stephensi* can thrive in urban environments (Batra et al., 2001), but elsewhere
457 it has been associated with suppressed malaria transmission through a reduction in potential *Anopheles*
458 larval habitats (de Castro et al., 2006), due to water pollution, better drainage and more impervious
459 surfaces, lower individual human exposure to anopheline vectors due to better housing and greater
460 population density in relation to vectors, and generally better access to health care. It is therefore
461 important that our understanding of events at microgeographic scales not be generalized nor
462 transposed to other regions, which have different vectors, hosts, habitats, and urbanization histories.
463 With this caveat in mind, a generalization that has been observed empirically is that wherever
464 urbanization occurs, some species thrive as urban commensals to the extent that they become
465 dependent on urban resources (McKinney, 2006). Such 'urban exploiters' are composed of a small
466 subset of the world's species and are well adapted to intensely modified human environments
467 (McKinney, 2002).

468

469 The increase in the urban and semi-urban populations is typically associated with rapid growth in
470 settlements that are poorly planned with insufficient infrastructure bases, including safe water, proper
471 waste/sewage systems, and organised refuse disposal (Neiderud, 2015; Vij, 2012; United Nations
472 Development Programme, 2016). Urban locations in tropical and sub-tropical areas are becoming
473 increasingly important foci for the transmission of dengue, chikungunya and Zika viruses, and
474 potentially for the spread of yellow fever from sylvan environments into built environments, because
475 they provide ideal habitats for *Ae. aegypti*, a species which thrives in small man-made collections of
476 water such as discarded plastic containers, gutters, tyres and water-storage containers. Similarly,
477 rubbish in the peri-domestic environment provides breeding sites for sand flies, increasing the risk of
478 leishmaniasis, and *Culex quinquefasciatus* has been found abundantly in newly developed and
479 urbanized areas of Haiti (Samson et al., 2015). The possibility exists that clearing forest vegetation and
480 developing a more urban environment will allow for other diseases to be transmitted (Asante et al.,
481 2011.)

482

483 Poor quality housing construction and poverty in mining areas can increase the risk of vector-borne
484 disease for individuals within households. There is evidence to indicate that well-built housing can
485 reduce house entry by malaria vectors and, therefore, exposure to infection. A systematic review of
486 literature and a meta-analysis showed that improved housing was associated with 47% lower odds of
487 malaria infection and 45-65% less clinical malaria than traditional housing in sites across Africa, Asia
488 and South America (Tusting et al., 2015). Similarly, a recent analysis of data from 21 countries in sub-
489 Saharan Africa found that, after adjusting for household wealth, the association between house design
490 and protection from malaria was similar to that of the use of insecticide-treated nets (ITNs) (Tusting
491 et al., 2017). Compared to malaria, there have been fewer studies linking housing quality with other
492 vector-borne diseases, but there is some evidence of an effect on *Aedes*-borne diseases and
493 leishmaniasis. Meta-analyses have indicated a significant protective effect of window and door
494 screens on dengue transmission (Bowman et al., 2016), and that ITNs were able to reduce the

495 incidence of cutaneous leishmaniasis by 77% (Wilson et al., 2014). However, the efficacy of ITNs in
496 preventing transmission is dependent on several key variables related to vector biology, type of nets
497 and human behaviour.

498

499 In the northwest of Zambia, the development of a copper mine was not associated with a significant
500 increase in the prevalence of *P. falciparum* infection in children. Baseline data collected from 483
501 children under five-years-of-age in both mine-impacted and comparison sentinel sites, before project
502 development, were compared with data collected four years later when the mine had become
503 operational. The study showed that whilst there was a significantly greater malaria prevalence in the
504 follow-up survey, this was observed both in the impacted and comparison sites (Knoblauch et al.,
505 2017). The overall trend of higher infection rates at this site may have been associated with prevailing
506 temperature and precipitation at the time. However, malaria control interventions implemented by
507 the mine project and district health management teams in the impacted areas, including indoor
508 residual spraying, distribution of ITNs, health awareness campaigns, and active case detection, were
509 generally associated with lower odds (risk) of acquiring infection. In particular, the resettlement of
510 families in new housing with closed eaves and window screens was associated with significantly lower
511 infection rates (Knoblauch et al., 2017).

512

513 3.5.4. Accessibility and lack of health infrastructure

514 Mining offers a substantial income, and an opportunity for upward mobility, to an estimated 500,000
515 small-scale miners across the Amazon region (Cremers and de Theije, 2013), and to millions in other
516 parts of the world (World Bank, 2002). Many malaria-infected miners suffer no significant illness
517 (compared to 'non-immune' individuals) and often do not seek or take prescribed antimalarial agents,
518 or self-medicate (Nacher et al., 2013). However, integrated malaria control programmes rely on early
519 detection and appropriate treatment of infections (Shiff, 2002), and there are specific problems
520 associated with limited access to remote mining concessions and the steady increase in drug-resistant
521 *Plasmodium* species that confound control efforts, such as chloroquine-resistant *P. vivax* in the
522 Brazilian Amazon (de Santana Filho et al., 2007). The more transient alluvial and artisanal gold-mining
523 sites can be important reservoirs of drug-resistant Plasmodia, placing non-miners and surrounding
524 communities, including indigenous residents, farmers, and forest workers, at increased risk of malaria
525 infection (Andrade et al., 1995).

526

527 Mining areas are often characterised by remote, poor accessibility, and marginal health infrastructure.
528 For example, there are many areas in the Amazon region where gold mining and agricultural activities
529 support populations that are too small or malaria prevalence too low to warrant a government clinic
530 for providing malaria diagnosis and treatment (Cunha et al., 2001). A study of knowledge, attitudes
531 and behaviours of small-scale mine workers in Suriname found that the main reasons for not seeking
532 malaria tests were related to geographical barriers, including long distance from a health post and
533 excessive travel time required (Duijves and Heemskerck, 2015). These regions may also be extremely
534 remote, and can be transitory settlements, adding to the difficulty establishing and maintaining health
535 facilities. The same situation occurs in many parts of Asia, where multi-lateral funding proposals for
536 the Greater Mekong Subregion recognise the lack of easier access to health services in general and
537 malaria services in particular, with an expressed need to expand microscopy services and the use of
538 malaria rapid diagnostic tests in remote areas of Myanmar and Southern China (World Health
539 Organization, 2010).

540

541 Economic and political instability, and an absence or inadequacy of local public and private
542 institutions, can contribute to increased disease burdens, particularly in the relatively low income
543 settings in which industrial operations can operate. For example, in 1961, Venezuela was the first
544 country in Latin America to declare itself malaria free; however, a notable and steady increase in
545 malaria cases has been observed since 2010, reaching 240,613 cases in 2016 (Pan American Health
546 Organization, 2017). The municipality of Domingo Sifontes recorded the highest number of cases in
547 Venezuela due to an expanding epidemic related to a surge in gold exploitation, which, in part, has
548 been driven by a large-scale loss of jobs and a prolonged country-wide economic crisis. The crisis is
549 also responsible for a shortage of medical supplies and for operational failures in the health system
550 that are leaving cases untreated and under-reported. Further, the government's anti-malaria
551 programme has effectively been dismantled, with supplies stolen or diverted to the informal black
552 market (Ebua, 2017). It is clear that the absence of a once-functional health system leads to more
553 people suffering needlessly from vector-borne diseases.

554

555 **4. Conclusions**

556 Environmental changes that result from small and large-scale industrial activities have been shown to
557 create new opportunities for enhancing vector-borne disease transmission. Where environmental
558 changes occur through large scale extraction projects they can be coupled with demographic factors
559 that expose large numbers of people to diseases for which they have no acquired immunity (Recht et
560 al., 2017). Gaining a better understanding of the influence of human activities on vector-borne disease
561 dynamics, and vector ecology and evolution, will help guide future efforts to minimize the potential
562 negative impacts of industrial development (Johnson and Munshi-South, 2017). For example,
563 deployment of ITNs against vectors that historically fed predominantly indoors on humans has in some
564 areas resulted in persisting transmission by residual populations that survive by feeding outdoors, or
565 on other animals, so an appropriate response is to target them with vapour-phase or veterinary
566 insecticides (Killeen et al., 2017). Similarly, there are opportunities to protect people involved in
567 industrial activities through land use planning and the development of suitable homes that reduce
568 contact with and abundance of vector species (Tusting et al., 2016; Kilpatrick, 2011). Where impacts
569 on disease burden have already been felt, it is crucial that strong, evidenced-based collaborations
570 between industry and health sector stakeholders be made to ensure that vulnerable groups are
571 reached with adequate tools for providing disease risk mitigation, diagnosis and treatment.

572

573

574 **List of Abbreviations**

575 API, Annual Parasite Incidence

576 ITN, insecticide treated net

577 NMCP, National Malaria Control Programme

578

579 **Declarations**

580 The authors declare that they have no competing interests. Declarations of interest: none

581

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587

588 **Authors' contributions**

589 RTJ, JGL, MBM and MJB were responsible for the initial study concept. All authors contributed to the
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599 **References**

600 Abella-Medrano, C.A., Ibáñez-Bernal, S., MacGregor-Fors. I., Santiago-Alarcon, D., 2015.
601 Spatiotemporal variation of mosquito diversity (Diptera: Culicidae) at places with different land-use
602 types within a neotropical montane cloud forest matrix. *Parasit. Vectors.* 8:487.

603

604 Abeyasinghe, R.R., Galappaththy, G.N.L., Smith Gueye, C., Kahn, J.G., Feachem, R.G.A., 2012. Malaria
605 control and elimination in Sri Lanka: Documenting progress and success factors in a conflict setting.
606 *PLoS One.* 7(8): e43162.

607

608 Adhikari, P., Haldar, J.P., 1995. Prevalence of bancroftian filariasis in Burdwan district, West Bengal: II.
609 Vector and microfilariae density in colliery and non-colliery areas. *J. Commun. Dic.* 27(3)181-185.

610

611 Ahumada, M.L., Orjuela, L.I., Pareja, P.X., Conde, M., Cabarcas, D.M., Cubillos, E.F.G., Lopez, J.A., Beier,
612 J.C., Herrera, S., Quinones, M.L., 2016. Spatial distributions of *Anopheles* species in relation to malaria
613 incidence at 70 localities in the highly endemic Northwest and South Pacific coast regions of Colombia.
614 *Malar. J.* 15(1): 407.

615

616 Almeida de Souza, A.A. Rocha Barata, das Graces Soares Silva, M., Nunes Lima, J.A., Lins Jennings, Y.L.,
617 Ishikawa, E.A.Y., Prevot, G., Ginouves, M., Silveira, F.T., Shaw, J., dos Santos, T.V., 2017. Natural
618 *Leishmania (Viannia)* infections of phlebotomines (Diptera: Psychodidae) indicate classical and
619 alternative transmission cycles of American cutaneous leishmaniasis in the Guiana Shield, Brazil.
620 *Parasite.* 24:13.

621

622 Amerasinghe, P.H., Amerasinghe, F.P., Konradsen, F., Fonseka, K.T., Wirtz, R.A., 1999. Malaria vectors
623 in a traditional dry zone village in Sri Lanka. *Am. J. Trop. Med. Hyg.* 60:421–429.

624

625 Andrade, A., Martelli, C., Oliveira, R., Arias, J., Zicker, F., Pang, L., 1995. High prevalence of
626 asymptomatic malaria in gold mining areas in Brazil. *Clin. Infect. Dis.* 20(2): 475.

627

628 Arrifano, G.P.F., Martín-Doimeadios, R.C.R., Jiménez-Moreno, M., Ramírez-Mateos, V., da Silva, N.F.S.,
629 Souza-Monteiro, J.R., Augusto-Oliveira, M., Paraense, R.S.O., Macchi, B.M., do Nascimento, J.L.M.,

630 Crespo-Lopez, M.E., 2018. Large-scale projects in the Amazon and human exposure to mercury: The
631 case-study of the Tucuruí Dam. *Ecotoxicol. Environ. Saf.* 147:299-305.
632

633 Asante, K., Zandoh, C., Dery, D., Brown, C., Adjei, G., Antwi-Dadzie, Y., Adjuik, M., Tchum, K., Dosoo,
634 D., Amenga-Etego, S., Mensah, C., Owusu-Sekyere, K., Anderson, A., Krieger, G., Owusu-Agyei, S.,
635 2011. Malaria epidemiology in the Ahafo area of Ghana. *Malar. J.* 10: 211.
636

637 Attuquayefio, D.K., Owusu, E.H., Ofori, B.Y., 2017. Impact of mining and forest regeneration on small
638 mammal biodiversity in the Western Region of Ghana. *Environ. Monit. Assess.* 189(5): 237.
639

640 Azevedo, P.C.B., Lopes, G.N., Fonteles, R.S., Vasconcelos, G., Moraes J.L.P., Rebêlo, J.M.M., 2011. The
641 effect of fragmentation on phlebotomine communities (Diptera: Psychodidae) in areas of
642 ombrophilous forest in São Luís, state of Maranhão, Brazil. *Neotrop. Entomol.* 40(2): 271-277
643

644 Barbieri, A., Sawyer, O., Soares-Filho, B. 2005. Population and land use effects on malaria prevalence
645 in the southern Brazilian Amazon. *Hum. Ecol.* 33(6): 847-874.
646

647 Bashar, K., Rahman, S., Nodi, I.J., Howlader, A.J., 2016. Species composition and habitat
648 characterization of mosquito (Diptera: Culicidae) larvae in semi-urban areas of Dhaka, Bangladesh.
649 *Pathog Glob Health.* 110(2): 48–61.
650

651 Batra, C.P., Adak, T., Sharma, V.P., Mittal, P.K., 2001. Impact of urbanization on bionomics of *An.*
652 *culicifacies* and *An. stephensi* in Delhi. *Indian J Malariol.* 38(3-4): 61-75.
653

654 Bauch, S.C., Birkenbach, A.M., Pattanayak, S.K., Sills, E.O., 2015. Public health impacts of ecosystem
655 change in the Brazilian Amazon. *Proc. Natl. Acad. Sci. U. S. A.* 112(24): 7414-7419
656

657 Barros, F.S.M., Honório, N.A., 2015. Deforestation and malaria on the Amazon frontier: Larval
658 clustering of *Anopheles darlingi* (Diptera: Culicidae) determines focal distribution of malaria. *Am. J.*
659 *Trop. Med. Hyg.* 93(5): 939-53.
660

661 Beebe, N. W., Russell, T.L., Burkot, T.R., Lobo, N.F., Cooper, R.D., 2013. The systematics and bionomics
662 of malaria vectors in the southwest Pacific. 357-394. In Manguin S. (ed). *Anopheles Mosquitoes – New*
663 *Insights into Malaria Vectors.* InTech, Rijeka, Croatia.
664

665 Beebe, N.W., Russell, T., Burkot, T.R., Cooper, R.D., 2015. *Anopheles punctulatus* group: evolution,
666 distribution, and control. *Annu. Rev. Entomol.* 60:335-50.
667

668 Beerntsen, B., James, A., Christensen, B., 2000. Genetics of mosquito vector competence. *Microbiol.*
669 *Mol. Biol. Rev.* 64(1): 115-137.
670

671 Beketov, M.A., Yurchenko, Y.A., Belevich, O.E., Liess, M., 2010. What environmental factors are
672 important determinants of structure, species richness, and abundance of mosquito assemblages? *J.*
673 *Med. Entomol.* 47(2): 129–139.
674

675 Bockarie, M.J., Dagoro, H., Hii, J., 1994. Health impact of a gold mine in Lihir: entomological
676 investigations. 15 p. Available from Lihir Medical Service, P.O. Box 380, New Ireland Province, Papua
677 New Guinea.

678

679 Bowman, L., Donegan, S. McCall, P., 2016. Is dengue vector control deficient in effectiveness or
680 evidence?: Systematic review and meta-analysis. PLoS Negl. Trop. Dis. 10(3): e0004551.

681

682 Brault, A.C., 2009. Changing patterns of West Nile virus transmission: altered vector competence and
683 host susceptibility. Vet Res. 2009 Mar-Apr; 40(2): 43.

684

685 Brito, A.C., Williams, P., Fontes, G., Rocha, E.M., 1997. A comparison of two Brazilian populations of
686 *Culex quinquefasciatus* (Say, 1823) from endemic and non-endemic areas to infection with *Wuchereria*
687 *bancrofti* (Cobbold, 1877). Mem Inst Oswaldo Cruz. 92(1):33-6.

688

689 Camargo, L.M., Ferreira, M.U., Krieger, H., De Camargo, E.P., Da Silva, L.P., 1994. Unstable
690 hypoendemic malaria in Rondonia (western Amazon region, Brazil): epidemic outbreaks and work-
691 associated incidence in an agro-industrial rural settlement. Am. J. Trop. Med. Hyg. 51(1):16-25.

692

693 Cardo, M.V., Rubio, A., Junges. M.T., Vezzani. D., Carbajo. A.E. 2018. Heterogeneous distribution of
694 *Culex pipiens*, *Culex quinquefasciatus* and their hybrids along the urbanisation gradient. Acta Trop.
695 178:229-235.

696

697 Castellanos, A., Chaparro-Narváez, P., Morales-Plaza, C.D., Alzate, A., Padilla, J., Arévalo, M. and
698 Herrera, S., 2016. Malaria in gold-mining areas in Colombia. Mem. Inst. Oswaldo Cruz. 111(1):59-66

699

700 Chandra, G., Chatterjee, S.N., Das, S., Sarkar. N., 2007. Lymphatic filariasis in the coastal areas of Digha,
701 West Bengal, India. Trop. Doct. 37(3):136-9.

702

703 Chang, M.S., Hii, J., Buttner, P., Mansoon, F., 1997. Changes in abundance and behaviour of vector
704 mosquitoes induced by land use during the development of an oil palm plantation in Sarawak. Trans.
705 Roy. Soc. Trop. Med. Hyg. 91(4): 382-386.

706

707 Chinery, W.A., 1984. Effects of ecological changes on the malaria vectors *Anopheles funestus* and the
708 *Anopheles gambiae* complex of mosquitoes in Accra, Ghana. J. Trop. Med. Hyg. 87(2): 75-81.

709

710 Coderre-Proulx, M., Campbel, B., Mandé, I., 2016. International migrant workers in the mining sector.
711 International Labour Office. Geneva.

712

713 Conde, M., Pareja, P.X., Orjuela, L.I., Ahumada, M.L., Durán, S., Jara, J.A., Cañon, B.A., Pérez, P., Beier,
714 J.C., Herrera, S., Quiñones, M.L., 2015. Larval habitat characteristics of the main malaria vectors in the
715 most endemic regions of Colombia: potential implications for larval control. Malar. J. 14: 476.

716

717 Confalonieri, U.E.C., Neto, C.C., 2012. Diversity of mosquito vectors (Diptera: Culicidae) in Caxiuanã,
718 Pará, Brazil. Interdisciplinary Perspectives Infect. Dis. 741273.

719

720 Confalonieri, U.E.C., Margonari, C., Quintão, A.F., 2014. Environmental change and the dynamics of
721 parasitic diseases in the Amazon. *Acta Tropica*. 129: 33-41.
722

723 Conn, J., Wilkerson, R., Segura, M., de Souza, R., Schlichting, C., Wirtz, R., and Póvoa, M., 2002.
724 Emergence of a new neotropical malaria vector facilitated by human migration and changes in land
725 use. *Am. J. Trop. Med. Hyg.* 66(1): 18-22.
726

727 Cooper, R.D., Waterson, D.G.E., Frances, S.P., Beebe, N. W., Sweeney, A.W., 2002. Speciation and
728 distribution of the members of the *Anopheles punctulatus* (Diptera: Culicidae) group in Papua New
729 Guinea. *J. Med. Entomolo.* 39(1): 16-27
730

731 Cooper, R.D., Waterson, D.G., Frances, S.P., Beebe, N.W., Pluess, B., Sweeney, A.W., 2009. Malaria
732 vectors of Papua New Guinea. *Int. J. Parasitol.* 39(13): 1495-501.
733

734 Cotter, C., Sturrock, H.J., Hsiang, M.S., Liu, J., Phillips, A.A., Hwang, J., Gueye, C.S., Fullman, N., Gosling,
735 R.D., Feachem, R.G., 2013. The changing epidemiology of malaria elimination: new strategies for new
736 challenges. *Lancet* 382: 900-911.
737

738 Crawford, J.E., Alves, J.M., Palmer, W.J., Day, J.P., Sylla, M., Ramasamy, R., Surendran, S.N., Black, W.C.,
739 Pain, A., Jiggins, F.M., 2017. Population genomics reveals that an anthropophilic population of *Aedes*
740 *aegypti* mosquitoes in West Africa recently gave rise to American and Asian populations of this major
741 disease vector. *BMC Biol.* 15(1):16.
742

743 Cremers, L., de Theije, M., 2013. Small-scale gold mining in the Amazon. Amsterdam, CEDLA.
744

745 Cunha, M.L., Piovesan-Alves, F., Pang, L.W., 2001. Community-based program for malaria case
746 management in the Brazilian Amazon. *Am. J. Trop. Med. Hyg.* 65(6): 872 - 876.
747

748 de Castro, M.C., Monte-Mór, R.L., Sawyer, D.O. and Singe, B.H., 2006. Malaria risk on the Amazon
749 frontier. *Proc .Natl. Acad. Sci. U.S.A.* 103(7): 2452-2457.
750

751 de Santana Filho, F.S., Arcanjo, A.R., Chehuan, Y.M., Costa, M.R., Martinez-Espinosa, F.E., Vieira, J.L.,
752 Barbosa, M. d. G. V., Alecrim, W.D., Alecrim, M. d. G. C., 2007. Chloroquine-resistant *Plasmodium*
753 *vivax*, Brazilian Amazon. *Emerg. Infect. Dis.* 13(7): 1125–1126.
754

755 Desjeux, P., 2001. The increase in risk factors for leishmaniasis worldwide. *Trans. R. Soc. Trop. Med.*
756 *Hyg.* 95(3): 239-43.
757

758 Dickson, L.B., Campbell, C.L., Juneja, P., Jiggins, F.M., Sylla, M., Black, W.C., 2017. Exon-enriched
759 libraries reveal large genic differences between *Aedes aegypti* from Senegal, West Africa, and
760 populations outside Africa. *G3 (Bethesda)*. 7(2): 571-582
761

762 Douine, M., Mosnier, E., Le Hingrat, Q., Charpentier, C., Corlin, F., Hureau, L., Adenis, A., Lazrek, Y.,
763 Niemetsky, F., Aucouturier, A.L., Demar, M., Musset, L., Nacher, M., 2017. Illegal gold miners in French
764 Guiana: a neglected population with poor health. *BMC Public Health*. 18(1): 23.

765
766 Dourado, M., Noronha, C., Alcantara, N., Ichihara, M. and Loureiro, S., 1989. Epidemiology of
767 tegumentary American leishmaniasis and its relations with agriculture and prospecting, in a locality of
768 the State of Bahia, Brazil. *Rev. Saude Publica* 23(1): 2-8.
769
770 Duarte, E.C., Fontes, C.J.F., 2002. Association between reported annual gold mining extraction and
771 incidence of malaria in Mato Grosso-Brazil, 1985-1996. *Rev. Soc. Bras. Med. Trop.* 35(6): 665-668.
772
773 Ducheyne, E., Tran Minh, N.N., Haddad, N., Bryssinckx, W., Buliva, E., Simard, F., Malik, M.R., Charlier,
774 J., De Waele, V., Mahmoud, O., Mukhtar, M., Bouattour, A., Hussain, A., Hendrickx, G., Roiz, D. 2018.
775 Current and future distribution of *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae) in WHO
776 Eastern Mediterranean Region. *Int. J. Health Geogr.* 17(1):4
777
778 Duijves, C.E., Heemskerk, M., 2015. Study on the knowledge, attitudes and practices of malaria and
779 malaria treatment in the small-scale gold mining sector in Suriname, South America. *Trop. Med. Int.*
780 *Health.* 20: 365-365.
781
782 Dutta, S.N., 1977. Evidence of *Culex fatigans* mosquito breeding in underground pits of a coalmine in
783 India. *Trans. R. Soc. Trop. Med. Hyg.* 71(2):180.
784
785 Ebsworth, P., Bryan, J., Foley, D., 2001. Ecological distribution of mosquito larvae of the *Anopheles*
786 *punctulatus* group on Niolam (Lihir) Island, Papua New Guinea. *J. Am. Mosq. Control Assoc.* 17(3): 181-
787 185.
788
789 Ebu, B., 2017. Malaria infections spreading in crisis-ridden Venezuela.
790 [www.aljazeera.com/indepth/features/2017/08/malaria-epidemic-spreading-crisis-ridden-venezuela-](http://www.aljazeera.com/indepth/features/2017/08/malaria-epidemic-spreading-crisis-ridden-venezuela-170802072924748.html?utm_source=Global+Health+NOW+Main+List&utm_campaign=5835c5233c-EMAIL_CAMPAIGN_2017_08_15&utm_medium=email&utm_term=0_8d0d062dbd-5835c5233c-862787)
791 [170802072924748.html?utm_source=Global+Health+NOW+Main+List&utm_campaign=5835c5233c-](http://www.aljazeera.com/indepth/features/2017/08/malaria-epidemic-spreading-crisis-ridden-venezuela-170802072924748.html?utm_source=Global+Health+NOW+Main+List&utm_campaign=5835c5233c-EMAIL_CAMPAIGN_2017_08_15&utm_medium=email&utm_term=0_8d0d062dbd-5835c5233c-862787)
792 [EMAIL_CAMPAIGN_2017_08_15&utm_medium=email&utm_term=0_8d0d062dbd-5835c5233c-](http://www.aljazeera.com/indepth/features/2017/08/malaria-epidemic-spreading-crisis-ridden-venezuela-170802072924748.html?utm_source=Global+Health+NOW+Main+List&utm_campaign=5835c5233c-EMAIL_CAMPAIGN_2017_08_15&utm_medium=email&utm_term=0_8d0d062dbd-5835c5233c-862787)
793 [862787.](http://www.aljazeera.com/indepth/features/2017/08/malaria-epidemic-spreading-crisis-ridden-venezuela-170802072924748.html?utm_source=Global+Health+NOW+Main+List&utm_campaign=5835c5233c-EMAIL_CAMPAIGN_2017_08_15&utm_medium=email&utm_term=0_8d0d062dbd-5835c5233c-862787)
794
795 Eisen, L., Bolling, B.G., Blair, C.D., Beaty, B.J., Moore, C.G., 2008. Mosquito species richness,
796 composition, and abundance along habitat-climate-elevation gradients in the northern Colorado Front
797 Range. *J. Med. Entomology.* 45(4): 800-811.
798
799 Eisler, R., 2003. Health risks of gold miners: a synoptic review. *Environ. Geochem. Health* 25(3): 325-
800 345.
801
802 Feliciangeli, M.D., 2004. Natural breeding places of phlebotomine sandflies. *Med. Vet. Entomol.* 18(1):
803 71-80.
804
805 Fernando, A.W., Jayakody, S., Wijenayake, H.K., Galappaththy, G.N., Yatawara, M., Harishchandra, J.,
806 2016. Species composition and population dynamics of malaria vectors in three previously ignored
807 aquatic systems in Sri Lanka. *Malar. J.* 15(1):268.
808

809 Ferraguti, M., Martínez-de la Puente, J., Roiz D., Ruiz, S., Soriguer R., Figuerola, J., 2016. Effects of
810 landscape anthropization on mosquito community composition and abundance. *Sci. Rep.* 6: 29002.
811

812 Ferreira, I.M., Yokoo, E.M. Souza-Santos, R. Galvão, N.D., Atanaka-Santos, M., 2012. Factors associated
813 with the incidence of malaria in settlement areas in the district of Juruena, Mato Grosso state, Brazil.
814 *Cien. Saude Colet.* 17: 2415-2424.
815

816 Frazer, D.J., Debes, P.V., Bernatchez, L., Hutchings, J.A., 2014. Population size, habitat fragmentation,
817 and the nature of adaptive variation in a stream fish. *Proc. Biol. Sci.* 281(1790): 20140370.
818

819 Garcez, L., Soares, D., Chagas, A., de Souza, G., Miranda, J., Fraiha, H., Flöeter-Winter, L., Nunes, H.,
820 Zampiere, R., Shaw, J., 2009. Etiology of cutaneous leishmaniasis and anthropophilic vectors in Juruti,
821 Pará State, Brazil. *Cad. Saude Publica.* 25(10): 2291-2295.
822

823 Gibb, H., O'Leary, K.G. 2014. Mercury exposure and health impacts among individuals in the artisanal
824 and small-scale gold mining community: a comprehensive review. *Environ. Health. Perspect.* 122(7):
825 667-72
826

827 Guyant, P., Canavati, S. Chea N., Ly, P. Whittaker, M., Roca-Feltrer, A., Yeung S., 2015. Malaria and the
828 mobile and migrant population in Cambodia: a population movement framework to inform strategies
829 for malaria control and elimination. *Malar. J.* 14: 252.
830

831 Hilson, G., Laing, T. 2017. Guyana gold: A unique resource curse? *J. Development Studies.* 53(2):229-
832 248.
833

834 Hiwat, H., Bretas, G. 2011. Ecology of *Anopheles darlingi* Root with respect to vector importance: a
835 review. *Parasit Vectors.* 4: 177.
836

837 IBRAM, 2012. Information and Analyses on the Brazilian Mineral Economy 7th Edition. Brasília, Brazil.
838

839 Jacobi, C.M., do Carmo, F.F., de Campos, I.C., 2011. Soaring Extinction Threats to Endemic Plants in
840 Brazilian Metal-Rich Regions. *Ambio.* 40(5): 540–543.
841

842 Kleinschroth, F., Healey, J.R., 2017. Impacts of logging roads on tropical forests. *Biotropica*, June.
843

844 Killeen, G.F., Marshall, J.M. Kiware, S.S., South, A.B., Tusting, L.S., Chaki, P.P., Govella, N.J., 2017.
845 Measuring, manipulating and exploiting behaviours of adult mosquitoes to optimise malaria vector
846 control impact. *BMJ Glob. Health.* 2(2): e000212.
847

848 Kilpatrick, A.M., 2011. Globalization, land use and the invasion of West Nile virus. *Science*, 334(6054):
849 323–327.
850

851 Kiszewski, A., Teffera, Z., Wondafrash, M., Ravesi, M., Pollack, R., 2014. Ecological succession and its
852 impact on malaria vectors and their predators in borrow pits in western Ethiopia. *J. Vector Ecol.* 39(2):
853 414-423.

854

855 Kitula, A.G.N., 2006. The environmental and socio-economic impacts of mining on local livelihoods in
856 Tanzania: A case study of Geita District. *J. Clean. Production* 14: 405e414

857

858 Knoblauch, A. M., Divall. M. J., Owuor, M., Archer, C., Nduna, K., Ng'uni H., Musunka, G., Pascall, A.,
859 Utzinger, J., Winkler, M.S., 2017. Monitoring of selected health indicators in children living in a copper
860 mine development area in Northwestern Zambia. *Int. J. Environ. Res. Public Health* 14(3): E315.

861

862 Knoblauch, A. M., Winkler, M.S., Archer, C., Divall, M.J., Owuor, M., Yapo, R.M., Utzinger, J., 2014. The
863 epidemiology of malaria and anaemia in the Bonikro mining area, central Côte d'Ivoire. *Malar. J.* 13:
864 194.

865

866 Kraemer, M.U.G., Sinka. M. A. Duda, K.A., Mylne, A.Q., Shearer, F.M., Barker, C.M., Moore, C.G.,
867 Carvalho, R.G., Coelho, G.E., Van Bortel, W., Hendrickx, G., Schaffner, F., Elyazar, I.R., Teng, H.J., Brady,
868 O.J., Messina, J.P., Pigott, D.M., Scott, T.W., Smith, D.L., Wint, G.R., Golding, N., Hay, I., 2015. The
869 global distribution of the arbovirus vectors *Aedes aegypti* and *Ae. albopictus*. *eLife* 4: e08347.

870

871 Kramer, L.D., Styer, L.M., Ebel, G.D., 2008. A global perspective on the epidemiology of West Nile virus.
872 *Ann. Rev. Entomol.* 53: 61–81.

873

874 Kruess, A. Tschardt, T., 1994. Habitat fragmentation, species loss, and biological control. *Science*,
875 264, 1581–1584.

876

877 Karunaweera, N.D, Galappaththy, G.N.L., Wirth, D.F., 2014. On the road to eliminate malaria in Sri
878 Lanka: lessons from history, challenges, gaps in knowledge and research needs. *Malar. J.* 13: 59.

879

880 Kwansomboon, N., Chaumeau, V., Kittiphanakun, P., Cerqueira, D., Corbel, V., Chareonviriyaphap, T.,
881 2017. Vector bionomics and malaria transmission along the Thailand-Myanmar border: a baseline
882 entomological survey. *J. Vector Ecology.* 42(1): 84-93.

883

884 Kweka, E.J., Kimaro, E.E., Munga, S. 2016. Effect of deforestation and land use changes on mosquito
885 productivity and development in Western Kenya Highlands: Implication for malaria risk. *Front Public*
886 *Health.* 4: 238.

887

888 LaBeaud, A., Pfeil S., Muiruri, S., Dahir, S., Sutherland, L., Traylor, Z., Gildengorin, G., Muchiri, E.,
889 Morrill, J., Peters, C., Hise, A., Kazura, J., King, C., 2015. Factors associated with severe human Rift
890 Valley fever in Sangailu, Garissa County, Kenya. *PLoS Negl. Trop. Dis.* 9(3): e0003548.

891

892 Loayza, N., Rigolini, J., 2016. The local impact of mining on poverty and inequality: evidence from the
893 commodity boom in Peru. *World Development*, 84(C): 219-234.

894

895 Lobo, N.F., St Laurent, B., Sikaala, C.H., Hamainza, B., Chanda, J., Chinula, D., Krishnankutty, S.M.,
896 Mueller, J.D., Deason, N.A., Hoang, Q.T., Boldt, H.L., Thumloup, J., Stevenson, J., Seyoum, A., Collins,
897 F.H., 2015. Unexpected diversity of *Anopheles* species in Eastern Zambia: implications for evaluating
898 vector behavior and interventions using molecular tools. *Sci. Rep.* 5: 17952

899

900 Malaria Consortium. 2013. Cambodia Malaria Survey. [www.malariaconsortium.org/media-](http://www.malariaconsortium.org/media-downloads/624/Cambodia%20Malaria%20Survey%202013)
901 [downloads/624/Cambodia%20Malaria%20Survey%202013](http://www.malariaconsortium.org/media-downloads/624/Cambodia%20Malaria%20Survey%202013).

902

903 Prothero, R.M., 2002. Population movements and tropical health. *Glob. Change & Human Health* 3(1):
904 20-32.

905

906 Mazigo, H.D., Obasy, E., Mauka, W., Manyiri, P., Zinga, M., Kweka, E.J., Mnyone, L.L., Heukelbach, J.,
907 2010. Knowledge, attitudes, and practices about malaria and its control in rural northwest Tanzania.
908 *Mal. Res. Treatment*. 794261.

909

910 McCullough, D., 1977. *Path between the seas: The creation of the Panama Canal 1870 to 1914*. Simon
911 & Schuster.

912

913 McKinney, M.L., 2002. Urbanization, biodiversity, and conservation. *BioScience*, 52(10): 883-890.

914

915 McKinney, M.L., 2006. Urbanization as a major cause of biotic homogenization. *Biological Conserv.*
916 127:247-260.

917

918 Mereta, S.T., Yewhalaw, D., Boets, P., Ahmed, A., Duchateau, L., Speybroeck, N., Vanwambeke, S.O.,
919 Legesse, W., De Meester, L., Goethals, P.L., 2013. Physico-chemical and biological characterization of
920 anopheline mosquito larval habitats (Diptera: Culicidae): implications for malaria control. *Parasit.*
921 *Vectors*. 6(1): 320.

922

923 Mitjà, O., Paru, R., Selve, B., Betuela, I., Siba, P., De Lazzari, E., Bassat, Q., 2013. Malaria epidemiology
924 in Lihir Island, Papua New Guinea. *Malar. J.* 12: 98.

925

926 Moreno, J. E., Rubio-Palis, Y. Páez, E. Pérez E., Sánchez, V., 2007. Abundance, biting behaviour and
927 parous rate of anopheline mosquito species in relation to malaria incidence in gold-mining areas of
928 southern Venezuela. *Med. Vet. Entomol.* 21: 339-349.

929

930 Nacher M, Guérin PJ, Demar-Pierre M, Djossou F, Nosten F, Carme B. 2013. Made in Europe: will
931 artemisinin resistance emerge in French Guiana? *Malar. J.* 12: 152.

932

933 Neiderud, C-J., 2015. How urbanization affects the epidemiology of emerging infectious diseases.
934 *Infect Ecol Epidemiol.* 5: 10.3402.

935

936 Noori, N., Lockaby, B.G., Kalin, L., 2015. Larval development of *Culex quinquefasciatus* in water with
937 low to moderate pollution levels. *J. Vect. Ecol.* 40(2): 208-220.

938

939 Obiri, S., Mattah, P.A.D., Mattah, M.M., Armah, F.A., Osa, S., Adu-kumi, A., Yeboah, P.O., 2016.
940 Assessing the environmental and socio-economic impacts of artisanal gold mining on the livelihoods
941 of communities in the Tarkwa Nsuaem municipality in Ghana. *Int. J. Environ. Res. Public Health.* 13(2):
942 160.

943

944 Olaleye, O., Tomori, O., Ladipo M., Schmitz H., 1996. Rift Valley fever in Nigeria: infections in humans.
945 Rev. Sci. Tech. 15(3): 923-935.
946

947 Olson, S.H., Gangnon, R., Abbad Silveira, G., Patz, J.A., 2010. Deforestation and malaria in Mâncio Lima
948 County, Brazil. Emerg. Infect. Dis. 16(7): 1108–1115.
949

950 Overgaard, H.J., Ekbohm, B., Suwonkerd, W., Takagi, M., 2013. Effect of landscape structure on
951 anopheline mosquito density and diversity in northern Thailand: Implications for malaria transmission
952 and control. Landscape Ecol. 18: 605.
953

954 United Nations Development Programme, 2016. Human development for everyone. New York, United
955 States.
956

957 Pan American Health Organization, 2014. Report on the situation of malaria in the Americas.
958 Washington D.C.
959

960 Pan American Health Organization, 2017. Epidemiological Alert. Increase in cases of malaria.
961 Washington, D.C., USA, 26-30 September 2016.
962

963 Patz, J.A., Daszak, P., Tabor, G.M., Aguirre, A.A., Pearl, M., Epstein, J., Wolfe, N.D., Kilpatrick, A.M.,
964 Fofopoulos, J., Molyneux, D., Bradley, D.J.; Working group on land use change and disease
965 emergence. 2004. Unhealthy landscapes: Policy recommendations on land use change and infectious
966 disease emergence. Environ. Health. Perspect. 112(10): 1092-1098.
967

968 Pearce, J.C., Learoyd, T.P., Langendorf, B.J., Logan, J.G., 2018. Japanese encephalitis: the vectors,
969 ecology and potential for expansion. J Travel Med. 25(suppl_1):S16-S26
970

971 Peeters Grietens, K., Gryseels, C., Dierickx, S., Bannister-Tyrrell, M., Trienekens, S., Uk, S., Phoeuk, P.,
972 Suon, S., Set, S., Gerrets, R., Hoibak, S., Muela Ribera, J., Hausmann-Muela, S., Tho, S., Durnez, L.,
973 Sluydts, V., d'Alessandro, U., Coosemans M, Erhart A. 2015. Characterizing types of human mobility to
974 inform differential and targeted malaria elimination strategies in northeast Cambodia. Sci. Rep. 5:
975 1683.
976

977 Petrić, D., Bellini, R., Scholte, E.J., Marrama Rakotoarivony, L., Schaffner, F. 2014. Monitoring
978 population and environmental parameters of invasive mosquito species in Europe. Parasit. Vectors.
979 7:187.
980

981 Pimenta, P.F.P., Orfano, A.S., Bahia, A.C., Duarte, A.P.M., Ríos-Velásquez, C.M., Melo, F.F., Pessoa,
982 F.A.C., Oliveira, G.A., Campos, K.M.M., Martínez Villegas, L., Barnabé Rodrigues, N., Nacif-Pimenta, R.,
983 Simões, R.C., Monteiro, W.M., Amino, R., Traub-Cseko, Y.M., Lima, J.B.P., Barbosa, M.G.V., Lacerda,
984 M.V.G., Tadei, W.P., Secundino, N.F.C., 2015. An overview of malaria transmission from the
985 perspective of Amazon *Anopheles* vectors. Mem. Inst. Oswaldo Cruz. 110(1): 23–47.
986

987 Pommier de Santi V. Dia, A., Adde, A., Hyvert, G., Galant, J., Mazevet, M., Nguyen, C., Vezenegho, S.B.,
988 Dusfour, I., Girod, R., Briolant, S., 2016a. Malaria in French Guiana linked to illegal gold mining. Emer.
989 Infect. Dis. 22, 344–346.
990
991 Pommier de Santi V. Girod, R., Mura, M., Dia, A., Briolant, S., Djossou, F., Dusfour, I., Mendibil, A.,
992 Simon, F., Deparis, X., Pagès, F., 2016b. Epidemiological and entomological studies of a malaria
993 outbreak among French armed forces deployed at illegal gold mining sites reveal new aspects of the
994 disease's transmission in French Guiana. Malar. J. 15, 35.
995
996 Pommier de Santi, V., Djossou, F., Barthes N., Bogreau, H., Hyvert, G., Nguyen, C., Pelleau, S., Legrand,
997 E., Musset. L., Nacher, M., Briolant, S., 2016c. Malaria hyperendemicity and risk for artemisinin
998 resistance among illegal gold miners, French Guiana. Emerging Infect. Dis. 22(5): 903-906.
999
1000 Potter, A., Jardine, A., Neville, P.J. 2016. A survey of knowledge, attitudes, and practices in relation to
1001 mosquitoes and mosquito-borne disease in Western Australia. Front Public Health. 2016. 4:32.
1002
1003 Prakash, A, Mohapatra, P.K., Das, H.K., Sharma, R.K., Mahanta, J., 1998. Bancroftian filariasis in
1004 Namrup tea estate, district Dibrugarh, Assam. Indian J Public Health. 42(4):103-7, 112.
1005
1006 Rahman, W.A., Che'Rus, A., Ahmad, A.H., 1997. Malaria and *Anopheles* mosquitos in Malaysia.
1007 Southeast Asian J. Trop. Med. Public Health. 28(3): 599-605.
1008
1009 Rawlings, P., Curtis, C.F., 1982. Tests for the existence of genetic variability in the tendency of
1010 *Anopheles culicifacies* species B to rest in houses and to bite man. Bull. World Health Org., 60 (3): 427
1011 – 432.
1012
1013 Recht, J., Siqueira A., Monteiro, W., Herrera, S.M., Herrera, S., Lacerda, M., 2017. Malaria in Brazil,
1014 Colombia, Peru and Venezuela: current challenges in malaria control and elimination. Malar. J. 16(1):
1015 273.
1016
1017 Richards, P., VanWey, D., 2015. Where deforestation leads to urbanization: how resource extraction
1018 is leading to urban growth in the Brazilian Amazon. Ann. Assoc. Am. Geogr. 105(4): 806-823.
1019
1020 Rodrigures, M. S., Batista E. P., Silva, A. A., Costa, F. M., Neto, V. A., Gil, L. H., 2017. Change in *Anopheles*
1021 richness and composition in response to artificial flooding during the creation of the Jirau hydroelectric
1022 dam in Porto Velho, Brazil. Malar. J. 16: 87.
1023
1024 Rosa-Freitas, M.G., Broomfield, G., Priestman, A., Milligan, P.J., Momen, H., Molyneux, D.H., 1992.
1025 Cuticular hydrocarbons, isoenzymes and behavior of three populations of *Anopheles darlingi* from
1026 Brazil. J. Am. Mosq. Control Assoc. 8(4) 357-366.
1027
1028 Rubio-Palis, Y., Bevilacqua, M., Medina, D.A., Moreno, J.E., Cárdenas, L., Sánchez, V., Estrada, Y.,
1029 Anaya, W., Martínez, Á., 2013. Malaria entomological risk factors in relation to land cover in the Lower
1030 Caura River Basin, Venezuela. Mem. Inst. Oswaldo Cruz. 108(2):220-8.
1031

1032 Russell, B., Muir, L., Weinstein, P., Kay B., 1996. Surveillance of the mosquito *Aedes aegypti* and its
1033 biocontrol with the copepod *Mesocyclops aspericornis* in Australian wells and gold mines. Med. Vet.
1034 Entomol. 10: 155-160.
1035
1036 Russell, P., Rao, T., 1942. On the ecology of larvae of *Anopheles culicifacies* Giles, in borrow-pits. Bull.
1037 Entomol. Res. 32(4): 341-361.
1038
1039 Saha S, Pattanayak, S., Sills, E. Singha, A., 2011. Under-mining health: environmental justice and mining
1040 in India. Health Place, 17: 140-148.
1041
1042 Sahu, S.S., Gunasekaran, K., Krishnamoorthy, N., Vanamail, P., Mathivanan, A., Manonmani, A.,
1043 Jambulingam, P. 2017. Bionomics of *Anopheles fluviatilis* and *Anopheles culicifacies* (Diptera:
1044 Culicidae) in relation to malaria transmission in East-Central India. J. Med. Entomol. 54(4): 821–830.
1045
1046 Sallum, M.A.M., Peyton, E.L., Wilkerson, R.C., 2005. Six new species of the *Anopheles leucosphyrus*
1047 group, reinterpretation of *An. elegans* and vector implications. Med. Vet. Entomol. 19:158–199.
1048
1049 Samson, D.M., Archer, R.S., Alimi, T.O., Arheart, K.L., Impoinvil, D.E., Oscar, R., Fuller, D.O., Qualls,
1050 W.A., 2015. New baseline environmental assessment of mosquito ecology in northern Haiti during
1051 increased urbanization. J. Vector. Ecol. 40(1):46-5.
1052
1053 Sanchez, J.F., Carnero, A.M., Rivera, E., Rosales, L.A., Baldeviano, G.C., Asencios, J.L., Edgel, K.A., Vinetz
1054 J.M. and Lescano, A., 2017. Unstable malaria transmission in the southern Peruvian Amazon and its
1055 association with gold mining, Madre de Dios, 2001–2012. Am. J. Trop. Med. Hyg 96(2): 304-311.
1056
1057 Sang, R., Kioko, E., Lutomia, J., Warigia, M., Ochieng, C., O'Guinn, M., Lee, J.S., Koka, H., Godsey, M.,
1058 Hoel, D., Hanafi, H., Miller, B., Schnabel, D., Breiman, R.F., Richardson, J., 2010. Rift Valley fever virus
1059 epidemic in Kenya, 2006/2007: the entomologic investigations. Am. J. Trop. Med. Hyg. 83 (2): 28–37.
1060
1061 Santos, V., Yokoo, E., Souza-Santos, R., Atanaka-Santos, M., 2009. Socioenvironmental factors
1062 associated with the spatial distribution of malaria in the Vale do Amanhecer settlement, Municipality
1063 of Juruena, State of Mato Grosso, 2005. Rev. Soc. Bras. Med. Trop. 42, 47-53.
1064
1065 Schmidt, K.A., Ostfeld, R.S., 2001. Biodiversity and the dilution effect in disease ecology. Ecology. 82:
1066 609–619.
1067
1068 Sheela, A.M., Ghermandi, A., Vineetha, P., Sheeja, R.V., Justus, J., Ajayakrishna, K. 2017. Assessment
1069 of relation of land use characteristics with vector-borne diseases in tropical areas. Land Use Policy. 93:
1070 369-380.
1071
1072 Shiff, C., 2002. Integrated approach to malaria control. Clin. Microbiol. Rev. 15(2): 278–293.
1073
1074 Silbergeld, E. K., Nash, D. Trevant, C. Strickland, G. T. Souza J. M. Silva R.S.U., 2002. Mercury exposure
1075 and malaria prevalence among gold miners in Pará, Brazil. Rev. Soc. Bras. Med. Trop. 35(5): 421-429.
1076

1077 Singhanetra-Renard, A., 1993. Malaria and mobility in Thailand. Soc. Sci. Med. 37(9): 1147-1154.
1078

1079 Sinka, M.E., Bangs, M.J., Manguin, S., Rubio-Palis. Y., Chareonviriyaphap, T., Coetsee, M., Mbogo, C.M.,
1080 Hemingway, J., Patil, A.P., Temperley, W.H., Gething, P.W., Kabaria, C.W., Burkot, T.R., Harbach, R.E.,
1081 Hay, S.I., 2012. A global map of dominant malaria vectors. Parasit Vectors. 5:69.
1082

1083 Sinka, M.E., Bangs, M.J. Manguin, S. Chareonviriyaphap, T., Patil, A.P., Temperley, W.H., Gething, P.W.,
1084 Elyazar, I.R., Kabaria, C.W., Harbach, R.E., Hay, S.I., 2011. The dominant *Anopheles* vectors of human
1085 malaria in the Asia-Pacific region: occurrence data, distribution maps and bionomic précis. Parasit.
1086 Vectors 4:89.
1087

1088 Sinka, M.E., Bangs, M.J., Manguin, S., Chareonviriyaphap, T., Patil, A.P., Temperley, W.H., Gething,
1089 P.W., Elyazar, I.R., Kabaria, C.W., Harbach, R.E., Hay, S.I., 2010. The dominant *Anopheles* vectors of
1090 human malaria in Africa, Europe and the Middle East: occurrence data, distribution maps and
1091 bionomic précis. Parasit. Vectors. 4: 89.
1092

1093 Soe, H.Z., Thi, A., Aye, N.N., 2017. Socioeconomic and behavioural determinants of malaria among the
1094 migrants in gold mining, rubber and oil palm plantation areas in Myanmar. Infect. Dis. Poverty. 6(1):
1095 142.
1096

1097 Soleimani-Ahmadi, M., Vatandoost, H., Hanafi-Bojd, A.A., Zare, M., Safari, R., Mojahedi, A.,
1098 Poorahmad-Garbandi, F., 2013. Environmental characteristics of anopheline mosquito larval habitats
1099 in a malaria endemic area in Iran. Asian. Pac. J. Trop. Med. 6(7): 510-515.
1100

1101 Steiger, D.B.M., Ritchie, S.A., Laurance, S.G.W., 2016. Mosquito communities and disease risk
1102 influenced by land use change and seasonality in the Australian tropics. Parasit Vectors. 9: 387.
1103

1104 Surendran, S.N., Ramasamy, M.S., De Silva B. G. D. N. K., Ramasamy, R., 2006. *Anopheles culicifacies*
1105 sibling species B and E in Sri Lanka differ in longevity and in their susceptibility to malaria parasite
1106 infection and common insecticides. Med. Vet. Entomol. 20; 153–156.
1107

1108 Surendran, S.N., Jude, P.J., Weerathne, T.C., Parakrama Karunaratne, S.H., Ramasamy, R., 2012.
1109 Variations in susceptibility to common insecticides and resistance mechanisms among
1110 morphologically identified sibling species of the malaria vector *Anopheles subpictus* in Sri Lanka.
1111 Parasit Vectors. 2012; 5: 34.
1112

1113 Sylla, M., Bosio, C., Urdaneta-Marquez, L., Ndiaye, M., Black, W.C., 2009. Gene flow, subspecies
1114 composition, and dengue virus-2 susceptibility among *Aedes aegypti* collections in Senegal. PLoS Negl.
1115 Trop. Dis. 3(4): e408.
1116

1117 Tauil, P. L., 1986. Comments on the epidemiology and control of malaria in Brazil. Mem. Inst. Oswaldo
1118 Cruz, 81: (suppl II): 39-41.
1119

1120 Tucker Lima, J.M., Vittor, A., Rifai, S., Valle, D., 2017. Does deforestation promote or inhibit malaria
1121 transmission in the Amazon? A systematic literature review and critical appraisal of current evidence.
1122 Philos. Trans. R. Soc. Lond. B Biol. Sci. 372(1722): 20160125.
1123
1124 Turell, M.J., 2012. Members of the *Culex pipiens* complex as vectors of viruses. J. Am. Mosq. Control
1125 Assoc. 28(4 Suppl):123-6.
1126
1127 Tusting, L.S., Ippolito, M.P., Willey, B.A., Kleinschmidt, I., Dorsey, G., Gosling, R.D. Lindsay, S.W., 2015.
1128 The evidence for improving housing to reduce malaria: a systematic review and meta-analysis. Malar
1129 J. 14: 209.
1130
1131 Tusting, L.S., Willey, B., Lines, J., 2016. Building malaria out: improving health in the home. Malar. J.
1132 15: 320.
1133
1134 Tusting, L., Bottomley, C., Gibson, H., Kleinschmidt, I., Tatem, A. Lindsay S. Gething P., 2017. Housing
1135 improvements and malaria risk in sub-Saharan Africa: A multi-country analysis of survey data. PLoS
1136 Med. 14(2): e1002234.
1137
1138 Yahner, R.H., Morrell, T.E., Rachael, J.S., 1989. Effects of Edge Contrast on Depredation of Artificial
1139 Avian Nests. The Journal of wildlife management. 53(4): 1136-1138.
1140
1141 van der Meide, W., de Vries, H., Pratlong, F., van der Wal, A., Sabajo, L., 2008. Epidemiology of
1142 cutaneous leishmaniasis in Suriname: A study performed in 2006. Emerging. Inf. Dis. 6(5): 857-859.
1143
1144 Veeken, H., 1993. Malaria and gold fever. Brit. Med. J. 307(6901): 433-434.
1145
1146 Verdrager, J., 1986. Epidemiology of the emergence and spread of drug-resistant falciparum malaria
1147 in South-East Asia and Australasia. J. Trop. Med. Hyg. 1986 Dec;89(6): 277-289.
1148
1149 Vij, D. Urbanization and solid waste management in India: Present practices and future challenges.
1150 Procedia – Social Behavioral Sciences. 37: 437-447.
1151
1152 Vittor, A.Y., Gilman R.H., Tielsch, J., Glass, G., Shields, T., Lozano, W. S., Pinedo-Cancino, V. Patz, J.A.,
1153 2006. The effect of deforestation on the human-biting rate of *Anopheles darlingi*, the primary vector
1154 of Falciparum malaria in the Peruvian Amazon. Am. J. Trop. Med. Hyg. 74(1):3-11.
1155
1156 Vittor, A. Y., Pan, W., Gilman, R. H., Tielsch J., Glass, G., Shields, T., Sánchez-Lozano, W., Pinedo, V.,
1157 Salas-Cobos, E., Flores, S., Patz, J.A., 2009. Linking deforestation to malaria in the Amazon:
1158 Characterization of the breeding habitat of the principal malaria vector, *Anopheles darlingi*. Am. J.
1159 Trop. Med. Hyg. 81: 5-12.
1160
1161 Wangroongsarb, P., Satimai, W. Khamsiriwatchara, A. Thwing, J. Eliades, J. Kaewkungwal J. C.
1162 Delacollette, C., 2011. Respondent-driven sampling on the Thailand-Cambodia border. II. Knowledge,
1163 perception, practice and treatment-seeking behaviour of migrants in malaria endemic zones. Malar J.
1164 9(10): 117.

1165
1166 Weetman, D., Kamgang, B., Badolo, A., Moyes, C.L., Shearer, F.M., Coulibaly, M., Pinto, J., Lambrechts,
1167 L., McCall, P.J., 2018. *Aedes* mosquitoes and *Aedes*-borne arboviruses in Africa: current and future
1168 threats. *Int. J. Environ. Res. Public Health*. 15(2).
1169
1170 Wijesundere, D.A., Ramasamy, R., 2017. Analysis of historical trends and recent elimination of malaria
1171 from Sri Lanka and its applicability for malaria control in other countries. *Front Public Health*. 5:212.
1172
1173 Wilson, A., Dhiman, R., Kitron, U., Scott, T., van den Berg H., Lindsay S., 2014. Benefit of insecticide-
1174 treated nets, curtains and screening on vector borne diseases, excluding malaria: A systematic review
1175 and meta-analysis. *PLoS Negl. Trop. Dis.* 8(10): e3228.
1176
1177 Wilson M.L., Elisha R., Roncoli C., Agyei-Baffour P., Tenkorang E.Y., 2015. Integrated assessment of
1178 artisanal and small-scale gold mining in Ghana—Part 3: Social sciences and economics. *Int. J. Environ.*
1179 *Res. Public Health*. 12:8133–8156.
1180
1181 Wongsrichanalai, C., Sirichaisinthop, J., Karwacki, J., Congpuong, K., Miller, R., Pang L., Thimasarn, K.,
1182 (2001). Drug resistant malaria on the Thai-Myanmar and Thai-Cambodian borders. *Southeast Asian J.*
1183 *Trop. Med. Public Health* 32(1): 41-49.
1184
1185 World Bank, 2002. Mining and development. *Global mining: Treasure or trouble? Mining in developing*
1186 *countries*. Washington, D.C.
1187
1188 World Health Organization, 2010. *Malaria in the Greater Mekong Subregion: Regional and country*
1189 *profiles*. India.
1190
1191 World Health Organization, 2017. *Malaria-Free Sri Lanka*. New Delhi, India.
1192 http://apps.searo.who.int/PDS_DOCS/B5395.pdf
1193
1194 Yapabandara, A.M.G.M., Curtis, C. F., 2004. Vectors and malaria transmission in a gem mining area in
1195 Sri Lanka. *J. Vect. Ecol.* 29(2): 264-276.
1196
1197 Yapabandara, A.M.G.M., Curtis, C.F. Wickramasinghe M.B. Fernando W.P., 2001. Control of malaria
1198 vectors with the insect growth regulator pyriproxyfen in a gem-mining area in Sri Lanka. *Acta Tropica*
1199 80: 265–276.
1200
1201 Yasuoka, J. and Levins, R., 2007. Impact of deforestation and agricultural development on anopheline
1202 ecology and malaria epidemiology. *Am. J. Trop. Med. Hyg.* 76(3): 450-460.
1203
1204 Young, K.I., Mundis, S., Widen, S.G., Wood, T.G., Tesh, R.B., Cardosa, J., Vasilakis, N., Perera, D., Hanley,
1205 K.A., 2017. Abundance and distribution of sylvatic dengue virus vectors in three different land cover
1206 types in Sarawak, Malaysian Borneo. *Parasit Vectors*. 10(1): 406.
1207

1208 Zahouli, J.B.Z., Koudou, B.G., Müller, P., Malone, D., Tano, Y., Utzinger, J., 2017. Effect of land-use
1209 changes on the abundance, distribution, and host-seeking behavior of *Aedes* arbovirus vectors in oil
1210 palm-dominated landscapes, southeastern Côte d'Ivoire. PLoS One. 12(12): e0189082.
1211
1212