Provisional chapter

Urban Ecology and the Effectiveness of *Aedes* Control

Wladimir J. Alonso and Benjamin J.J. McCormick

Additional information is available at the end of the chapter

This study is dedicated to the memory of the researcher, colleague and friend Ellis Mackenzie.

Abstract

Past initiatives to control *Aedes* mosquitoes were successful, in part because they implemented draconian top-down control programs. To achieve similar results now, explicit recognition of the complexity in urban ecologies in terms of land ownership, law enforcement and accessibility for control interventions are required. By combining these attributes, four classes of spaces, along with corresponding control strategies, are suggested to better target *Aedes* species population control efforts. On one end of the spectrum there are accessible and accountable spaces (e.g. backyards and closely managed public facilities), where interventions can rely predominantly on bottom-up strategies with the local population playing the principle role in the implementation of actions, but with government coordination. On the other end of the spectrum are inaccessible and unaccountable spaces, which require top-down and extensive approaches. By identifying these and the intermediate classes of space, government and private resources can be allocated in a more efficient customized manner. Based on this new framework, a set of actions is proposed that might be implemented in dengue and other *Aedes*-borne crises. The framework considers existing limitations and opportunities associated with modern societies–which are fundamentally different from those associated with the successful control of *Aedes* species in the past.

Keywords: *Aedes*, mosquitoes control, prevention, dengue, community action, urban health, policy

1. Introduction

Urban pest species are highly effective and opportunistic in their use of the physical, legal and administrative interstices of the landscape we inhabit, and *Aedes* mosquitoes are a case in point. Any inaccessible nook or cranny, any vacant land or neglected facility permits adult mosquitoes to hide and, in as little water as might accumulate in the lid of a bottle, find ideal breeding places. *Aedes* mosquitoes take advantage of the heterogeneous urban ecologies through "skip oviposition," laying a few eggs, spread across the largest possible number of sites. It is an especially well suited strategy for urban environments with abundant, but sparse and even temporary breeding sites [1].

The control of *Aedes* mosquitoes is failing in most tropical regions [1–3], and human diseases transmitted by this vector, like dengue, chikungunya, yellow fever and Zika, are among the top public health priorities [4, 5]. The strategies for suppressing mosquito populations below a threshold at which they no longer support viral amplification [6–10] has focused on two strategies [7, 11, 12]: (a) negating larval development opportunities by eliminating breeding places and the sites of immature stages; and (b) killing adults by fumigation with insecticides. More recently biomolecular and biogenetic approaches have also been suggested, although their effectiveness under field conditions are uncertain [13, 14]. Therefore new approaches are urgently needed, especially in urban landscapes [15].

Here we propose that an important strategic aspect that is currently overlooked in *Aedes* control programs: recognition of the complexity of urban ecologies in terms of land ownership, enforcement and accessibility for control interventions. We suggest that a systematic strategy that accounts for this physical complexity is essential to best implement *Aedes* control.

2. Physical and legal accessibility for control purposes

In the current absence of safe and economically sustainable methods to sterilize or kill whole populations of adult mosquitoes, and especially ones that might be deployed on a scale and speed required to impact an epidemic, control over potential breeding and resting sites (PBRP) continues to play a pivotal role in the strategies against *Aedes*.

We suggest tackling this challenge by framing it based on these two variables that are especially relevant to the control of PBRPs: accessibility and accountability. The first relates to how easily breeding sites can be accessed for cleaning and intervention purposes. Although most PBRPs can be readily managed by private citizens (e.g., plant pots, fountains, household refuse and sidewalks), some are physically difficulty to locate or access for control purposes (e.g., roof gutters, cracks in houses or water-containing holes in trees). The second factor relates to how the stewardship of land is distributed between individuals, companies or the state. Even though all PBRPs are, in theory, under some legal responsibility (private residence, public buildings and tended public spaces), neglected public spaces (particularly in developing nations) and areas with uncertain ownership are under *de facto* diffuse or a non-accountable authority and frequently result in a state of abandonment (e.g. vacant lands, neglected public parks, open sewage).

The interaction between these physical and legal factors yields an actionable categorization of areas for vector control (**Figure 1**) that goes beyond the traditional system of "domestic, peridomestic and public spaces" [16], which is limited to types of habitat. The framework

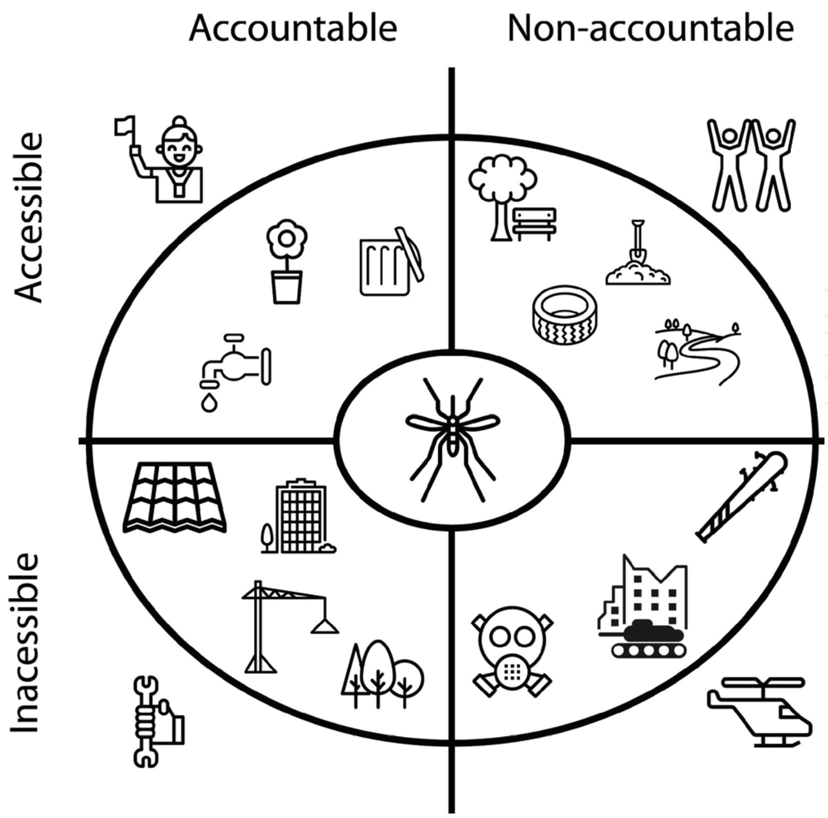

Figure 1. Strategy of societal organization of interventions against *Aedes* species based on the physical and legal accessibility of the space where the mosquito can be eliminated. The concentric rings contain: (i) the threat (*Aedes* mosquitoes), (ii) putative breeding and resting places (PBRP) of *Aedes* mosquitoes based on ownership accountability and physical accessibility, (iii) intervention that would be needed (clockwise, starting from upper-left: Individual citizens, community involvement, governmental direct action, professional assistance) (icon sources: Icons made by Becris, mynamepong, Smashicons, Good Ware, Revicon, Zlatko Najdenovski, Nikita Golubev and Freepik from www.flaticon.com).

proposed in **Figure 1** distinguishes societal actors (individuals, communities, government) who can be engaged in and held responsible for *Aedes* management. This classification, detailed below, enables both the identification of optimal allocation of private and public responsibilities in each case, but also defines the most suitable set of strategies:

(A) Easily accessible & accountable PBRPs. In areas that are both easily accessed and under accountable stewardship, for example, occupied private dwellings, or public facilities under effective management, we propose that the private individuals within the premises are engaged and mobilized. Plates under potted plants, water tanks, garden fountains, birdbaths, water bowls for pets, laundry tubs, toys, swimming pools, cisterns, ponds, etc. can be directly managed by individuals either by draining out the water or filling with sand to prevent adults laying eggs. Current WHO recommendations [17, 18] already charge private individuals with management of PBRPs within 100 m of their homes, which is likely to capture the majority of *Aedes aegypti* PBRPs [19, 20], and places of public congregation. However we would suggest this be expanded to all owners of accessible spaces with the active encouragement and support of government agencies (an interesting example is the “domestic trap strategy”; **Box 1**). Such activities are likely to be regular, for example putting out garbage, or infrequent, for example putting lids on water containers, but are seldom labor intensive, assuming changes in routine behavior. Ironically, some urban areas may be more accountable to individuals than municipal authorities as facilities (such as piped water or sewerage) fail to keep pace with urban spread [21, 22].

BOX 1. Domestic traps: Crowdsourcing Aedes elimination.
Controlling domestic pests like cockroaches, fleas, flies or ants depends on denying them basic resources (e.g., exposed food and breeding places). However, more radical measures are often needed, and traps are a popular choice, not only due to their effectiveness, but also because they (as opposed to chemical sprays) present less danger to humans and pets. The use of mosquito traps domestically is, however, not simple. For example, blood-feeding traps are not practical, as they can hardly compete with mosquitoes' attraction towards human bodies. Similarly, nectar-feeding based traps have no specificity, and would kill many insects (including bees and butterflies). Breeding traps, although potentially effective, are perceived as dangerous if not well implemented or supervised could promote the multiplication of mosquitoes.

Domestic breeding traps that eliminate the aquatic stages of mosquitoes hold great potential if their hazardous implementation can be eliminated. One way to attempt to bias oviposition to more manageable sites is the use of domestic traps that can be readily managed through regular reminders, once a week, for volunteer households and public facility managers who are charged with cleaning out the water in containers functioning as PBRPs [23–25].

The domestic trap strategy (which would be greatly beneficial to the *Mosquito Drain;* **Box 2**) is gaining impetus with the invention of an ingenious house-made trap made with widely available and affordable components (**Figure 2**, an empty PET bottle, adhesive tape and few square centimeters of mesh fabric source). When the eggs hatch in the cone, the larvae migrate to the bottom of the trap through the mesh, but this same mesh prevents adult mosquitoes from leaving the trap. The "mosquitérica," as it is known, presents several advantages over other domestic trap methods. First, it eliminates the concern about occasional negligence in the periodic need to cleaning up and/or adding larvicide to breeding traps. Second, it is unlikely that mosquitoes would develop resistance to this sort of trap –as opposed to chemical spray or even traps that use larvicide (as in the latter case mosquitoes could avoid surfaces or breeding places based on the odors of those substances). And third, it has been shown that egg-laying females are most attracted to sites containing other immature *Ae. aegypti* [9] – something this trap offers, since only the hatching adults are killed (by entrapment). Instructions for building such traps went viral in social networks, and it is having wide acceptance among the population.

This crowdsourcing method of mosquito elimination could be promoted by governments through, for instance, calls for co-ordinated action on a fixed date (e.g. mosquito eradication day [26]). Setting a weekly reminder during the epidemic season would be epidemiologically sound, as it is more frequent than the time of larval development (approximately 8–10 days), hence ideal for cleaning plant pots, water fountains, etc. Concerted action propelled by an official reminder (mainly in TV and social media) could create a collective drive and a positive sense of societal engagement–a study of community-based *Aedes* control showed, the most prominent benefit was the satisfaction created by 'working together' [27].

(B) Difficult to access, but accountable PBRP sites. Despite the best efforts of conscientious individuals, it can be difficult to eliminate all breeding places that can be hidden in corners of the urban landscape such as building cracks, roof gutters, crevices in the high trees canopy and slabs [1]. Both private and public agents who find such situations should be encouraged to request professional assistance. Legislation can also be used to improve building practices to

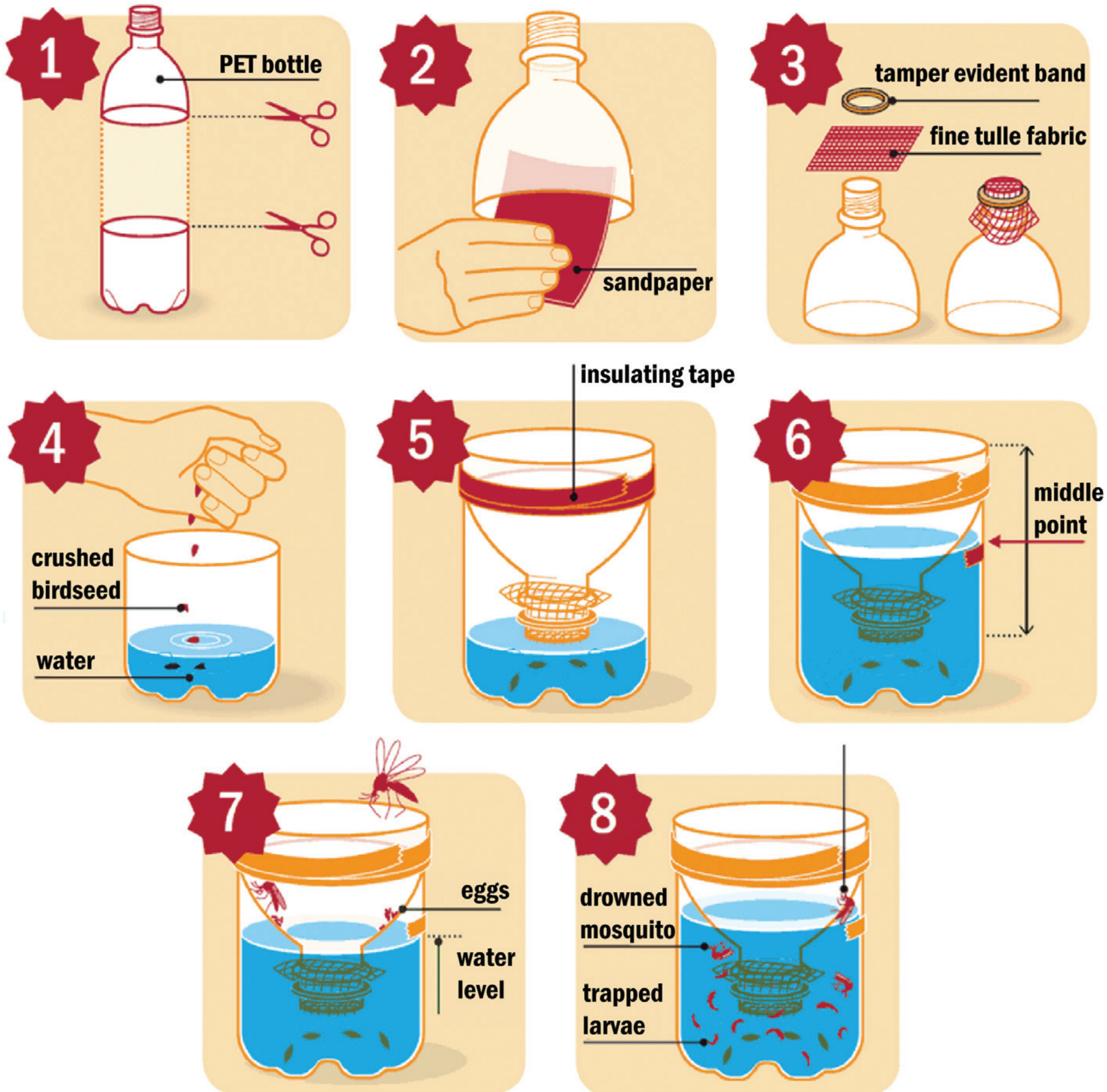

Figure 2. The mosquitérica, a simple larval trap that can be fashioned from common household products (reproduced and translated with permission from UOL, Brazil).

reduce PBRPs with difficult access [28], for example, encouraging architects to eliminate open gutters that are hard to access [29]. However, the inevitable existence of those PBRPs almost ubiquitously demand interventions that are applied in a "diffuse way", such as "peri-focal" interventions with residual insecticides [1], release of sterile adult mosquitoes or strategies involving multiple traps ("Mosquito Drain"; **Box 2**).

Box 2. Mosquito drain.

The *Mosquito Drain* is based on the idea of attracting females to ubiquitous oviposition places where larvae can be eliminated (e.g. domestic breeding traps, see **Box 1**) rather than natural, but inaccessible sites thereby eliminating the next generation of mosquitoes.

In an urban environment, some breeding and resting sites are likely to be inaccessible for cleaning and control (e.g., roofs, crevices, tree holes, etc.; **Figure 1**). However, not all potential breeding places are equally attractive to laying mosquitoes and "compete" for females' preference. Removal of accessible breeding sites would have the following effects on female mosquitoes in search for oviposition sites:

1. impel females to search for alternative potential breeding places;
2. impel females to over-disperse [30, 31] (so infected mosquitoes will cover an area quicker)
3. reduce the quality of potential breeding places sought by females (potential reduction -but not elimination- of viable broods).

Because "egg-laying females were most attracted to sites containing other immature *Aedes*, rather than to sites containing the most food" [9], home traps could become especially attractive to gravid females, and therefore be disproportionally important in reducing the mosquito population. Alternatively, attractants can be added to encourage mosquitoes to preferentially use lethal ovitraps that can be managed or left to biodegrade rather than inaccessible natural PBRPs [32–34]. The *Mosquito Drain* posits that it is not necessary to eliminate all breeding sites to cause the population to crash, which would not be practicable anyway, but that by (i) removing manageable breeding sites (e.g. putting lids on water containers), (ii) providing alternative attractive breeding sites that are easily managed (e.g. 'lure' breeding adults with a suitable trap) and that (iii) kill future generations of mosquitoes (e.g. adding larvicide to ovitraps) would eliminate sufficient reproductive capability of the mosquito population as to drive the population to extinction or at least pushing the biting population below levels at which virus circulation is sustained.

This is a societal effort that depends on collaboration between (many) individuals and government agencies: individuals would be in charge of eliminating any larvae, pupae and/or eggs that could have been accumulated in domestic breeding places (like plant pots and fountains) whilst governments should broadcast a reminder and coordinate that effort. Government agencies would then be freed to tackle hard to access and public spaces.

(C) Accessible, but non-accountable PBRP sites. Neglected public spaces with rubble, trash (tires, cups, cans, plastic bags and discarded containers) and facilities in neglected public spaces and vacant lands or empty lots are accessible to individuals without special knowledge or expertise. Volunteers from the neighborhood (e.g. coordinated by the community), could engaged, and perhaps incentivized, by government or emerging from social media networks in clean-up campaigns where, periodically, debris is removed, trash cleaned, ditches on the ground sealed, and other sensible interventions that destroy and negate breeding sites for *Aedes* performed. A survey in Singapore found that vacant properties and construction sites (the latter more appropriately belonging to accountable sites) had a four to seven times higher premises index than landed premises (which were three and a half times higher than apartments) [19, 35].

(D) Difficult to access and non-accountable sites. A comprehensive strategy that accounts for the whole gamut of access for mosquito control measures cannot ignore that there are patches where the capability of the government to influence behavior, enforce the law, or simply access places can provide major challenges - for example due to violent conflict. In those circumstances, top-down interventions (fogging, aerial fumigation, biological control and release of biologically modified Aedes males [7, 11, 36]) may be the only strategies that can promote vector control. We need to be caution about these approaches though, as these specialized and expensive activities offer diffuse control efforts that target adult mosquitoes rather than destroy PBRPs have a long history of use, but little recent evidence for effectiveness in reducing disease burden [37]. Restricting their use to epidemics is recommended because of cost and environmental impact [17].

3. A comprehensive approach for engaging society

Mosquito control depends on human actions, yet those actions are often at the mercy of legal and physical constraints. Dissecting the legal and physical complexity of contemporary urban ecosystems results in a categorization that can assist the effective implementation of interventions. These categories – based on the diversity of putative oviposition and resting sites – can be easily integrated into existing habitat management behaviors, and can be readily integrated into GIS mapping technologies to generate actionable information to tackle endemic infestations and unfolding outbreaks [29, 38].

One principle reason for successful control in the past century was the implementation of aggressive top-down measures [8, 12, 39]. The erosion of governmental capabilities to interfere with individual liberties does not necessarily impede mosquito control, as that "loss" may be compensated by an increasingly technologically-savvy, knowledge-avid and social media linked population can be mobilized to combat mosquito populations [40–42]. The proposed framework assumes that it is possible to effectively engage the local population [7], not only by suppressing areas of infection where they can easily act (e.g. their properties), but also by collaborating in a forcing a "Mosquito Drain" (**Box 2**) to reach beyond their immediate domain of direct impact.

Prioritizing citizens' actions has several potential benefits: (a) reduced strain on limited public resources that are stretched during public health crises (e.g. epidemics); (b) individuals can act on more targeted and sustained activities [43]; (c) reduction of harmful interventions (e.g. use of fogging in urban spaces that can be practically managed by community initiatives). The local population is also most likely to recognize hotspots of mosquitoes [41, 44, 45] and appreciate local conditions of epidemiological importance [18]. Although evidence for effectiveness of individual community-based interventions is sparse [37], it appears that integrating community participation into schemes reduces costs and increases effectiveness [46–48].

Engaging populations need not be costly (in time or money) given new communication technologies [40] (**Figure 3**) and, by stimulating and coordinating positive bottom-up initiatives, health agencies can co-opt allies in collective health emergencies [49]. In contrast, top-down approaches to combat Aedes risk treating citizens like irresponsible actors (for example threatening fines [35, 39]) fail to realize the emergent benefits of community participation. Emphasizing the power of bottom-up initiatives is not meant to marginalize the role of top-down activities [7, 8, 12]: as shown in our categorization (**Figure 1**), even the most engaged community will not be able to manage all putative mosquitoes breeding sites. Public authorities have an immense role to play, but are perhaps more efficient exercising their mandate in the expensive activities of avoiding a state of neglect in public spaces that risks them becoming the foci of urban pests and then efficiently using a smaller budget to encourage and support societal initiatives (e.g. nudging behavioral change [52]) to address readily accessible environments that would otherwise rapidly drain central resources.

The challenge is also to effectively manage activities, whether top-down or bottom-up that risk being popular, but ill conceived. The WHO emphasizes detailed planning to achieve successful behavioral change and recommend a series of steps to capitalize on public engagement to avoid what they consider the two greatest barriers of doing nothing or, perhaps worse, doing the wrong thing (hence putting people off further interventions if their efforts fail) [50]. In addition to combating lack of knowledge or misinformation, governmental activities need to manage social engagement campaigns beyond planning and into co-ordination since such campaigns to change behaviors have been most successful when combined with feedback

Figure 3. Interface from a citizen-science mosquito identification and reporting application used in Spain to assist in the surveillance efforts. Provided by mosquito alert CC-BY [41].

and regular reminders [39, 51]–for example to clean out water containers, mosquito traps or remove refuse each week [17]. Over reliance on past success risks mosquito populations rebounding, for example because surveillance priorities shift and vigilance suffers [35].

The key challenge in community participation is sustaining interest. As an example of citizen engagement in action, in two Cuban cities house blocks were randomly enrolled in a trial to control PBRPs (2000–2002), resulting in 75% reduction in *Aedes* populations through adding lids to water containers (*i.e.* monitoring accessible and accountable), repairing drains and transforming areas of garbage into (maintained) flowerbeds (*i.e.* accessible but not necessarily accountable) [53]. Importantly, these neighborhood task forces were still in operation 5 years later when there was an outbreak of dengue and proved cost and health effective [43, 47, 48]. However this sustainability may be unusual with evidence from other studies suggest that success may lead to changes in focus that risk lapses in effort [35], volunteers lose enthusiasm [22] and that adherence to control measures diminishes over time (though still out-perform no activity) [54, 55], more so if initiatives (and official cajoling) end [21]. Evidence of citizen science mosquito surveillance suggests good initial participation that rapidly decreased [41], and the few studies that evaluate the effectiveness of community interventions, whilst generally positive for vector control, lasted a year of less [55, 56]. Encouraging appropriate community participation in control measures is likely to be easier in the midst of epidemics when the benefits are visible, but it remains unclear whether this is sustainable in the longer-term in between episodes of, for example, dengue. That is why it is so important that control measures are "cross-cutting" within the context of a community, as we will see below.

4. Transforming cities in a large mosquito trap while improving their livability

Aedes-transmitted diseases are, largely, diseases emanating from neglected private and social spaces [57]. In backyards, buildings, vacant lands and empty lots, trash and untended structures provide perfect breeding places not only for *Aedes* mosquitoes, but also for many other urban and domestic pests. These neglected places have a negative impact on the environment and quality of life of the community, as well as on their economic development and safety [58]. Therefore, a campaign to remove mosquito breeding places is also a campaign to reinvigorate depressed or unplanned urban areas, thereby improving living conditions [59–61].

It is important to highlight that mosquito control has to be integrated into "cross-cutting" solutions for public health, turning societal vulnerabilities into resilience [61, 62] – i.e. what is good for elimination of *Aedes*, should also be beneficial on other societal fronts. For instance, environmental management of *Aedes* might discourage traditional *ad hoc* water storage practices such as private water-storage systems [16, 28]. But resilience to crises and catastrophes are enhanced through decentralized and resource-autonomous societies [63], for example potable water that is locally collected, treated [64] and appropriately stored (so that it is inaccessible to mosquitoes) would still be available even if the water supply from a centralized provider is unavailable, disrupted or fails.

5. Conclusion

The impact of *Aedes* mosquitoes on human health and the prospect of losing the battle against this species requires urgent and scientifically sound strategies [6, 7]. Here, we propose an adaptation to existing recommendations to rationalize, catalyze and coordinate the capabilities of modern society. More responsible societal co-ordination and allocation of limited resources based on existing accountability and physical accessibility can more effectively eliminate these deadly foes, but as a fortuitous by-product presents an opportunity to additionally improve the quality of life by improving the livability, cleanliness and beauty of shared social spaces.

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Author details

Wladimir J. Alonso[1]* and Benjamin J.J. McCormick[2]

*Address all correspondence to: wladimir.j.alonso@gmail.com

1 Laboratory for Human Evolutionary and Ecological Studies, Department of Genetics and Evolutionary Biology, University of São Paulo, Brazil

2 Fogarty International Center, National Institutes of Health, Bethesda, MD, USA

References

[1] Reiter P. Control of urban Zika vectors: Should we return to the successful PAHO/WHO strategy? PLoS Neglected Tropical Diseases. 2016;**10**:e0004769. DOI: 10.1371/journal.pntd.0004769

[2] Gubler DJ. Prevention and control of Aedes aegypti-borne diseases: Lesson learned from past successes and failures. Asia-Pacific Journal of Molecular Biology and Biotechnology. 19th ed. 2011:111-114

[3] Reiner RC Jr, Achee N, Barrera R, Burkot TR, Chadee DD, Devine GJ, et al. Quantifying the epidemiological impact of vector control on dengue. PLoS Neglected Tropical Diseases. 2016;**10**:e0004588. DOI: 10.1371/journal.pntd.0004588

[4] Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, et al. The global distribution and burden of dengue. Nature. 2013;**496**:504-507. DOI: 10.1038/nature12060

[5] Paixão ES, Teixeira MG, Rodrigues LC. Zika, chikungunya and dengue: The causes and threats of new and re-emerging arboviral diseases. BMJ Global Health. 2018;**3**:e000530. http://dx.doi.org/10.1136/bmjgh-2017-000530

[6] Achee NL, Gould F, Perkins TA, RCR J, Morrison AC, Ritchie SA, et al. A critical assessment of vector control for dengue prevention. PLoS Neglected Tropical Diseases. 2015;**9**: e0003655. DOI: 10.1371/journal.pntd.0003655

[7] Erlanger TE, Keiser J, Utzinger J. Effect of dengue vector control interventions on entomological parameters in developing countries: A systematic review and meta-analysis. Medical and Veterinary Entomology. 2008;**22**:203-221. DOI: 10.1111/j.1365-2915.2008.00740.x

[8] Morrison AC, Zielinski-Gutierrez E, Scott TW, Rosenberg R. Defining challenges and proposing solutions for control of the virus vector *Aedes aegypti*. PLoS Medicine. 2008;**5**: e68. DOI: 10.1371/journal.pmed.0050068

[9] Wong J, Stoddard ST, Astete H, Morrison AC, Scott TW. Oviposition site selection by the dengue vector Aedes aegypti and its implications for dengue control. PLoS Neglected Tropical Diseases. 2011;**5**:e1015. DOI: 10.1371/journal.pntd.0001015

[10] PAHO. Dengue and Dengue Hemorrhagic Fever in the Americas: Guidelines for Prevention and Control. Washington, DC: Pan American health Organization; 1994. Available from: http://apps.who.int/bookorders/anglais/detart1.jsp?codlan=1&codcol=61&codcch=548

[11] WHO. Mosquito control: Can it stop Zika at source? [cited 28 Sep 2016]. Available from: http://www.who.int/emergencies/zika-virus/articles/mosquito-control/en/

[12] Gubler DJ. Aedes aegypti and Aedes aegypti-borne disease control in the 1990s: Top down or bottom up. Charles Franklin Craig lecture. The American Journal of Tropical Medicine and Hygiene. 1989;**40**:571-578

[13] Nguyen TH, Nguyen HL, Nguyen TY, Vu SN, Tran ND, Le TN, et al. Field evaluation of the establishment potential of wMelPop wolbachia in Australia and Vietnam for dengue control. Parasites & Vectors. 2015;**8**:563. DOI: 10.1186/s13071-015-1174-x

[14] Ritchie SA, Johnson BJ. Advances in vector control science: Rear-and-release strategies show promise… but don't forget the basics. The Journal of Infectious Diseases. 2017;**215**: S103-S108. DOI: 10.1093/infdis/jiw575

[15] Lindsay SW, Wilson A, Golding N, Scott TW, Takken W. Improving the built environment in urban areas to control Aedes aegypti-borne diseases. Bulletin of the World Health Organization. 2017;**95**:607-608. DOI: 10.2471/BLT.16.189688

[16] Arunachalam N, Tana S, Espino F, Kittayapong P, Abeyewickreme W, Wai KT, et al. Eco-bio-social determinants of dengue vector breeding: A multicountry study in urban and periurban Asia. Bulletin of the World Health Organization. 2010;**88**:173-184. DOI: 10.2471/BLT.09.067892

[17] World Health Organization. Special programme for research and training in tropical diseases (TDR). In: Dengue Guidelines for Diagnosis, Treatment, Prevention and Control: New Edition [Internet]. Geneva, Switzerland: World health Organization; 2009 Available from: http://www.who.int/rpc/guidelines/9789241547871/en/

[18] UNICEF. World Health Organization, Pan American Health Organization, International Federation of Red Cross and Red Crescent Societies (IFRC). Risk Communication and Community Engagement for Zika Virus Prevention and Control [Internet]. New York, USA: UNICEF. 2016 Available from: http://www.who.int/csr/resources/publications/zika/community-engagement/en/

[19] Chan KL, Ho BC, Chan YC. *Aedes aegypti* (L.) and *Aedes albopictus* (Skuse) in Singapore City. 2. Larval habitats. Bulletin of the World Health Organization. 1971;**44**:629-633

[20] Maciel-de-Freitas R, Avendanho FC, Santos R, Sylvestre G, Araújo SC, Lima JBP, et al. Undesirable consequences of insecticide resistance following *Aedes aegypti* control activities due to a dengue outbreak. PLoS One. 2014;**9**:e92424. DOI: 10.1371/journal.pone.0092424

[21] Crabtree SA, Wong CM, Mas'ud F. Community participatory approaches to dengue prevention in Sarawak, Malaysia. Human Organization. 2001;**60**:281-287. DOI: 10.17730/humo.60.3.3767huwef8fdtv5c

[22] Chan KL, Chang MS, Laird M, Phanthumachinda B. Control of Aedes mosquitoes by the community. In: Curtis CF, editor. Appropriate Technology in Vector Control. Boca Raton, FL: CRC press; 1990. pp. 103-119 Available from: https://www.cabdirect.org/cabdirect/abstract/19900500195

[23] Alonso WJ. Epidemiology and ethology in the study of the infectious agents: A desirable mutual contamination. In: Research Gate. 2002 Available from: https://www.researchgate.net/publication/215677443_Epidemiology_and_ethology_in_the_study_of_the_infectious_agents_a_desirable_mutual_contamination

[24] dothnews.com.br. Ajudar Aedes a botar ovos é melhor tática, diz doutor [cited 28 Sep 2016]. Available from: http://www.diariodigital.com.br/geral/dengue-tirar-agua-do--potinho-nao-dianta-nada/140130/

[25] United Nations. UN news-Zika: UN agriculture agency provides expertise to help curb spread of virus. 2016 [cited 28 Sep 2016]. Available from: http://www.un.org/apps/news/story.asp?NewsID=53198#.V-t9FjI-Ku7

[26] Ribeiro Montiani HC, Gutemberg Lima Silva C. Social Mobilization of City Residents in Dengue Control. Best Practices for Dengue Prevention and Control in the Americas. Washington, DC: USAID; 2003. pp. 43-50

[27] Arunachalam N, Tyagi BK, Samuel M, Krishnamoorthi R, Manavalan R, Tewari SC, et al. Community-based control of *Aedes aegypti* by adoption of eco-health methods in Chennai City, India. Pathogens and Global Health. 2012;**106**:488-496. DOI: 10.1179/2047773212Y.0000000056

[28] WHO. Environmental management. [cited 28 Sep 2016]. Available from: http://www.who.int/denguecontrol/control_strategies/environmental_management/en/

[29] Teng TB. New Initiatives in Dengue Control in Singapore; 2001. Available from: http://www.who.int/iris/handle/10665/163695

[30] Reiter P, Amador MA, Anderson RA, Clark GG. Short report: Dispersal of *Aedes aegypti* in an urban area after blood feeding as demonstrated by rubidium-marked eggs. The American Journal of Tropical Medicine and Hygiene. 1995;**52**:177-179

[31] Edman JD, Scott TW, Costero A, Morrison AC, Harrington LC, Clark GG. *Aedes aegypti* (Diptera: Culicidae) movement influenced by availability of oviposition sites. Journal of Medical Entomology. 1998;**35**:578-583

[32] Ritchie SA, Long SA, McCaffrey N, Key C, Lonergan G, Williams CR. A biodegradable lethal Ovitrap for control of container-breeding Aedes. Journal of the American Mosquito Control Association. 2008;**24**:47-53. DOI: 10.2987/5658.1

[33] Williams CR, Ritchie SA, Russell RC, Zborowski P. Development and application of "lure and kill" strategies for the dengue vector Aedes aegypti in Australia. Arbovirus Research in Australia. 2005;**9**:397-402

[34] Ulibarri G, Betanzos A, BetanzosM, Rojas JJ. Preliminary results on the control of Aedes spp. in a remote Guatemalan community vulnerable to dengue, chikungunya and Zika virus: Community participation and use of low-cost ecological ovillantas for mosquito control [version 3; referees: 1 approved, 3 approved with reservations]. F1000 Research. 2017;**5**:598 DOI: 10.12688/f1000research.8461.3

[35] Ooi E-E, Goh K-T, Gubler DJ. Dengue prevention and 35 years of vector control in Singapore. Emerging Infectious Diseases. 2006;**12**:887-893. DOI: 10.3201/10.3201/eid1206.051210

[36] Alphey L. Genetic control of mosquitoes. Annual Review of Entomology. 2014;**59**:205-224. DOI: 10.1146/annurev-ento-011613-162002

[37] Bowman LR, Donegan S, McCall PJ. Is dengue vector control deficient in effectiveness or evidence?: Systematic review and meta-analysis. PLoS Neglected Tropical Diseases. 2016; **10**:e0004551. DOI: 10.1371/journal.pntd.0004551

[38] Chang AY, Parrales ME, Jimenez J, Sobieszczyk ME, Hammer SM, Copenhaver DJ, et al. Combining Google Earth and GIS mapping technologies in a dengue surveillance system for developing countries. International Journal of Health Geographics. 2009;**8**:49. DOI: 10.1186/1476-072X-8-49

[39] Trewin BJ, Darbro JM, Jansen CC, Schellhorn NA, Zalucki MP, Hurst TP, et al. The elimination of the dengue vector, Aedes aegypti, from Brisbane, Australia: The role of

surveillance, larval habitat removal and policy. PLoS Neglected Tropical Diseases. 2017;**11**: e0005848. DOI: 10.1371/journal.pntd.0005848

[40] Lwin MO, Vijaykumar S, Fernando ONN, Cheong SA, Rathnayake VS, Lim G, et al. A 21st century approach to tackling dengue: Crowdsourced surveillance, predictive mapping and tailored communication. Acta Tropica. 2014;**130**:100-107. DOI: 10.1016/j.actatropica.2013.09.021

[41] Palmer JRB, Oltra A, Collantes F, Delgado JA, Lucientes J, Delacour S, et al. Citizen science provides a reliable and scalable tool to track disease-carrying mosquitoes. Nature Communications. 2017;**8**:916. DOI: 10.1038/s41467-017-00914-9

[42] Ledogar RJ, Arosteguí J, Hernández-Alvarez C, Morales-Perez A, Nava-Aguilera E, Legorreta-Soberanis J, et al. Mobilising communities for *Aedes aegypti* control: The SEPA approach. BMC Public Health. 2017;**17**:403. DOI: 10.1186/s12889-017-4298-4

[43] Toledo ME, Rodriguez A, Valdés L, Carrión R, Cabrera G, Banderas D, et al. Evidence on impact of community-based environmental management on dengue transmission in Santiago de Cuba. Tropical Medicine & International Health: TM & IH. 2011;**16**:744-747. DOI: 10.1111/j.1365-3156.2011.02762.x

[44] Ranard BL, Ha YP, Meisel ZF, Asch DA, Hill SS, Becker LB, et al. Crowdsourcing—Harnessing the masses to advance health and medicine, a systematic review. Journal of General Internal Medicine. 2013;**29**:187-203. DOI: 10.1007/s11606-013-2536-8

[45] Hay SI, George DB, Moyes CL, Brownstein JS. Big data opportunities for global infectious disease surveillance. PLoS Medicine. 2013;**10**:e1001413. DOI: 10.1371/journal.pmed.1001413

[46] Alvarado-Castro V, Paredes-Solís S, Nava-Aguilera E, Morales-Pérez A, Alarcón-Morales L, Balderas-Vargas NA, et al. Assessing the effects of interventions for *Aedes aegypti* control: Systematic review and meta-analysis of cluster randomised controlled trials. BMC Public Health. 2017;**17**:384. DOI: 10.1186/s12889-017-4290-z

[47] Baly A, Toledo ME, Boelaert M, Reyes A, Vanlerberghe V, Ceballos E, et al. Cost effectiveness of Aedes aegypti control programmes: Participatory versus vertical. Transactions of the Royal Society of Tropical Medicine and Hygiene. 2007;**101**:578-586. DOI: 10.1016/j.trstmh.2007.01.002

[48] Baly A, Toledo ME, Vanlerberghe V, Ceballos E, Reyes A, Sanchez I, et al. Cost-effectiveness of a community-based approach intertwined with a vertical Aedes control program. The American Journal of Tropical Medicine and Hygiene. 2009;**81**:88-93

[49] Alonso WJ, Schuck-Paim C. Public preparedness guidance for a severe influenza pandemic in different countries: A qualitative assessment and critical overview. PLOS Currents Influenza. 2010 Apr 15. Edition 1. DOI: 10.1371/currents.RRN1128

[50] Parks W, Lloyd L, Diseases UBSP for R and T in T. Planning social mobilization and communication for dengue fever prevention and control: A step-by-step guide. Planificación de la movilización y comunicación social para la prevención y el control del dengue: guía paso a paso; 2004. Available from: http://www.who.int/iris/handle/10665/42832

[51] Webb TL, Joseph J, Yardley L, Michie S. Using the internet to promote health behavior change: A systematic review and meta-analysis of the impact of theoretical basis, use of behavior change techniques, and mode of delivery on efficacy. Journal of Medical Internet Research. 2010;**12**:e4. DOI: 10.2196/jmir.1376

[52] Marteau TM, Ogilvie D, Roland M, Suhrcke M, Kelly MP. Judging nudging: Can nudging improve population health? BMJ. 2011;**342**:d228. DOI: 10.1136/bmj.d228

[53] Toledo ME, Vanlerberghe V, Baly A, Ceballos E, Valdes L, Searret M, et al. Towards active community participation in dengue vector control: Results from action research in Santiago de Cuba, Cuba. Transactions of the Royal Society of Tropical Medicine and Hygiene. 2007;**101**:56-63. DOI: 10.1016/j.trstmh.2006.03.006

[54] Kay BH, Tuyet Hanh TT, Le NH QTM, Nam VS, PVD H, et al. Sustainability and cost of a community-based strategy against Aedes aegypti in northern and Central Vietnam. The American Journal of Tropical Medicine and Hygiene. 2010;**82**:822-830. DOI: 10.4269/ajtmh.2010.09-0503

[55] Tapia-Conyer R, Méndez-Galván J, Burciaga-Zúñiga P. Community participation in the prevention and control of dengue: The patio Limpio strategy in Mexico. Paediatrics and International Child Health. 2012;**32**(Suppl 1):10-13. DOI: 10.1179/2046904712Z.00000000047

[56] Heintze C, Garrido MV, Kroeger A. What do community-based dengue control programmes achieve? A systematic review of published evaluations. Transactions of the Royal Society of Tropical Medicine and Hygiene. 2007;**101**:317-325. DOI: 10.1016/j.trstmh.2006.08.007

[57] Gubler DJ. Dengue, urbanization and globalization: The unholy trinity of the 21st century. Tropical Medicine and Health. 2011;**39**:3-11. DOI: 10.2149/tmh.2011-S05

[58] Srinivasan S, O'Fallon LR, Dearry A. Creating healthy communities, healthy homes, healthy people: Initiating a research agenda on the built environment and public health. American Journal of Public Health. 2003;**93**:1446-1450

[59] Wallace R, Wallace D. Origins of public health collapse in new york city: The dynamics of planned shrinkage, contagious urban decay and social disintegration. Bulletin of the New York Academy of Medicine. 1990;**66**:391-434

[60] MacGregor C. Urban regeneration as a public health intervention. The Journal of Social Intervention: Theory and Practice. 2010;**19**:38. DOI: 10.18352/jsi.225

[61] Harpham T, Molyneux C. Urban health in developing countries: A review. Progress in Development Studies. 2001;**1**:113-137. DOI: 10.1177/146499340100100202

[62] Alonso WJ, McCormick BJ, Miller MA, Schuck-Paim C, Asrar GR. Beyond crystal balls: Crosscutting solutions in global health to prepare for an unpredictable future. BMC Public Health. 2015;**15**:955. https://doi.org/10.1186/s12889-015-2285-1

[63] Taleb NN. Antifragile: Things that Gain from Disorder. New York: Random House, Penguin; 2012

[64] Sobsey MD. Managing Water in the Home : Accelerated Health Gains from Improved Water Supply. Geneva, Switzerland: World Health Organization; 2002