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UNMEASURED SIDE EFFECTS OF MOSQUITO CONTROL ON BIODIVERSITY

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Abstract.
Intensive mosquito control programs are likely to contribute to insect diversity loss, but these effects are both underestimated and understudied. We recommend to conduct direct biodiversity monitoring programs to understand the effects of both chemical and biological control.

Key words: biodiversity loss, ecosystem service, non-target insects, Culicidae, extensive mosquito control, ecological side effect.

Insects play essential ecosystem roles, such as primary and secondary consumption, decomposition, or pollination. However, our knowledge of the global conservation status of insects is still very limited (Hochkirch, 2016), and biased towards some well-known species groups and Western industrialized countries (Sánchez-Bayo & Wyckhuys, 2019). Recently, a massive decline in flying insect biomass (75% over 27 years) has been reported from Western Germany (Hallmann et al., 2017). European grassland butterfly populations declined by 50% between 1990 and 2011 (van Swaay et al., 2015), and 26% of all European Orthoptera are threatened by extinction (Hochkirch et al., 2016). Also globally massive arthropod species and population extirpations has been detected, which is based on severe minor local species abundance losses (Dirzo et al., 2014; Leather, 2017; van Strien et al., 2019; van Klink et al. 2020). Agricultural intensification, industrial forestry, urbanization, and climate change are among the most important drivers behind these declines, which are expected to provoke and jeopardize ecosystem services (Sánchez-Bayo & Wyckhuys, 2019). In addition, globalization (tourism and transport) and climate change create favourable conditions for several exotic invasive species and pathogens.

However, some insects also provide "ecosystem disservices" (Dunn, 2010), by acting as pests or vectors for pathogens. These insects are often actively combated with adverse side effects on many other biota (Hochkirch et al., 2016). The high frequency of mosquito control programs potentially contributes to insect diversity loss in an underestimated and understudied way. Mosquitoes (Culicidae) are one of the most studied and well-known dipteran families (Manguin & Boëte 2011), but not in terms of their ecosystem roles or conservation status. The positive roles of mosquitoes are often neglected in global ecosystems, e.g. they comprise a substantial biomass in aquatic ecosystems worldwide (Addicott, 1974; Heard, 1994; Daugherty et al., 2000). Due to their blood-sucking behaviour, some vector species are able to transmit pathogens or parasites, such as viruses (Dengue virus, Yellow Fever virus; Hubálek, 2008), bacteria (*Rickettsia* spp.; Dieme et al., 2015), protozoans (*Plasmodium* spp.; Piperaki & Daikos, 2016) and nematodes (*Wuchereria bancrofti*, *Brugia malayi*; Becker et al., 2010). These can cause serious diseases, which threaten human wellbeing, particularly in tropical regions.

Dark Side of Chemical Control of Mosquitoes

Intensive mosquito control programs started in Europe in the early 20th century partly because of the malaria epidemic, partly to reduce nuisance by mosquito bites in areas with high mosquito abundances.

A series of discoveries during the late 1930s provided new synthetic insecticides (e.g. DDT), which had enormous potential for widespread use and reinforced the emphasis on chemical insect control. Many toxic substances have broad-spectrums and several of them have a high risk when used in sensitive habitats. These toxins are non-selective and might harm other insects and vertebrates, too (Hochkirch et al., 2018; Bolzonella et al., 2019).

Even though malaria disappeared already in 1970 in Europe, chemical mosquito control has prevailed in large parts of the continent (Figure 1; Piperaki & Daikos, 2016). Today there is a widespread use of deltamethrin products, an effective larvicide and adulticide against mosquitoes, which are among the most popular and highly active synthetic insecticides recommended by the WHO. These pesticides are highly toxic to aquatic life, non-target aquatic insects, and particularly fishes, and, therefore, must be used with extreme caution around water (Urbina et al., 2019). Csillik et al. (2000) observed waves of fish deaths in Lake Balaton, which is the largest fresh-water lake in Europe. Fish death coincided with airborne mosquito control campaigns. In addition, Vanzetto et al. (2019) detected sublethal effects of amphibians, which decreased swimming activity, speed, and oral morphology. A similar study by Oliveira et al. (2018) showed that physiological changes caused by exposure to deltamethrin in bats may have direct consequences in flight capacity, reproduction, and metabolism of these animals.

Other pesticides such as tetramethrin, cypermethrin, pyrethroid, dieldrin induce mortality, but also show sublethal effects on invertebrates (e.g. pest control enemies; Abeyasuriya et al., 2017) and vertebrates (e.g. birds; Corcellas et al., 2017). Some studies highlight lethal and sublethal effects on pollinators (*Apis* and non-*Apis* bees; Scott-dupree et al., 2009, Tomé et al., 2017), which then showed reduced the visitation rates that consequently led to lower productivity and yield rate (Costa et al., 2014; Tschoeke et al., 2019).

One reason for the frequent chemical control in lakesides and waterfronts are the mosquito bites, which disturb local inhabitants and negatively affect touristic development. However, while these bites may be inconvenient, they lack any further harm and do not cause epidemics in most parts of Europe (yet).

Figure 1. Chemical mosquito control in Hungary by Dániel Kőszegi, Noxious Kft. Szúnyoglárvaprogram.

In Hungary, for example, frequent control projects are largely based on ground and aerial application of insecticides at least two times per year, which covers over ten percent of the country. Furthermore, the cities have extra mosquito control programs, independently of the country-level control program. Despite the potential strong and harmful side effects, monitoring of community changes due to such large-scale chemical control in urban and semi-natural (wetland and riparian) areas are largely lacking throughout the continent.

Dark Side of Biological Control of Mosquitoes

Environment-friendly mosquito control may be a promising alternative to chemical control. A well-known example is the global use of *Bacillus thuringiensis serovar israelensis* (Bti), but even this may have more side effects on the food web than usually acknowledged. Due to the fact that Bti is more selective than insecticides (but still affects several non-target families of Diptera, such as Dixidae, Chironomidae, Tipuloidea; Timmermann & Becker, 2017), its side effects are thought to be less harmful. However, Bti can decrease chironomid abundances and thereby threaten the reproduction of many vertebrate species, especially in spring when chironomid midges represent their key food resource (Kästel et al., 2017). The considerable reduction of the abundant chironomids, which usually dominate insect emergence in wetlands, along with other non-target mosquitoes may subsequently lead to unwanted indirect negative effects for birds, bats, and other aquatic organisms feeding on them (Allgeier et al., 2019). For example, insect prey availability and breeding success of house martins were much reduced in Bti treated sites of the Camargue, France (Poulin et al., 2010).

Strengthening Monitoring and Research

We urge to pay more attention to the fact that the widespread application of chemicals for mosquito control is highly risky. First, we recommend that each control program is evaluated by an Environmental Impact Assessment, taking into account not only side effects on non-target organisms, but also the role of mosquitos in the food web (Figure 2). As suggested by the mitigation hierarchy (e.g. McKenney & Kiesecker, 2010), avoiding impacts should be

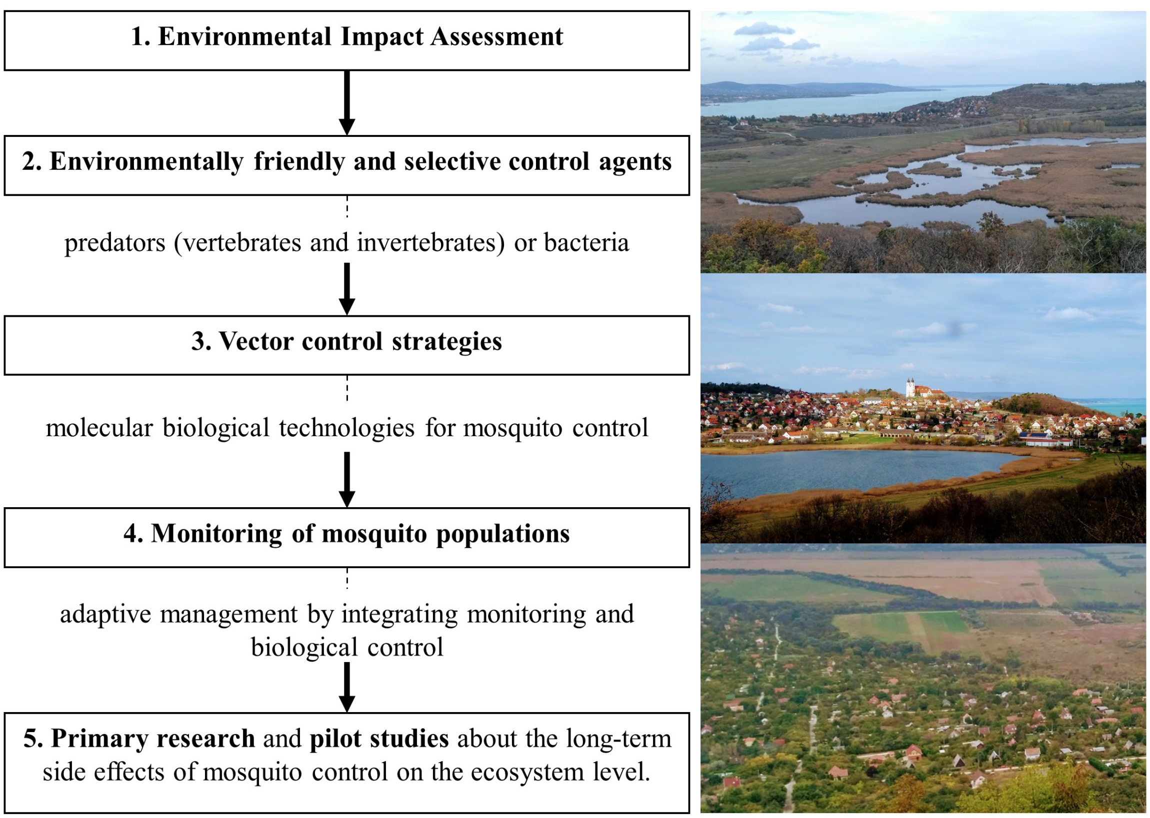

Figure 2. Summary diagram of five suggestions of mosquito control. The photos represent urban and semi-natural areas near the Lake Balaton, Hungary (photo credit: E. Török).

a priority and thus control should only be applied if well justified. Second, side effects should be minimized by the use of more environmentally friendly and selective control agents, such as predators (vertebrates and invertebrates) or bacteria (Bti, *Wolbachia*; Zheng et al., 2019). Although, Bti side effects on insect families such as Chironomidae, which are most important in aquatic-terrestrial food webs, have been apparently underestimated (Allgeier et al., 2019). Third, the use of vector control strategies might be the best option, which focus on exclusively one vector species (e.g. on *Aedes albopictus*, a vector of West Nile virus) (Zheng et al. 2019). The development of such a strategy requires thorough knowledge of the biology of target mosquito (daily change of resting place, oviposition sites, overwintering stage, number of generations), as well as vector species. Finally, the advancement of molecular biological technologies for mosquito control (Huang et al., 2017) should also be carefully evaluated. In theory, using gene drives for spreading disease-resistant mosquito lineages might be less harmful than producing sterile lines of mosquitos, as side effects on the food web may be lower. However, recent experience from field trials with these techniques (Evans et al., 2019) show that their application is still unpredictable and that it may be far too early to apply them in the field.

Also, besides a more integrated framework of mosquito control also needs to include the monitoring of mosquito populations, public health surveillance, and public education. Adaptive management by integrating monitoring and biological control is a more useful solution to prevent large scale epidemics. Finally, there is a high need for primary research and pilot studies in Europe about the long-term side effects of mosquito control on the ecosystem level.

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