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Mini Review

Modeling Invasive *Aedes aegypti, Aedes albopictus* and Arboviral Transmission through the Batumi Port in the Republic of Georgia

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Abstract

The Batumi Port in the Republic of Georgia serves international customers and is therefore vulnerable to import and invasion by mosquito vectors and arboviruses. Recent studies in the Batumi area have detected the presence of *Aedes aegypti* and *Ae. albopictus*. The Bioagent Transport and Environmental Modeling System (BioTEMS) was used to model invasion of infected mosquitoes through the port and provide information for integrated mosquito management planners. In previous studies, surveillance for invasive species has focused to the south of the port and city of Batumi; however, it is recommended that this surveillance be expanded to the north of the port and application of pesticides in the port area be initiated to mitigate or prevent infected invasive mosquitoes from entering through the port.

INTRODUCTION

This report discusses the potential for *Aedes* (*Steogomyia*) *aegypti* (L.) and *Ae. albopictus* (Skuse) to invade through the Batumi Port and spread into adjacent areas in the Republic of Georgia, increasing the risk of invasive arboviruses becoming established in the community. Integrated mosquito management zones, control methods and surveillance sites were identified in the region to prevent or mitigate invasion by infected mosquito species and/or haplotypes. Arboviruses, particularly dengue viruses (DENV), chikungunya virus (CHIKV) and Zika virus (ZIKAV) are being introduced globally where competent vectors, hosts and habitats occur. ZIKAV is the most recent arbovirus placed into Public Health Emergency status by the World Health Organization [1]. In November, 2016 the WHO Emergency Committee removed ZIKAV as a Public Health Emergency of International Concern but suggested it remain a significant and long-term public health problem [1].

Aedes aegypti and *Ae. albopictus* have been shown or are suspected of being vectors of DENV, CHIKV and/or ZIKAV [2]. Thirty two mosquito species have been recorded in the Republic of Georgia [3] including *Ae. aegypti* and *Ae. albopictus*. Previous distribution modeling of the Black Sea region predicted a high probability of occurrence of *Ae. albopictus* in Georgia and moderate probability for *Ae. aegypti* [4]. *Aedes aegypti* was first reported in Georgia in 1926 [5]. *Aedes albopictus* has recently invaded Georgia, and was first collected in Georgia in 2014 and subsequently in 2015 [2,3]. Both studies report *Ae. aegypti* and *Ae. albopictus* in the port city of Batumi.

Assessing the risk of invasion into ports and implementation of integrated mosquito management (IMM) at the local level is critical in protecting communities from medically important vectors and the arboviruses they may harbor. Where *Aedes* species have already invaded, immigration of susceptible and infected haplotypes should be of concern. Once introduced into an area, the invasive mosquito species may disperse naturally or spread rapidly across regions through ground transport [6,7]. In addition to the import of infected mosquitoes, local transmission and amplification of arboviruses into a new geographic area can occur when local mosquitoes bite infected travelers and become infected, or when people become infected through sexual contact or contaminated blood [8,9].

Samy [10], identified areas in the Republic of Georgia, including the city of Batumi, as being at risk of Zika virus. The Port of Batumi is Georgia's most important seaport and gateway, serving cargo ships, cruise liners and military vessels and it is listed as an approved International Health Regulation Approved Port by the World Health Organization [11]. The port and surrounding area of Batumi are at risk for the introduction of mosquito vectors and arboviruses from ships originating from endemic countries or from ships having had a previous port of call in an endemic country. For example, as part of the United States Navy 6th Fleet, the US Naval Ship Mount Whitney travels from the port in Puerto Rico to ports in Europe, including Batumi [12]. Puerto Rico is endemic for DENV, CHIKV and ZIKAV [13], as are other nations in the Caribbean Sea, therefore a possibility exists for infected mosquito species to invade from docking ships or cargo. An example of this is the continued spread of *Ae. albopictus* through cargo transport [2].

EXPERIMENTAL METHODS

The Bioagent Transport and Modeling System (BioTEMS) was used to model the potential for *Ae. aegypti and Ae. albopictus* and arbovirus species to enter the region through the Batumi Port, and subsequently disperse to the surrounding area. BioTEMS has previously been used for modeling biological weapons defense and infectious diseases in several countries and utilized for consequence management planning for military installations and vulnerability/risk assessment during special events [14]. BioTEMS utilizes up to several hundred abiotic and biotic factors to produce risk and vulnerability assessments for biological agents and infectious diseases. Examples of biotic and abiotic factors include pathogen strain, vector/host relationship, vectorial capacity, host/vector physiology, colonization ability, population dynamics of hosts and vectors, soil, shade, and weather conditions, such as wind, temperature, precipitation, and shade. Analytical methods within BioTEMS include artificial intelligence, fuzzy logic, niche analysis, and general additive regression. Ecological niche and dynamic change modeling are used within BioTEMS to identify areas at risk for invasion by vectors, arboviruses and provide information for integrated mosquito management [15]. Output from BioTEMS identifying recommended IMM zones, control methods and surveillance sites are discussed in order to provide practical information to local medical and public health professionals. The research conducted by Kutateladze [3], was supported by the Biotechnology Technology and Engagement Program, and provides geographic coordinates and habitat information used as part of the present study.

The BioTEMS TIGER model was developed to assist in identifying areas at high risk for invasive mosquito species and pathogens and to optimize surveillance and control efforts and information. The acronym TIGER represents the steps in the invasion of a mosquito species or haplotype: Transport- identifies the point of origin, method and rate of transport to a locality. Introduction- identifies point or area of initial invasion/entry of species or haplotypes and preliminary spread into a locality (I-zone). Gap- determines the area where vector/pathogen infiltrates and initially spreads once it has gained a foothold (G-zone). Escalade- incorporates abiotic and biotic factors as possible resistance to invasion. Residence and recruitment - incorporates factors and area where vector/pathogen adds to genetic diversity or becomes endemic and recruits con-specifics/haplotypes. In predictive modeling, it is imperative to use external data to validate the model where possible [16,17]. The BioTEMS model was validated using data from several countries, including Brazil, Honduras, and the USA [18]. In addition to published predictive maps for *Aedes* species and ZIKAV, Samy et al. [10,19], data from Kutateladze [3], was used to validate the BioTEMS model for the Batumi Port area. BioTEMS and the geographic information software ArcGIS (ESRI, Redlands, California) were used to produce output into Google® Earth.

RESULTS AND DISCUSSION

The principle factor responsible for the invasion of disease vectors is air and ship transport [20,21], with rapid transport through cars, trucks and possibly trains. Geographic probability models have been developed for *Ae. aegypti* and *Ae. albopictus* [6,22]. Models have also been developed in order to identify the nature and spread of arboviruses, e.g. ZIKAV [10]. Most models are of low resolution but are valuable for ascertaining the current and potential geographic range of vector species, and the pathogens they transmit, for example the 5 km resolution maps for *Ae. aegypti* and *Ae. albopictus* produced by Kraemer [19].

The preliminary study of the *Aedes* population of Batumi by Kutateladze [3], provides excellent collection and habitat records for the area south of the port. Although only a few collections of these two species have been conducted in Georgia, displacement of *Ae. aegypti* by *Ae. albopictus* in Batumi is likely as this interaction is common in other temperate regions [23]. Using data from Kutateladze [3], the number of sites with *Ae. albopictus* versus *Ae. aegypti* was 18:1. There were significant difference among the habitat sites. Sites with tires had a significantly higher mean number of *Ae. albopictus* captured than sites with only containers or sites with gardens without containers, and sites with containers had a higher mean number than garden sites without containers (ANOVA MS=3109.1, df=38, $p < 0.05$). BioTEMS predicted the likely points of introduction for *Ae. aegypti* and *Ae. albopictus* and arboviruses through the Batumi port with movement northward and southward (Figure 1). The predicted southward expansion overlaps with the interpolated capture records of *Ae. albopictus* capture from Kutateladze [3].

One of the principal routes of dispersal of invasive mosquito species across regions is by vehicular transport, particularly with the movement of used tires [2]. The BioTEMS TIGER model prediction for the invasion southward also corresponds to the high density of *Ae. albopictus* found by Kutateladze [3], found in sites with tires. BioTEMS predicts the suitability of the Batumi area for *Ae. albopictus*, and ZIKAV, supporting the predictive models of Kraemer and Samy [10,19]. In previous studies, BioTEMS was accurate in predicting the presence of ZIKAV cases in Brazil and Miami, USA where BioTEMS identified marine ports as the most likely route of invasion of infected *Aedes* species or humans and area of origin for the subsequent infection and spread through the local *Aedes* population [18].

Unlike low resolution models, BioTEMS includes I and G zones in Batumi (Figure 2). High risk zones are defined as an area likely to be invaded or to have already been invaded by infected mosquitoes or to have localized transmission. The Gap zone includes areas where ZIKAV will spread through infected mosquitoes. In the Batumi port area, the I-zone is approximately 8 km^2. Based upon BioTEMS, *Ae. albopictus* likely invaded Batumi between 2009 and 2011. Intensive surveillance and control of mosquitoes as well as epidemiologic surveillance of the human

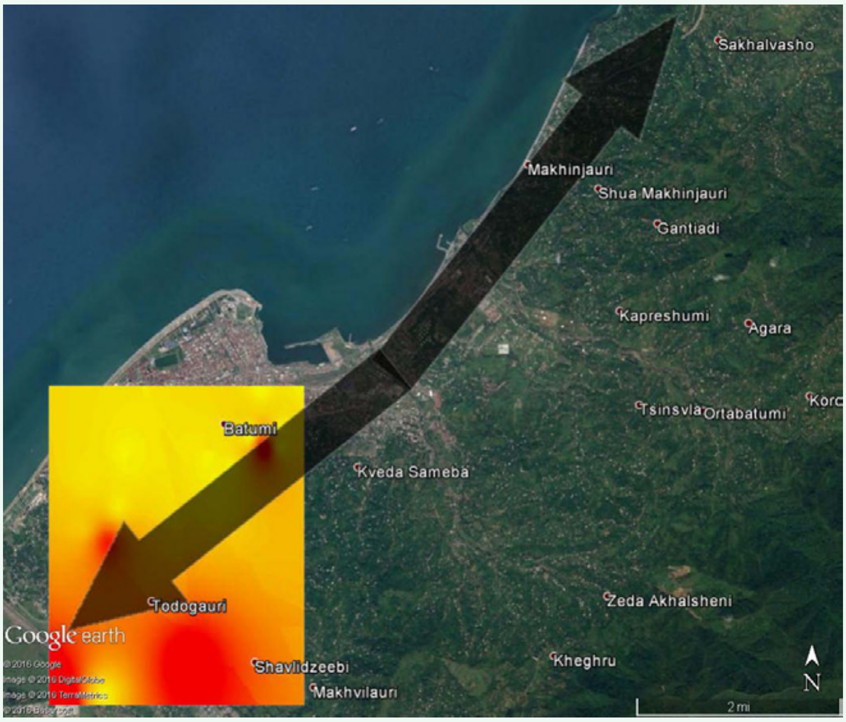

Figure 1 Predicted northern and southward movement (black arrows) of *Aedes* species and arboviruses invading through the Batumi port (BioTEMS). Colored block represents estimated density of *Aedes albopictus* (yellow to red = low to high) in the area using kriging from data collected by Kutateladze et al. (2106). (Base Map: US Dept. of State Geographer © 2016 Google Image Landsat/Copernicus, Data SIO, NOAA, US Navy, NGA, GEBCO).

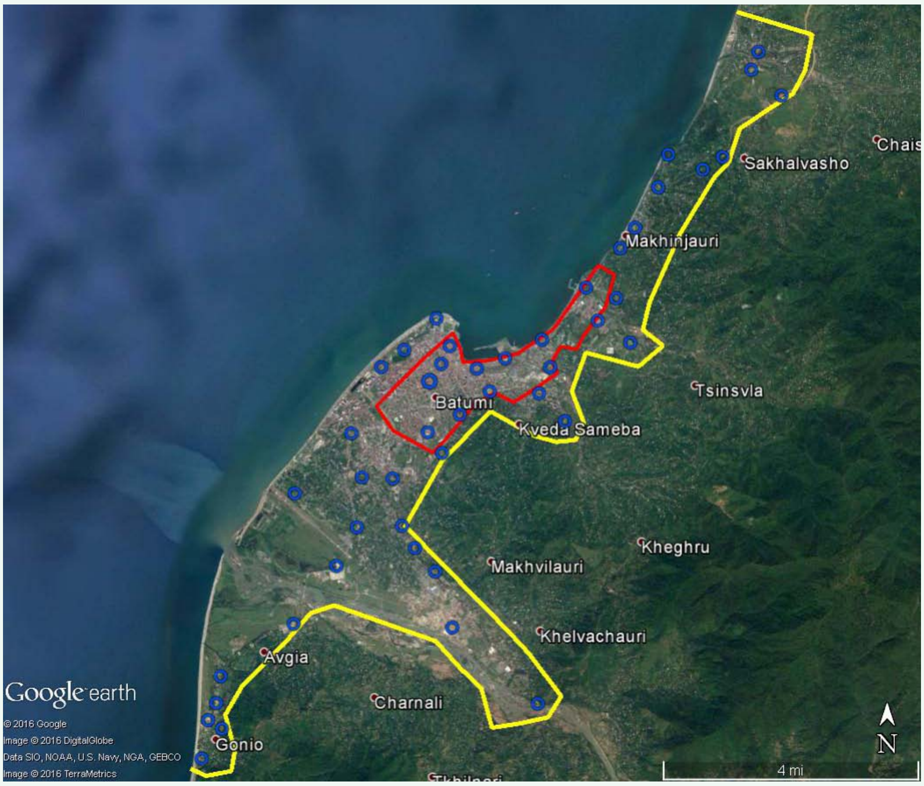

Figure 2 Invasion/Introduction zone (red) and Gap zone (yellow) BioTEMS TIGER model. Blue circles represent recommended surveillance sites. (Base Map: US Dept. of State Geographer © 2016 Google Image Landsat/Copernicus, Data SIO, NOAA, US Navy, NGA, GEBCO).

population should be conducted within the I-zone. The Gap zone consists of ~60 km^2 (including the I-zone) where surveillance sites and control should conducted based on prioritization of resources. From the data of Kutateladze [3], it appears that *Ae. albopictus* is in the G phase of the BioTEMS TIGER model. The Gap zone includes areas where arboviruses could spread through infected mosquitoes. Commensalism of a mosquito species plays an important role of a species having the capacity to invade [24]. One must gather all the relevant evidence and include possibilities when attempting to interdict an invasive species. As can be seen from Figure 2, the Gap zone is a large area that is susceptible to infiltration and breeding by *Aedes* vectors. It is important for medical and public health officials in Batumi to consider implementing monthly mosquito surveillance and control as the season dictates.

Seaports play a critical role in the invasion of *Aedes* vector species, including recruitment of new haplotypes [25]. The possible invasion of mosquitoes and arboviruses through ports, both aviation and maritime, is not a new concept [26]. Focusing control and surveillance efforts primarily on travelers and not including ports of entry does a disservice to the population to whom public health officials are charged to protect. For example, if Miami and Rio de Janeiro had an active ZIKAV surveillance system in place for mosquitoes in the port areas, the chance of finding an infected mosquito would have been increased and IMM could have been initiated sooner. Vaux and Medlock [27], implemented the following surveillance procedures in port areas in the United Kingdom; 1) establish a baseline of mosquito breeding habitats, 2) conduct active surveillance for invasive mosquitoes at the ports, 3) identify appropriate surveillance method suited to port environments, and 4) develop the capability and capacity of Port Health Officers to conduct invasive mosquito surveillance. In addition to surveillance, preventing establishment of invasive species and haplotypes into the port area is critical. BG-Sentinel traps (Biogents, Regensburg, Germany) are very effective in capturing *Aedes* species and can be used for both surveillance and reducing *Aedes* populations. Application of pesticides on ships, cargo, and port areas can reduce the risk of invasion by mosquitoes; however, the continuous spraying of pesticides is expensive and may damage the environment. Low cost and environmentally friendly methods using new pesticide technologies like the ProVector (MEVLABS, Statesboro, US) [28], can be used to lower the risk of the establishment of invasive species while reducing the local mosquito population. Pesticides with mosquito bait, can be delivered using devices hung in structures to reduce the mosquito population without the need for spraying for up to several months [29].

CONCLUSION

Local transmission of DNV, CHIKV and ZIKAV have not been documented in Batumi; however, with the establishment of either or both *Ae. aegypti* and *Ae. albopictus*, the risk is increased. The BioTEMS model provides high resolution information to medical and public health officials in Batumi they can use to assess the risk of invasive mosquito species, associated arboviruses and in the development of an integrated mosquito management plan. It is recommended, if not already in place, continuous active surveillance and control of mosquitoes. For example, expanded surveillance to the north of the port and application of pesticides in the port area can be initiated to mitigate or prevent infected invasive mosquitoes from entering through the port [30]. In addition, epidemiologic surveillance in mosquitoes and humans can be conducted, particularly around air and marine ports and in vehicle maintenance sites along high use roadways.

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