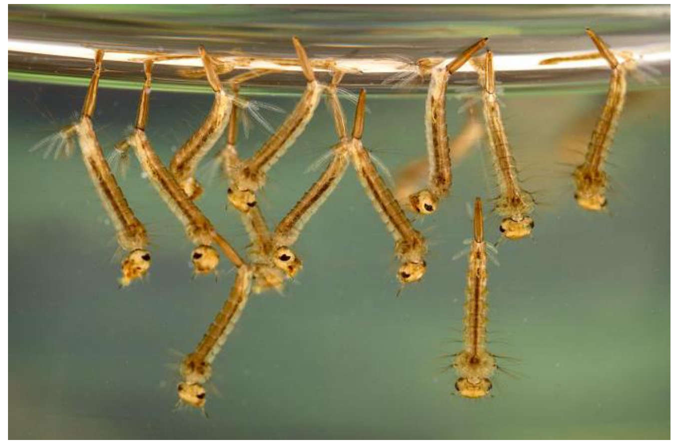

# The Intersection of Phenology and Public Health: Disease Vectors in Arizona

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**USA National Phenology Network**

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# EXECUTIVE SUMMARY

In 2018, in partnership with a Peace Corps Coverdell Fellow in the Master of Public Health program at the University of Arizona, staff members at the USA-National Phenology Network (USA-NPN) began an exploration of the applicability of phenology data and information to the field of public health. A major focus area of the USA-NPN is to create phenology data products and tools to assist human health decision-makers to carry out their work (USA-NPN Strategic Plan 2019). This report provides guidance to the USA-NPN on disease vectors of concern in the state of Arizona, information on the existing tools and resources currently used to predict their activity, and identifies gaps that the USA-NPN may be able to fill. The report provides recommendations to guide future collaborations between the USA-NPN and public health researchers and practitioners in the Southwest.

Phenology, the timing of plant and animal life cycle events, can inform important public health planning and decisions by providing information on anticipated onset of disease vector activity for mosquitoes and ticks. Phenology has many applications to the field of public health, including information on when to expect disease vectors such as mosquitoes and ticks and the start and intensity of allergy season. In this initial exploratory effort, we restricted our scope to the applicability of phenology to disease vectors, namely mosquitoes and ticks, in the Southwest U.S. Through supporting vector surveillance and management efforts, the USA-NPN aims to reduce the burden of vector-borne diseases on the public health community and the public. The purpose of this project was to engage public health researchers and practitioners who serve urban and rural public health agencies to determine their need for phenology data and information. We also assessed how predictive maps, such as those operationalized by the USA-NPN to predict the seasonal activity of insect pests and invasive plants (www.usanpn.org/data/forecasts), could potentially inform disease vector management. If we did find these maps to be feasible and useful to the community, we aimed to uncover the components of an effective model.

This project assessed the needs of public health researchers and urban and rural public health practitioners for phenology information. Project goals included:

- Determine existing applications, resources, and tools for predicting phenology of disease vectors and informing management actions in the southwestern U.S.
- Summarize the existing diseases of concern in the southwestern U.S., and assess how phenology can be used in their management.
- Determine the needs of public health practitioners and researchers for phenology data and information related to their work with vector-borne diseases.

- Determine needs of underrepresented communities for information about vector-borne diseases.

We aimed to understand the gaps in information-sharing amongst researchers, public health practitioners, and underrepresented communities. Beginning in August 2018, we gathered information through phone interviews, online surveys, and in-person discussions with public health practitioners and researchers within Arizona. We recruited participants based on recommendations from well-trusted researchers and practitioners. Our inclusion criteria for practitioners and researchers were those considered as experts in their field, those that were well-established in research and the community, and those that had previously created functional programs/interventions for disease vector work.

We began interviews in January 2019 and included researchers who are serving at the University of Arizona, the Translational Genomics Research Institute (TGen), the CDC, and the Environmental Health Tracking Portal focusing on urban, border, and rural health. We conducted 14 interviews with public health practitioners from June to August 2019. Public health practitioners were located at the Arizona Department of Health Services, the CDC, Maricopa County, and Pima County health departments. We analyzed interview content in preparation for this report from September 2019 to December 2019.

We received input from 17 researchers and 14 practitioners in 31 interviews. From these interviews, we synthesized common information gaps in disease vector surveillance and management and recommendations for addressing these gaps. The first gap identified was the lack of consistent data on both mosquitoes and ticks. The data are collected at low frequencies, sporadic, and at inconsistent locations. Additionally, there is limited understanding of how temperature thresholds and climate affect disease vectors. Some participants mentioned that communication between researchers and practitioners is poor even when there is available data on vectors.

Additionally, there is often little to no communication between states and counties. Other challenges included inconsistent resources, staffing, vector control methods, and duties for different states and counties. There have yet to be any reliable technological applications of predictive models to inform timing of surveillance or treatment activities.

Both researchers and practitioners highlighted key solutions. Multiple researchers mentioned that data on vegetation cover, canopy cover, and flowering of plant species used by mosquitoes could inform mosquito activity and abundance. Multiple practitioners stated forecasting models could improve their work in surveillance and treatment of mosquitoes. Some respondents felt that the best way for the USA-NPN to assist the public health community would be to enhance existing applications and technological programs that are already conducting vector surveillance. To address the poor communication between researchers and public health practitioners at various organizations, some respondents recommended regular conference calls/meetings, workshops, or symposiums. Many also suggested a public project that involves citizen scientists would help collect needed data on activity and abundance of mosquitoes.

In early 2020, we intended to interview library attendees in underrepresented locations of Tucson to determine their needs for information about vectors and vector-borne diseases, their interest in involvement in citizen-science projects, and the resources needed to promote their representation in vector management efforts. Though the coronavirus pandemic interrupted this work in March 2020, we identified potential survey locations and created a survey to interview library attendees on their familiarity with citizen science and their interests in disease vector-related information. To further our understanding of how to engage community members in citizen science efforts, we conducted a literature search to guide the USA-NPN on how to involve underrepresented community members in research and how to best disseminate findings to this audience.

The USA-NPN will use the information from this report to bring together public health practitioners, researchers, and health department representatives to shape robust and relevant tools and resources to support the public health community.

# INTRODUCTION

The USA National Phenology Network (USA-NPN) is an initiative that aims to advance science and decision-making across a diversity of realms, from natural resource management and conservation to public health and human well-being.

In 2018, in partnership with a Peace Corps Coverdell Fellow and Master of Public Health student, Brenda Mbaabu, staff members at the USA-National Phenology Network (USA-NPN) began an exploration of the applicability of phenology data and information to the field of public health. A major focus area of the USA-NPN is the creation of phenology data products and tools to assist human health decision-makers to carry out their work (USA-NPN Strategic Plan 2019).

Phenology has many applications to the field of public health, including information on when to expect disease vectors such as mosquitoes and ticks and the start and intensity of allergy season. In this exploratory effort, we restricted our scope to the applicability of phenology to disease vectors, namely mosquitoes and ticks in the Southwest U.S.

We used a framework of co-production to pursue this integration of phenology and public health to determine the needs of public health practitioners and researchers for phenology forecasts for disease vectors in the Southwest. Co-production is the act of involving stakeholders throughout the project process from defining the project, creating the product, testing the product, and evaluation/monitoring of the project. This research served as that first phase of co-production — connecting with stakeholders, building relationships with them, and understanding their needs for predictive maps.

# BACKGROUND RESEARCH

**Disease Vectors of Interest**

We started our exploration by first identifying the vector-borne diseases of highest concern in the state of Arizona. Vector-borne diseases are infectious diseases transmitted by living organisms between humans and animals. The majority of vectors carry disease-producing microorganisms during a blood meal from a host (human or animal) and later inject it into the new host during their next blood meal. Some common vectors include mosquitoes, ticks, triatomine bugs, flies, and fleas. Globally, vector-borne diseases contribute to 17% of infectious diseases, leading to more than 700,000 deaths annually (WHO, 2019). We decided to focus on mosquitoes and ticks due to their prevalence and the impact of the diseases they carry. Table 1 below highlights vector-borne diseases of concern as well as key information on the disease vectors, their life cycles, seasonal patterns, and control methods.

**Table 1.** Vector-borne diseases, vectors, life cycle information, seasonal patterns, and control methods for vector-borne diseases in Arizona.

| **Vector-borne diseases** | **Diseases vectors** | **Life cycle** | **Seasonality of the disease-vector** | **Control methods** |
|---|---|---|---|---|
| West Nile Virus | Mosquitoes (*Culex Pipiens, C. tarsalis*, and *C. quinquefasciatus*) | Transmits between mosquitoes and birds, people, horses, and other animals. Very rare in cats and dogs.<br><br>Mosquito feeds on an infected bird and acquires virus. Mosquito transmits to humans, horses, and other mammals in the next blood meal. **Mosquito-bird- mosquito cycle.** | Summer through Fall **<u>with peak in Aug</u>** | • Eliminate standing water<br>• Larvicide, adulticides, and insecticides<br>• Treat storm drains with larvicides |
| St. Louis Encephalitis | Mosquito (*C. pipiens* and *C. quinquefasciatus* in the east, *C. nigripalpus* in Florida, and *C. tarsalis* and members of the *C pipiens complex* in western states.) | Transmits in wild birds, mosquitoes, people, horses, and other animals<br><br>Mosquito feeds on an infected bird and acquires virus. Mosquito transmits to humans and mammals in next blood meal. **Mosquito-bird-mosquito cycle**. | Late summer or early fall (US). **<u>Year round</u>** (southern states) | • Eliminate standing water<br>• Larvicide, adulticides, and insecticides |
| Chikungunya Virus | Mosquitoes (*Aedes aegypti* and *A. albopictus* mosquitoes) | Mosquitoes and people.<br><br>Mosquito feeds on an infected person. Mosquito transmits the virus to other | Seasonality similar to dengue; hot and wet conditions favor transmission; first chikungunya cases occur during the relatively cool and dry winter months | • Eliminate standing water<br>• Larvicide, adulticides, and insecticides |

| | | | | |
|---|---|---|---|---|
| | | humans in blood meal. **Mosquito-human- mosquito cycle**. | (**<u>Sept-Dec</u>**) when dengue cases are also generally low, but transmission across the region took off with the warmer and wetter summer weather (**<u>Jul</u>**) | |
| Dengue Fever | Mosquitoes (*A. aegypti* and *A. albopictus*) | Mosquitoes and people<br><br>Mosquito feeds on an infected person. Mosquito transmits the virus to other humans in blood meal. **Mosquito-human- mosquito cycle**. | Dengue cases showed region-specific peaks for Southeast Asia (Jun, Sep), South Central Asia (Oct), South America (Mar), and the Caribbean (Aug, Oct). Travel-related dengue exhibited annual oscillations with several epidemics occurring during the study period **<u>(Mar - Oct)</u>** | • Eliminate standing water.<br>• Larvicide, adulticides, and insecticides |
| Zika virus | Mosquitoes (*A. aegypti* and *A. albopictus*; also a dozen other *Aedes* species, as well as *Anopheles coustani*, *C. perfuscus*, and *Mansonia uniformis)* | People and mosquitoes<br><br>Mosquito feeds on an infected person. Mosquito transmits the virus to other humans in blood meal. **Mosquito-human- mosquito cycle**. | Typically brought in by travelers. **<u>Difficult to see a pattern</u>** because equatorial regions experience less seasonality than non-equatorial regions, where changes in temperature have a strong impact on the mosquito population. | • Eliminate standing water.<br>• Larvicide, adulticides, and insecticides |
| Yellow Fever | Mosquitoes (*A. aegypti*) | Humans, primates, intermediate semi-domestic mosquitoes of the *Aedes* species.<br><br>Mosquito feeds on an infected person. Mosquito transmits the virus to other humans in blood meal. **Mosquito-** | Typically brought in by travelers. Depending on where a traveler goes, the pattern is different. Jan–May, with a peak incidence in Feb - Mar in South America. In Africa, Jul–Oct. | • Eliminate standing water<br>• Larvicide, adulticides, and insecticides |

| | | | | |
|---|---|---|---|---|
| | | **human- mosquito cycle**.<br><br>The jungle type involves transmission through non-human primates. **Mosquito-primate-mosquito cycle.** | | |
| Malaria | Mosquitoes (Female *Anopheles* spp.) | People and mosquitoes<br><br>Mosquito feeds on an infected person. Mosquito transmits the virus to other humans in blood meal. **Mosquito-human- mosquito cycle**. | Typically brought in by travelers. Major transmission of malaria follows the Jun – Sep rains and occurs between **Sep - Dec** while the minor transmission season occurs between Apr – May following the Feb – Mar rains. | • Eliminate standing water<br>• larvicide, adulticides, and insecticides |
| Rocky Mountain Spotted Fever | Ticks (*Rhipicephalus sanguineus* in Arizona; *Dermacentor variabilis* and *Dermacentor andersoni* in other parts of the United States.) | Humans become infected through the bite of an infected tick<br><br>Tick is infected with bacteria. Tick transmits the virus to other humans in blood meal. **Tick-human-tick cycle**. | In Arizona, majority of RMSF cases are spread by brown dog tick and cases occur year-round with peak months of illness onset **Apr - Oct**. | • Remove organic debris in the yard<br>• Treat dogs with tick products (incl. collars)<br>• Exterior and interior treatments with granules, residual sprays, and dusts |

Mosquitoes

Mosquitoes are of great concern within the state of Arizona, particularly because they carry debilitating and potentially fatal diseases such as West Nile Virus and Saint Louis Encephalitis. Both West Nile Virus and Saint Louis Encephalitis are mostly spread through the bite of the *Culex* species of mosquitoes, though they can also spread through blood transfusions, organ transplants, and from mother to child during pregnancy, delivery, or breastfeeding. *Culex* mosquitoes typically bite from evening to early morning.

Annual cases of St. Louis Encephalitis are usually fewer in number than cases of West Nile Virus. Last year alone, there were more than 2,000 cases of West Nile Virus nationwide, while there have been less than 100 cases of St. Louis Encephalitis since 2008 (CDC, 2019). There were 392 cases of West Nile Virus in the Southwest of the United States with 176 of those cases in Arizona (CDC, 2019, AzDHS, 2019). In addition, the number of mosquito samples testing positive for both diseases has increased in recent years. Just in July 2019, 87 mosquitoes tested positive for West Nile virus compared to only seven samples in July 2018. Those that tested positive for St. Louis Encephalitis amounted to 53 positive tests as opposed to only two positive samples in July 2018 (CDC, 2019).

Mosquito-borne diseases are highly directed by changes in the climate. Temperature, precipitation, and other climatic conditions guide the breeding, reproduction, development, and survival of mosquitoes. Additional factors that affect prediction models include complex interactions between hosts and mosquitoes, which are mediated by mosquito susceptibility to infection, climate, and host properties. These factors further vary among mosquito populations, pathogens, and vector development rates. West Nile Virus may be more common in dry years because too much water flushes larvae out of storm drains. Also, birds, which are amplifier hosts for West Nile, may be more likely to cluster at water sources and increase transmission rates of the virus. Dengue Fever and Chikingunya may be more common in wet years, which create many small water sources used by the disease-vectors of these viruses.

Human activities such as excess watering, unmaintained pools or fountains, ponds, sewers, irrigation, and discarded containers with standing water can create habitat for mosquitoes such as *Aedes aegypti*, *Culex pipiens* and *Culex tarsalis* (Brown, 2015).

Ticks

Ticks are also vectors of great concern in Arizona with more than 25 species recorded in the state. The most common species encountered by humans are the brown dog ticks, *Rhipicephalus sangiuneus.* This species also carries the most common tick borne disease in Arizona, Rocky Mountain Spotted Fever (RMSF). RMSF is caused by the bacteria *Rickettsia rickettsii* that is transmitted to humans through the bite of an infected tick. Most cases of RMSF occur between the months of April and August although tick activity occurs year round. Most common cases of RMSF are found in areas with many free-roaming dogs and severe tick infestations. If not treated within the first 5 days of symptoms, cases can become rapidly fatal with fatality rates ranging between 20-80% (Maricopa.gov, 2019). This disease used to be rare in Arizona although it has become more common in the last decade. Between 2003 and 2012, there were over 250 RMSF cases and 19 deaths. During 2010-2011, the RMSF rate in Arizona was approximately 200 times that of the national average (Maricopa.gov, 2019).

Tick surveillance programs and applications are not as extensive as those for mosquitoes. The primary means of surveillance for the brown dog tick is assessing the tick burden on dogs by counting and categorizing the species of ticks. Dead ticks are also tested at specialized CDC laboratories for *R. rickettsia* and recorded in a database. This database provides robust information on geographic locations where infections are likely to occur. An environmental assessment is also conducted by trained CDC and AzDHS personnel, the tribal animal control team, and volunteers to give a rough estimate of the population density of ticks in a given area (Walker, 2018).

One tick-borne disease prevention program that has gained traction is the RMSF Rodeo, which the Center for Disease Control and Prevention (CDC) initiated in 2012 in Arizona. This community-based integrated tick-bite prevention campaign started in a tribal community with high rates of RMSF. Each year, long-acting tick collars are placed on dogs in the communities, environmental acaricides are applied in yards, and residents are educated on proper animal care practices such as spaying, neutering, and tethering. After the first two years of this program, 3% fewer dogs showed visible tick infestations and significantly decreased presence of ticks in the surroundings as opposed to non-project communities (Drexler, 2014).

**Gaps in Prediction and Phenology**

We explored the literature to determine how phenology, or seasonal life cycle events, are relevant to the surveillance and control of disease-vectors. We used search terms including "prediction model + disease vectors + Arizona + California + U.S. Southwest." We paid particular attention to papers by researchers whom we also interviewed in our project. In discussions with public health practitioners and researchers about predictions of disease-vector activity, we observed that there is a large interest in long-term projections related to disease-vector activity and ranges. While our focus in this project was on short-term predictions of disease-vector activity on the scale of days to weeks, we recognize the potential of phenology information to inform long-term projections as well. Here we provide a summary of existing information about how climate information has been used to inform long-term projections disease-vectors activity in the Southwest for mosquitoes and ticks.

Mosquitoes

The Building Resilience Against Climate Effects (BRACE) framework, created by the CDC, is a five-step process that allows health officials to develop strategies and programs to help communities prepare for the effects of climate change (www.cdc.gov/climateandhealth/BRACE.htm). The Arizona Department of Health Services, in collaboration with the University of Arizona CLIMAS team, have used this framework for extensive work using climate predictions to estimate future infectious disease risk in Arizona. These predictions focus primarily on mosquito borne diseases such as Valley Fever and West Nile virus.

The BRACE Framework used daily temperature and precipitation data to create simulation models that estimate the future abundance of the West Nile virus vectors in Arizona. The parameters were set using temperature-dependent growth and death rates. They used precipitation to understand the best habitats for the early stages of mosquito development. However, using precipitation as a predictor came with limitations since mosquitoes are common in larger, more permanent bodies of water. Due to the relationship between temperature and mosquito development, future vector abundance was projected using data from global climate models (Roach, 2017).

Based on those projections, there were two primary patterns of West Nile Virus mosquito abundance. First, there is a lengthened season with mosquito abundance beginning earlier in the year and extending longer into the fall. Secondly, cooler cities that also have higher elevation such as Flagstaff and Nogales show a single period of increased abundance while hotter cities have a bimodal curve with two seasons of increased abundance of *Culex* spp. abundance. The bimodal curves showed a mid-summer decrease as temperatures reach and exceed mosquito survival thresholds. However, for the cooler cities, there is no bimodal curve (Roach, 2017).

Another 2015 University of Arizona study took into account the effects of climate change on disease vectors. The study included a dynamic simulation model for *Culex* spp. mosquitoes, which can be utilized as a tool to understand the future risk of West Nile virus due to the effects of climate change. The model was parameterized with temperature-dependent *Culex* mosquito growth and death rates. In addition, in this model, they also used downscaled daily weather data to project mosquito population dynamics for various places within the United States (Brown, 2015).

The results predicted *Culex* spp. mid-summer abundance to increase in areas of higher latitudes and decrease in areas of lower latitudes. Cool regions showed an increased likelihood of vector abundance while hotter areas had a decreased mid-summer abundance due to exceeded temperature thresholds for vector development. They also predicted an increase in the number of weeks of mosquito activity. These findings of a lengthened vector abundance season echo those found by the projections of the CLIMAS group.

*Key recommendations for using climate information to predict mosquito activity*

Recommendations from the CLIMAS mosquito study were the incorporation of adaptation to temperature, changes in seasonality, and egg desiccation resistance of the species of interest in prediction and projection maps. Researchers have found that egg desiccation can prevent development and limit *Aedes aegypti* distribution. This egg desiccation is driven by climate, namely the dry seasons. This study suggests that future models would need to consider how adaptation in egg desiccation resistance could lead to larger species abundance (Brown, 2015).

The BRACE Framework points to using daily temperature and precipitation to create simulation models that estimate vector abundance. Models would also need to set parameters using temperature dependent growth and death rates. Additionally, global climate models are useful in projecting future abundance, taking into account the effect of temperature and precipitation on mosquito habitat and development. These models would be further enhanced by a phenological approach in which the seasonal timing of disease vectors is predicted.

<u>Ticks</u>

A study of ticks used ensemble species distribution modeling to understand the ideal climatic conditions for ticks. The researchers' interests were in *Ixodes pacificus* in the western region of the U.S. and *Ixodes scapularis* in the eastern region of the U.S., the main tick species that carry Lyme disease. The researchers gathered data on locations in California where two or more tick samples were collected from vegetation. They then created distribution models with restrictions on land cover classes where ticks are usually found such as forests, grass, and scrub-shrub and riparian since these were the land cover classes where the samples were collected. In these models, phenology came into play as they took into account the effects of climate predictor variables such as cold-season temperature, seasonal precipitation, humidity, vapor pressure, summer day length, growing degree days, and temperature in the warmest months of the year, and low-temperature variability during the year (Eisen, 2018).

The results showed that locations with warm and wet winters are most likely to harbor ticks. They found that suitable areas for *Ixodes pacificus* breeding and development are those with temperatures above 0 degrees Celsius during the coldest period of the year. The likelihood for tick activity in these areas increases if precipitation ranges from 400 to 800 mm during the coldest period. Based on their models of coastal California, the northern coast and the western Sierra Nevada foothills have the highest likelihood of *Ixodes pacificus*.

The study mentioned that despite their usefulness, species distribution models have undergone ample criticism. One of the criticisms is that models assume that the climate niches being modeled are affected only by physical, non-interactive factors distributions. However, niches are often affected by interacting factors that can be hard to predict. For example, animal host mobility in territories can impact species' distributions. It can be hard to predict future plant and animal interactions using current observations as there might be other unmeasured confounding factors that affect these relationships.

An additional criticism is that the temporal and spatial scale of the data are insufficient to depict climate niches. The lack of detail in data especially affects the larger picture because models usually use downscaled climate data from large databases. Lastly, models vary significantly from each other making them seem unreliable. Models differ so much from each other that relying on only one model is not useful.

These criticisms speak to the need for more phenological data to aid in understanding how the occurrence of ticks could be associated with the changes in seasons and climates. Tick surveillance is not as well researched as mosquitoes; for there to be successful future endeavors, phenology will need to be a key part of the research.

*Key recommendations for using climate information to predict tick activity*

In the case of ticks, prediction models would need to take into account land cover where ticks are usually found such as forests, grass, and scrub. Additionally, robust models would have to consider the effect of climate predictor variables such as cold-season temperature, seasonal precipitation, humidity, vapor pressure, summer day length, growing degree days, temperatures of the warmest months, and annual low-temperature variability. Although this information speaks to current and future abundance of these species, how this might affect disease prevalence is not known.

**Gaps in Vector Surveillance**

Next, we sought to understand the current challenges and gaps that exist in tracking the activity and abundance of mosquitoes and ticks.

<u>Mosquitoes</u>

Researchers at the Center for Disease Control and Prevention (CDC) conducted a survey in 2016 that showed a gap in county-level mosquito distribution data in the United States. This led to heightened surveillance and collection of *Aedes aegypti* and *Aedes albopictus* samples by local health departments personnel, even in locations where there had been no records of these species in previous decades. The recommendation was continuous surveillance of these species to understand whether they had established new habitats. Modelling the distribution of these vectors was proposed as a solution to these gaps (Hahn, 2017).

We reviewed the outcomes from the Worldwide Insecticide Resistance Network meeting and identified gaps including a lack of human, financial, and infrastructural capacity for mosquito control. The outcomes mentioned that program implementation and interventions do not include active community engagement and lack public acceptance. Strategies proposed include biological and chemical advancements in research such as novel larvicides, spatial repellents, autocidal gravid ovitraps, attractive toxic sugar baits, insecticide treated clothes, and genetic control of mosquito species (Achee, 2019).

In a different study conducted by the University of California, Berkeley, authors reviewed current gaps in epidemiology in the context of mosquito borne diseases. This study recommended vector control efforts that include community participation that is sustained annually and in between epidemics particularly in areas of high disease risk. Community participation methods would need to follow evidence-based practices and include active entomological surveillance (Eisen, 2018). These suggestions are of interest to the USA-NPN particularly because of the involvement of citizen scientists in data collection through their *Nature's Notebook* plant and animal phenology program (www.naturesnotebook.org).

Ticks

In order to identify the gaps in surveilling tick-borne diseases, we examined the future recommendations of various studies about tick activity. One study indicated a need for more precise measurements of abiotic and biotic factors related to the occurrence of ticks and pathogens. These factors include humidity, open areas vs. forests, ground floor temperatures, canopy cover, and wind shelter based on tree density (McCoy, 2013).

Additionally, other studies have noted that working with ticks is especially difficult due to their host specialization over ecological and evolutionary time periods. It is difficult to understand tick patterns and frequencies of attaching to hosts. In addition, ticks have complex genetics and long life cycles and for this reason, they are difficult to maintain under laboratory conditions. The recommendation for preventing tick-borne diseases is a greater focus on host diversity and attachment patterns (Institute of Medicine, 2011).

In one study conducted by the Institute of Medicine Committee on Lyme Disease and other Tick-Borne Diseases, a panel of stakeholders shared their views on research gaps and priorities in understanding tick-borne diseases. First, a gap exists between textbook criteria of diseases and clinical practice in diagnosis of tick-borne diseases. Some cases, which are reported by epidemiologists as "probable", might actually be "confirmed" cases. The recommendation for this gap is to create better agreement among stakeholders on definitions of diseases and diagnosis criteria.

Secondly, there is a gap between current research and information given to clinicians. The panel recommended a multicenter network where clinicians, researchers, laboratories, and patient care facilities can communicate best clinical evaluation and treatment strategies. Third, as far as prevention is concerned, vaccines alone are not a viable solution for the future of tick-borne diseases. There needs to be more research on the complex ecological factors affecting ticks, targeted surveillance of geographical changes in tick range, and an understanding of the human behavioral factor in tick activity. Finally, one of the most common gaps was a poor comprehension on the part of the patient of the geographical distribution and magnitude of Lyme disease (Hahn, 2017).

# EXISTING RESOURCES IN DISEASE VECTOR WORK

**Existing Programs and Applications**

Nationally, there are multiple organizations working together to conduct vector mitigation efforts. These include surveillance efforts to document presence of disease, and vector control efforts that require knowing when disease vectors will be active. Such bodies include but are not limited to the Center for Disease Control and Prevention (CDC), state/county health departments, academic institutions, and local public health agencies. Through various collaborations, they conduct daily surveillance of vector-borne diseases and try to address gaps in current programs.

Information and data sharing in the public health system is distributed differently amongst the various tiers. The components of the American public health system (Figure 1) range from federal agencies such as the CDC to local organizations such as non-profit organizations. For this project, we focused our attention on applications and programs created by all levels of the public health system.

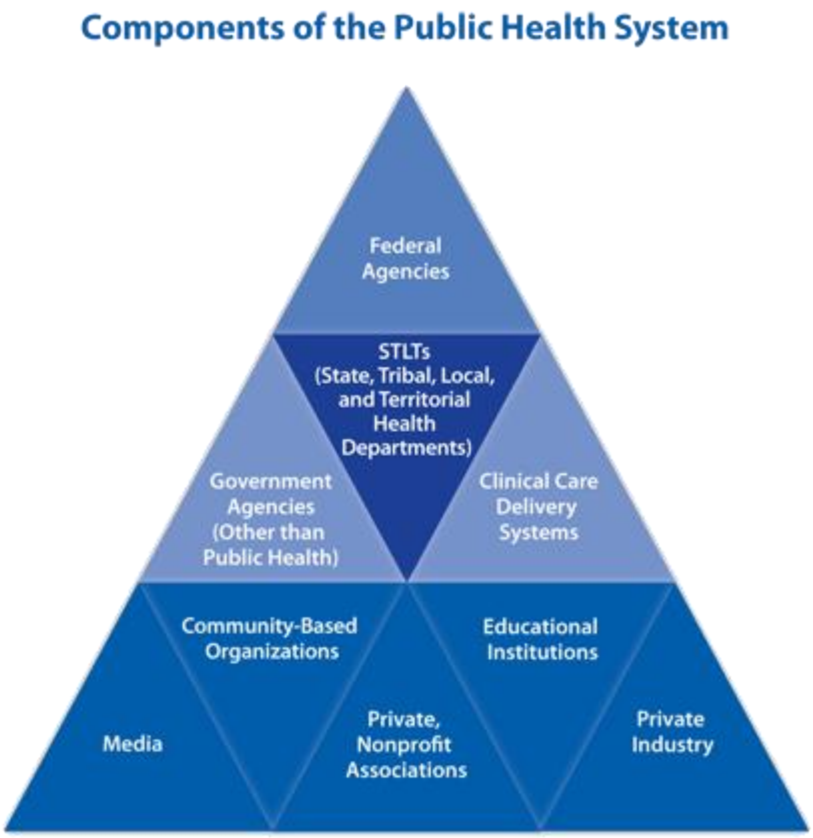



**Figure 1**. Pyramid depicting the United States' public health system. The tier ranges from the top, federal agencies (e.g. CDC), state health departments at the middle level, and community institutions at the bottom level (Chapman, 2013).

We also identified local vector surveillance programs within Arizona in our preparation process. The goal was to identify potential collaborators from whom we could learn how to integrate phenology in public health. We summarize these programs in table 2 below.

**Table 2.** Vector surveillance programs in Arizona.

| **Vector of Interest** | **Program Name** | **Affiliated organization** | **What does it do?** | **Data Storage URL** |
|---|---|---|---|---|
| Mosquitoes | Maricopa County Mosquito Surveillance Program | Maricopa County Department of Public Health | Monitors hundreds of routine sites. Deploy over 750 mosquito traps to these areas every week. Set up traps based on complaints received. Generally apply treatment 7-10 days post-rain. Treatments (chemical larvicides, gambesia fish) last 180 days | https://www.maricopa.gov/2467/Mosquitoes-in-Your-Neighborhood |

| | | | | |
|---|---|---|---|---|
| Mosquitoes | Fight the Bite! | Maricopa County Department of Public Health | Informs the public on how to fight mosquito related diseases. Offers information about prevention, disease symptoms, disease information, how to contact a healthcare professional, traveler information, and vector information. | https://www.maricopa.gov/1608/Mosquito-Related-Diseases |
| Mosquitoes | Integrated Mosquito Management Program | Vector Disease Control International (VDCI) | 4- Pronged approach to target all phases of mosquito life cycle. Include public education, vector surveillance, disease testing, and larval/adult mosquito control. | By approval http://www.vdci.net/data-collection-gis-mapping-reporting |
| Ticks | The Tribal Rocky Mountain spotted fever (RMSF) prevention program | Arizona Department of Health Services and San Carlos Animal Control | Conduct environmental tick control and surveillance. They conduct community outreach and education. | MEDSIS - https://www.azdhs.gov/preparedness/epidemiology-disease-control/infectious-disease-services/index.php#medsis-home<br>AzDHS - https://www.azdhs.gov/preparedness/epidemiology-disease-control/index.php#data-stats |

However, technological applications seemed to be much more diverse and connected to not only national bodies but also international efforts. We highlight technological applications identified for vector surveillance in Table 3 below. As is evident, mosquito surveillance in Arizona is well established with specific technology to meet its needs. We could not find software or technology specifically geared towards surveillance of ticks within Arizona.

**Table 3.** Technology used in vector-surveillance (2018)

| **Vector of Interest** | **Website/App. title** | **Affiliated organization** | **What does it do?** |
|---|---|---|---|
| All Vectors | Arizona Health Alert Network | Arizona Department of Health Services | Distributes important public health alerts to public health officials and healthcare professionals. |
| All vectors | National Notifiable Diseases Surveillance System (NNDSS) | CDC | This tool is used by public health practitioners to monitor, control, and prevent about 120 diseases. Receives, secures, processes, and provides nationally notifiable infectious diseases data to disease-specific CDC programs. |

| | | | |
|---|---|---|---|
| All Vectors | National Environmental Public Health Tracking Network | CDC | Brings together health data and environment data from national, state, and city sources and provides supporting information to make the data easier to understand. |
| Mosquitoes | Mosquito Study Map | Pima County Department of Health | Map depicting where mosquito surveillance is taking place. |
| Mosquitoes | ArboNet System | CDC | Maintains data on arboviral infections among presumptive viremic blood donors, veterinary disease cases, mosquitoes, dead birds, and sentinel animals. |
| Mosquitoes | ArboAZ | Arizona Department of Health Services | Gathers data on year to date mosquito surveillance in Arizona. Reported by county, tribal, and local vector control partners. |

**Resources for Predictions**

Table 4 below highlights different programs and research institutions that have undertaken vector prediction efforts in the U.S. and Arizona. As is evident, mosquito prediction has had more attention than other vectors of interest.

**Table 4.** Vector prediction programs in U.S. and Arizona.

| **Vector of Interest** | **Prediction Program** | **Affiliated organization** | **What does it do?** |
|---|---|---|---|
| All Vectors | Epidemic Prediction Initiative - *Aedes Challenge* | CDC | This is an open forecasting challenge to predict the monthly presence of vectors in a subset of U.S. counties during the 2019 calendar year. |
| All Vectors | National Center for Emerging and Zoonotic Diseases | CDC | Research to identify suitable climatic conditions and habitats for ticks. |
| Mosquitoes | BRACE framework | CDC, Arizona Department of Health Services, and the University of Arizona | A resource to health departments to aid in the development of adaptation plans specific to their communities. |

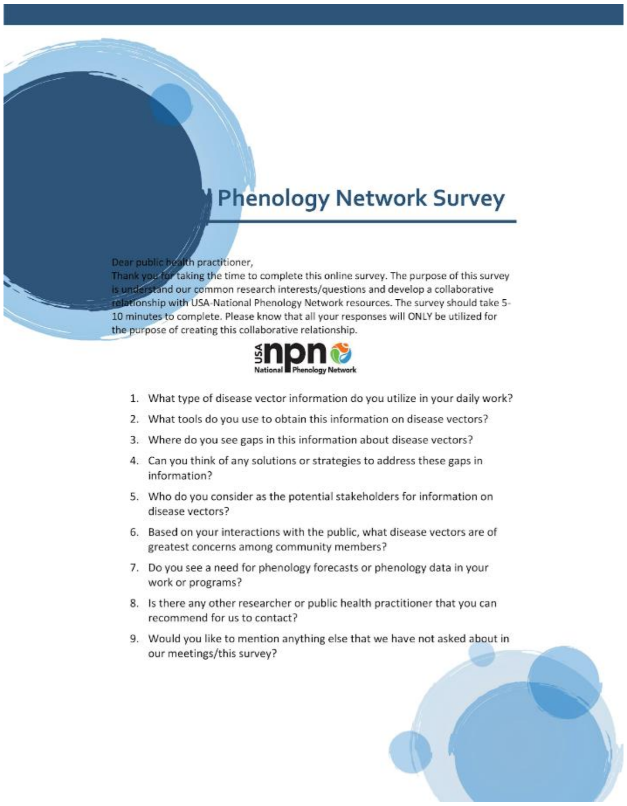
# PUBLIC HEALTH NEEDS ASSESSMENTS RELATED TO PHENOLOGY

**Data collection**

After the completion of the background research, we created needs assessment surveys (Fig. 2) to find out how phenology could be useful to researchers and practitioners in their work. We identified participants for key informant interviews through recommendations by well-established researchers and practitioners at the University of Arizona as well as those we identified during our background research of vector control applications and programs. We also included CDC input in order to represent all the realms of the public health system in our analysis.

We completed an IRB application to ensure that the survey questions were ethical and that we considered participants' rights and welfare. Our goal was to have at least 10-12 practitioners complete the surveys.

After multiple email recruitment messages, six participants stated they were willing to complete the online survey in Google Forms, and we received four responses. We exported these responses to a spreadsheet that was only accessible by research personnel. The majority of the participants expressed interest in either in person interviews or phone conversations. The phone interviews allowed an understanding of both content and contexts that were not fully reflected in the online surveys. In the end, we interviewed 17 researchers and 14 public health practitioners for a total of 31 responses. We stored notes from these conversations in USA-NPN's secured Basecamp project management software.



Phenology Network Survey

Dear public health practitioner,
Thank you for taking the time to complete this online survey. The purpose of this survey is understand our common research interests/questions and develop a collaborative relationship with USA-National Phenology Network resources. The survey should take 5-10 minutes to complete. Please know that all your responses will ONLY be utilized for the purpose of creating this collaborative relationship.

1. What type of disease vector information do you utilize in your daily work?
2. What tools do you use to obtain this information on disease vectors?
3. Where do you see gaps in this information about disease vectors?
4. Can you think of any solutions or strategies to address these gaps in information?
5. Who do you consider as the potential stakeholders for information on disease vectors?
6. Based on your interactions with the public, what disease vectors are of greatest concerns among community members?
7. Do you see a need for phenology forecasts or phenology data in your work or programs?
8. Is there any other researcher or public health practitioner that you can recommend for us to contact?
9. Would you like to mention anything else that we have not asked about in our meetings/this survey?

**Figure 2**. The survey tool that we utilized for our interviews.

**Key Findings**

We split out our results for analysis into two groups, researchers and practitioners and assessed responses for common themes.

<u>Researchers</u>

*Current gaps in disease vector research*

We interviewed sixteen researchers associated with the University of Arizona and one researcher associated with the University of Colorado who we included due to her extensive research on the mosquito species, *Culex tarsali*s, a potential species for future prediction models.

One common gap identified was a lack of geographical, temporal, and phenology data on vectors, particularly mosquito species. Moreover, the available data are collected at low frequencies, sporadic, and not surveilled consistently at the same places. In addition, not much is known about climate-related thresholds for disease-vector activity; there are no growing degree day models for the brown dog tick although there are implications of climate driving tick activity.

Moreover, there is no threshold information for *Aedes aegypti*, *Culex tarsalis*, and *Aedes vexans* mosquito species.

Some participants mentioned ongoing work to collect data on vectors. However, communication of these data is poor. There is little to no state-to-state communication, though each state is doing their own modelling and surveillance. In addition, the data that are being collected related to public health more generally are difficult to obtain from researchers and not publicly available. For example, one respondent indicated that there has been extensive research on the predicted range expansion of allergens like ragweed; however, much of this research does not find its way to the public health community. This means that fellow researchers and community members are not able to create fruitful collaborations. Others felt that there is a lack of use of citizen science, which could be beneficial to researchers.

*Potential areas of collaboration with researchers*

One potential area of collaboration mentioned was a better understanding of the impact of vegetation cover, canopy cover, and flowering plants on mosquito abundance. Two researchers mentioned they had submitted an NIH proposal that focused on the link between vegetation cover and mosquito abundance. They were trying to understand whether greater levels of tree cover lead to earlier mosquito activity. They stated that flowering plants provide food for male mosquitoes, which are nectar feeders. One opportunity that emerged is for the USA-NPN to use *Nature's Notebook* data to understand the relationships between plant species and increased mosquito populations.

Another common need we heard from researchers is the creation of forecasting models for the vectors of interest. One researcher is currently working on developing climate-related thresholds for *Culex* species to inform Vector Control when to treat mosquitoes. Her long-term goal is an app that Vector Control can use to time treatment activities. Researchers see predictive information as useful for health departments especially to know when to put out traps. Suggested species for predictive models are *Culex tarsalis* and *Aedes vexans* because their life cycles are regulated by precipitation. Participants stated *Aedes aegypti* would be difficult to forecast because it makes use of artificial, human-created water sources such as small containers of water, water storage tanks etc. and is therefore less regulated by precipitation.

Some participants felt that the USA-NPN could be most effective by supporting existing applications and technological programs related to vector surveillance. These participants expressed that there are many researchers and modelers that seem to be "re-inventing the wheel" where it would be more feasible to collaborate with a pre-existing effort. Applications and programs mentioned include the Kidenga, NextDoor app, and the CDC's Environmental Public Health Tracking Network. Mosquito modeling efforts have been conducted in other states, such as Texas (Evans, 2015), to predict the risk of West Nile Virus. Perhaps these other technology-based programs can guide our own modeling efforts.

Participants recommended regular conference calls between state surveillance teams to tackle the issue of poor communication. Participants suggested that data sharing should be more deliberate rather than coincidental. They also suggested a publicly available database with information on species distribution and life cycle observations, which would make it easier for people to research the topic. Lastly, they recommended a public project that involves citizen scientists in the monitoring of vectors.

### Practitioners

#### *Current gaps in disease vector information*

We conducted interviews with fourteen public health practitioners. Among practitioners, a range of gaps were highlighted. Firstly, there have yet to be any reliable technological applications or predictive models for activity of disease vectors. There have been successful efforts in the past but they did not endure for a long term. Challenges have included a lack of funding and modeling expertise. The Environmental Public Health Tracking Network is one existing platform which could be improved with additional disease vector information (Evans, 2015).

Practitioners noted there is a gap in geographical and temporal data on vectors, particularly ticks. Some practitioners mentioned that the data gaps are always changing each year and are often unpredictable. This could be the reason why there is inconsistency in data countrywide.

Practitioners also mentioned a lack of efficient communication between counties and other organizations. Surveillance is taking place on humans, animals, and mosquitoes but there is not a lot of communication taking place between county, state, and federal agencies and organizations. There is extensive work being done by mosquito control entities ranging from public health agencies and vector control programs to public works, however they are not sharing their work. Some practitioners mentioned that there are monthly conference calls with county and state health departments. While the discussions are usually about recent occurrences of diseases, rarely do they talk about survey methods, gaps in knowledge, and potential solutions to resolve these gaps.

Other practitioners noted that health departments do not always have consistency with the work that they do. Not all departments utilize the same vector control tools. Health departments with more resources, funds, and staffing are able to do more extensive work than smaller or more rural health departments. For example, in one county there might only be six staff members whereas another county might have 60 staff members. For this reason, there is large variability in the capacity and specialization of duties conducted.

Figures 3-5 below depict the distribution of data collected or both practitioners and researchers combined. Among those asked whether prediction models would be useful, the majority of the participants reported that they would be useful, as is evident in Figure 3 below. Among those who responded to our question about the length of time that would be ideal for a predictive model, all participants indicated that they would want information 2-4 weeks ahead of time. They all preferred the spatial scale of the county rather than regional or state.

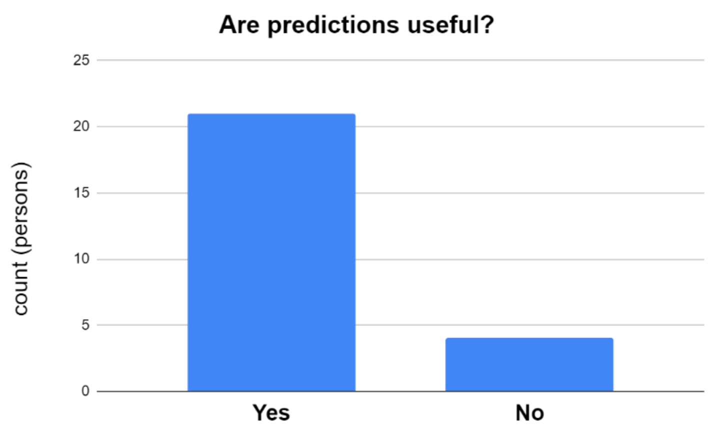



**Figure 3**. Answers to the needs assessment question, “Do you see a need for phenological forecasts or phenology data in your work or programs?”

Most stated the primary gaps in disease vector work are in the quality and frequency of data (Figure 4). Thirteen researchers and eight practitioners expressed the usefulness of prediction models to their work. Two researchers and two practitioners said that prediction models would be problematic. The responses mentioned that data were sporadic, not collected in the same places, were hard to access and use, and were insufficient. There were equal distributions between those who identified communication and knowledge as the major gaps. The knowledge category includes those who mentioned the need for more information on environmental and climatic conditions that guide vector activity. The category “other” includes those who mentioned the gaps in funding, resources, and staff members.

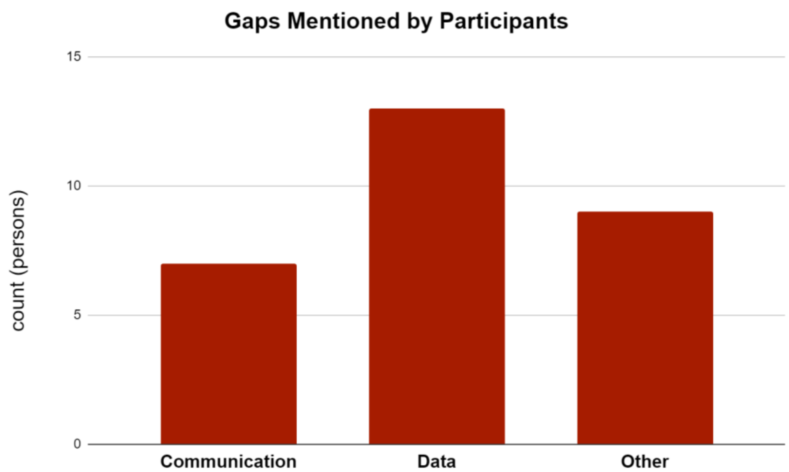



**Figure 4.** Answers to the needs assessment question, “Where do you see gaps in information about disease vectors?”

Twelve participants gave information about what they perceived to be community member concerns related to disease vectors. A majority mentioned that most community members wanted to know if this year would be a “bad year” as far as disease was concerned and what the impact would be in their own neighborhood (Figure 5).

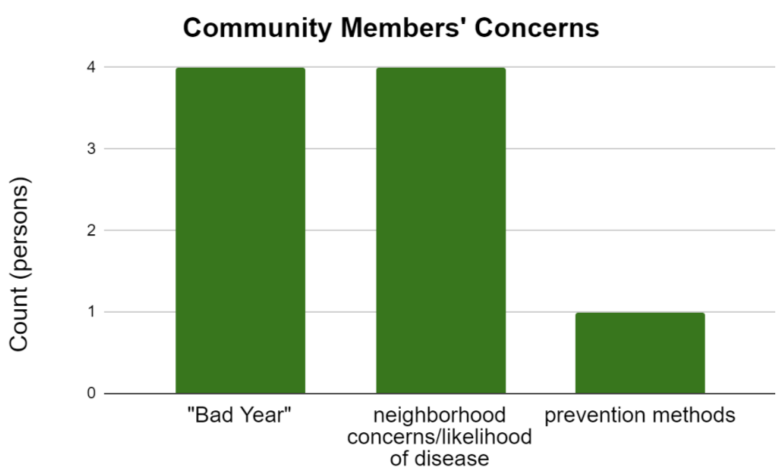



**Figure 5**. Answers to the needs assessment question, “Based on your interactions with the public, what disease vectors are of greatest concern among community members?”

Although not depicted in Figure 5 above, some practitioners mentioned that language barriers are a gap in the messaging of the models and data to community members. Messages about vector distributions and abundance need to be culturally appropriate, confidential, and avoid stigmatizing communities.

*Potential areas of collaboration*

While it is not a topic related to disease vectors, the need for predictive information about pollen and allergy season was a common theme in our discussions with practitioners. Pollen data can be useful in predicting conditions that can increase the risk of respiratory diseases such as asthma. Maps that indicate times of highest risk could help practitioners to begin prevention strategies. One state-level representative mentioned that predictive information about pollen could be included on the Arizona's state-level node of the Environmental Public Health Tracking Network for public access.

Two-thirds of participants stated that mosquito prediction models would be useful in their work, and recommended predictions with a 2-4 weeks prediction lead-time. Some practitioners highlighted that there have been attempts to create predictive models and forecasts, which suffered from a lack of funding and modeling expertise. For this reason, they are open to any predictions that the USA-NPN could offer. They mentioned that local, county level predictions that incorporate vector abundance, presence, and development rates per county would be best. County level data would allow them to observe unusual occurrences and trends over time in certain parts of the state.

Participants stated that any messaging that might label certain locations as "hot spots" might create stigma. One group of practitioners also expressed concerns that if they labeled certain areas as at high risk for mosquito activity, people outside those high risk areas would have an inflated (and possibly incorrect) sense of safety from vector-borne diseases.

Other practitioners felt that predictive models would not be useful for the state of Arizona. In some areas, both *Culex* and *Aedes* mosquitoes can be active all year and therefore a predictive model would not provide useful additional information to time trapping or control efforts. In addition, mosquitoes can breed in artificially-created water sources that are disconnected from local weather events, making the use of prediction by weather difficult. One respondent from Maricopa County also noted that the Vector Control staff in his jurisdiction rely on their own local knowledge of rainfall patterns in specific areas, as well as a county map created by the Flood Control District, to know when to trap and treat mosquitoes, and would not see great advantage in forecasted information. The incidence of disease also has linkages to human travel to places where vector-borne diseases are more common, making predictions complex. Additionally, prediction models based on precipitation data may not be fine enough scale to be useful.

As far as tick activity is concerned, some practitioners felt that prediction models would not be useful due to year-round seasonality of the brown dog tick in Arizona. One researcher stated that the main driver of tick phenology is photoperiod and not seasonal or climatic changes. Since there is no particular time of higher risk, it would be challenging to put too much weight on a predictive strategy based on climatic and seasonal factors. Although predictive models on tick species might not be beneficial, the practitioners mentioned that additional collection, identification, and studying of tick species could be useful. They also stated a need to continue mobilizing resources and scaling up prevention strategies among tribal communities and other resource-limited areas.

As the USA-NPN moves forward with collaboration with public health organizations in the field of vector-borne diseases, it will be useful to understand the communication tools used by these groups (Table 5).

**Table 5.** Communication tools used by researchers and practitioners to gather and disseminate information.

| **Organization** | **Level in Public Health Pyramid** | **Communication Tools Used** |
|---|---|---|
| CDC | Federal Agency | • National Environmental Public Health Tracking Portal<br>• Info by location<br>• Data Explorer |
| Arizona Department of Health Services | State Health Department | • USDA<br>• U.S. public health labs<br>• Reports from the department of agriculture or wildlife.<br>• Electronic lab reports<br>• Direct reports from physicians<br>• Information to/from local and county health departments<br>• National Environmental Public Health Tracking Portal |
| Maricopa County Department of Health | Local Health Department | • Social media<br>- Serve alerts (for providers)<br>- listservs<br>- NextDoor (also used by vector control)<br>- health alerts |
| Pima County Health Department | Local Health Department | Data Maps |

| | | |
|---|---|---|
| University of Arizona researchers | University | • Kidenga<br>• National Environmental Public Health Tracking Portal<br>• NEON portal<br>• Extreme Heat Maps |
| T-Gen | Non-profit organization | • One Health Collaborative website |

**Strengths and weaknesses of study**

We conducted this study using in-person interviews, phone interviews, and online surveys. We found that phone interviews were the most flexible form of communication with such a diverse range of people in locations all over the United States. Additionally, phone interviews allowed a large group to communicate at the same time. Although in-person interviews were also beneficial, it was difficult to coordinate multiple schedules. Online surveys yielded the least amount of responses demonstrating their inefficiency. Much was missed in the responses from surveys as some responses needed better clarification. We suggest following up with participants of online surveys via an in-person or phone interview to have a more refined understanding of the participant's views.

One of the strengths of this study was that it could aid researchers and practitioners to understand one another's concerns. The responses can be a tool for both of these groups to learn the most common gaps and the recommendations given to address them. This study is able to capture the state of the field of disease vector surveillance at one point in time. There will need to be continuous follow-up with participants in order to capture a well-rounded image of this field.

This study allowed the USA-NPN to join the conversation on best practices for vector surveillance. As a new approach for the USA-NPN, it also allowed researchers and practitioners an awareness of the capacity that this organization carries as well as their willingness to support current efforts towards vector work. Through building a foundation based on collaboration and co-production, the hope is that the USA-NPN will find an efficient means of filling the identified gaps.

Although there are many strengths to this study, it has a small study population with a total of 31 participants. This is not a large study due to the limited time frame of eight months and limited social connections within the field of public health. This study could be improved with continued dialogue with participants over time to get a more comprehensive picture of how the gaps evolve. The USA-NPN would need to reach out to a larger number of participants to ensure a well-informed approach.

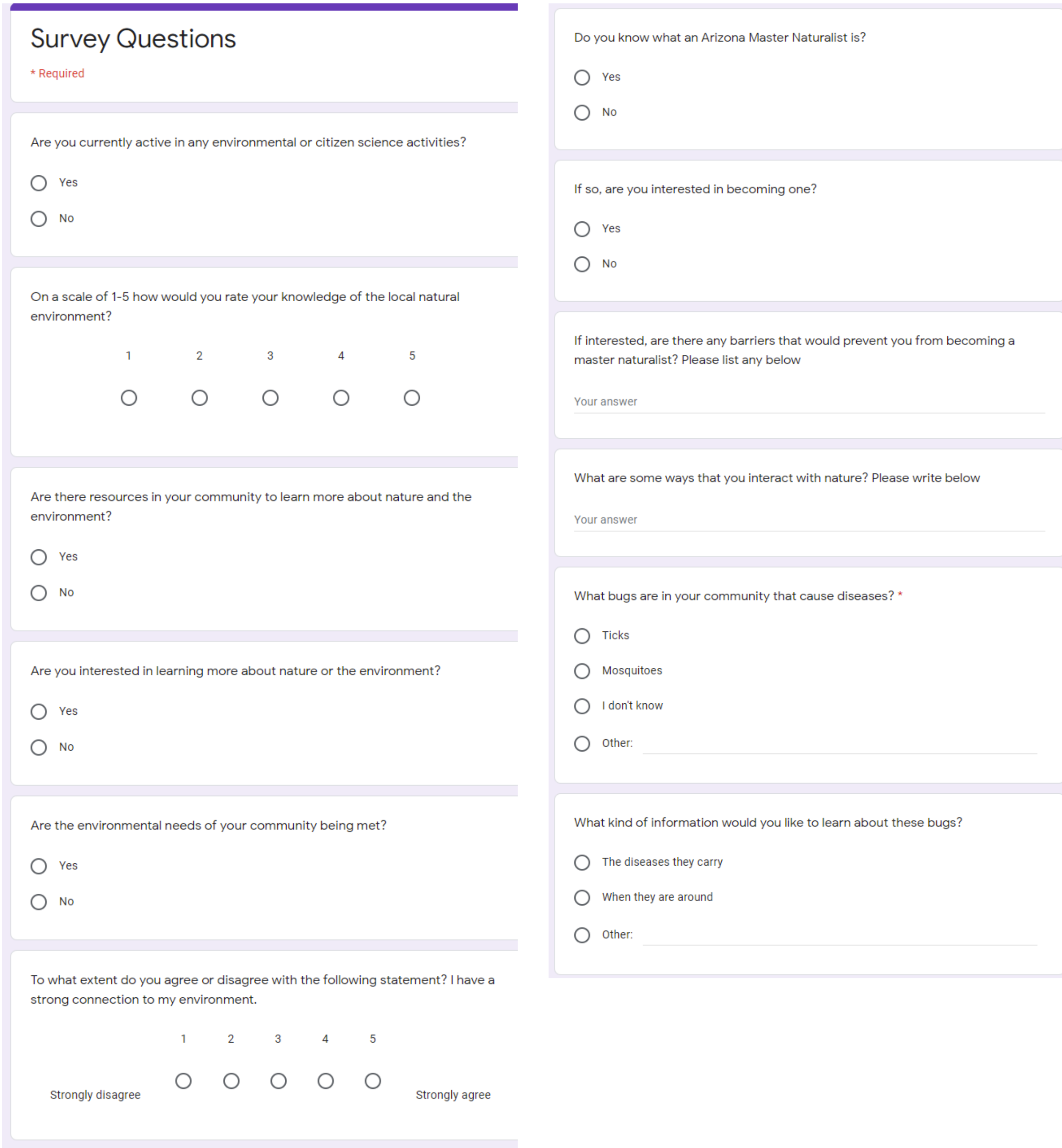
# UNDERSERVED COMMUNITY NEEDS RELATED TO DISEASE-VECTOR INFORMATION

The USA-NPN seeks to create an equitable and inclusive network by creating programs, tools, and partnerships that aid all backgrounds reflected in the US population. Better understanding the needs of underserved community members related to disease-vector information was of particular interest to Brenda Mbaabu as a component of her Peace Corps Coverdell Fellowship. It was also recommended by one of the practitioners in our needs assessment surveys that involving community members in data collection could result in more diverse data collection and bridge the gap of communication between researchers and the community.

We planned to gain community input through conducting in-person surveys at local libraries in Tucson during the spring of 2020. However, the COVID-19 pandemic prevented us from completing these surveys. Here we summarize our progress toward identifying locations for these surveys, survey questions, and other planning that will aid the USA-NPN in moving forward with these surveys in the future.

We combined forces with the Diversity, Equity, and Inclusion (DEI) project at USA-NPN that was already conducting surveys in the community to add questions for community member about their concerns related to disease vectors. The goal of the DEI project is to identify which cultural and ethnic groups are not participating in the USA-NPN's *Nature's Notebook* plant and animal phenology program and determine how to increase their participation. The USA-NPN staff members built relationships with library staff to plan the best dates and methods for interviewing patrons. The project involved visiting local libraries, particularly the Sam Lena library, in conjunction with the Arizona Master Naturalists programs. At the libraries, they hosted three tabling sessions in February and March resulting in four informal interviews and one completed survey (Figure 6).

The single survey respondent indicated they did not know about which bugs are in the community that cause disease, and that the information they wanted to know was "anything." We identified one potential group that is missing in NPN's data collection process that could potentially be an asset as they do interact heavily with nature – this group being people experiencing homelessness. One person showed an interest in collecting data on mosquitoes and ticks but we were not able to follow-up with him due to the COVID-19 pandemic. The DEI project continued remotely but was not able to include our questions about disease vectors.


Survey Questions

* Required

Are you currently active in any environmental or citizen science activities?

Yes

No

On a scale of 1-5 how would you rate your knowledge of the local natural environment?

1 2 3 4 5

Are there resources in your community to learn more about nature and the environment?

Yes

No

Are you interested in learning more about nature or the environment?

Yes

No

Are the environmental needs of your community being met?

Yes

No

To what extent do you agree or disagree with the following statement? I have a strong connection to my environment.

1 2 3 4 5

Strongly disagree Strongly agree

Do you know what an Arizona Master Naturalist is?

Yes

No

If so, are you interested in becoming one?

Yes

No

If interested, are there any barriers that would prevent you from becoming a master naturalist? Please list any below

Your answer

What are some ways that you interact with nature? Please write below

Your answer

What bugs are in your community that cause diseases? *

Ticks

Mosquitoes

I don't know

Other:

What kind of information would you like to learn about these bugs?

The diseases they carry

When they are around

Other:

**Figure 6**. Survey used to engage community members at public libraries.

To further our understanding of how to engage community members in citizen science efforts, we conducted a literature search to understand known best practices. This will guide the USA-NPN on how to involve underrepresented community members in research and how to best disseminate findings to this audience. Although not exhaustive, the content below highlights recommendations from researchers who have studied the best ways to involve underrepresented communities in citizen science, as well as recommendations for how best to communicate information about disease vectors with this audience.

**How to involve underrepresented groups in data collection**

Participation in citizen science has often not attracted underrepresented groups. For example, the Neighborhood Nestwatch program assessed an informal education program focused on improving knowledge of families. When they reached out to 45 participants, they received only 5 responses from underrepresented members of the community while the other 40 were from overrepresented community members (Hickey, 2018). Other studies aimed at involving community members also found that overrepresented groups continue to be the primary participants interested (Peper, 2018). Overrepresented groups were white, between 30 and 60 years old, had a 4-year college degree or higher, and had previous experience in science (Trumbull, 2000).

Many programs have not addressed this disparity in participants. However, for those that have, one recommendation is to involve underrepresented communities in defining the project. This can be done through interviews and advisory committees with community leaders (Button, 2009), broad distributions of surveys or questionnaires, community forums, and targeted focus groups (Brossard, 2005). Additionally, to make it more feasible for underrepresented groups to participate in defining the project, there needs to be the implementation of mentoring tools, consistent training, and reflective feedback (Pandya, 2012).

Others have suggested having regular informal meetings between the organization representatives, scientists, and community members. This can take place through organization members and scientists presenting their intended goals in community events organized by underrepresented groups (Jolly, 2009). Community participation can also align the organization's members with the cultural practices and values of these underrepresented groups.

The most successful co-production projects were those that combined traditional knowledge, historical accounts, and participant observations with scientific processes from the very beginning. When scientists place themselves on the same level as community members, the project takes on a co-learning and co-participation tone rather than an elitist view (Dominique, 2018). Projects that have incorporated traditional ecological knowledge into management and conservation efforts include the migrant and immigrant harvesters of non-timber forest products in the U.S. Northwest (Fazey, 2010) and fishermen in the Louisiana Bayou (Pandya, 2012). Both of these projects utilized indigenous knowledge to enhance their efforts and prevent overstepping of sacred or culturally sensitive boundaries. A recent global assessment of the engagement of indigenous communities in climate science provides key analysis and guidelines for this work (Chavez, 2018).

Even after the project has been defined, underrepresented participants should be involved in the implementation of the project, data analysis, and data presentation. In the project implementation stage, community members can be responsible for distributing equipment, collecting data, and training other community members on proper data collection efforts. In the data analysis stage, community members can assist with data entry and putting the results in context that is relevant to their needs. After the data is analyzed by expert scientists in collaboration with community members, underrepresented communities can be key players in determining what the results mean for them and their communities. In consideration of the varying education levels in the larger population, it is important to not only disseminate research findings in the form of scientific publications (Brossard, 2005). Community members can make the dissemination of findings a component of their community events through bulletin boards, posters, radio broadcasts, formal presentations, or fun rallies.

This way they can feel a sense of ownership as key players in the overall success of the project. The organization needs to understand that this will require additional training and possibly employing staff who specifically focus on supporting community members throughout these processes (Jolly, 2009). Although this will incur more time and expenses, co-ownership with underrepresented populations yields more diverse outcomes and a broader perspective on the utility of data in implementing community programs.

**How underrepresented groups prefer to receive public health information**

Including underrepresented groups in citizen science is key as it allows communities to be more aware of and address their own communities' needs. It is therefore essential that these groups receive information in a feasible and preferred manner. This section of the literature review focuses on findings from previous studies on best efforts for disseminating information to underrepresented groups.

A project done in West Baltimore to include underrepresented groups found that Photovoice presentations by personnel and participants of the research at key neighborhood meetings yielded fruitful discussions and responsive action**.** Photovoice is a qualitative community-based participatory research method to document and reflect an individuals' experience through photographs and storytelling (Riggs, 2005).

Library education programs that allow participants to utilize technology and computers for learning have been found as an effective way to communicate with underrepresented groups; especially when these programs incorporate free education on how to use and read Geographic Information System (GIS) maps or pertinent data (Ballard, 2006).

Underrepresented groups prefer for information to be communicated through public and frequently visited websites, as opposed to the institution's research website. Additionally, they prefer to see information in newsletters and social media such as YouTube and Facebook since these are the platforms that are easily and frequently accessible (Sorensen, 2019).

# FUTURE DIRECTIONS

We used a framework of co-production to pursue this integration of phenology and public health. Co-production is the act of involving stakeholders throughout the project process from defining the project, creating the product, testing the product, and evaluation/monitoring of the project (Hickey, 2018).

Below, we discuss recommendations that we have gleaned from our needs assessment surveys that should guide the activities of the USA-NPN in future collaborations with the public health community. We also make recommendations to assist the USA-NPN to better serve all communities in need of phenology information related to public health.

**Recommendations from practitioners and researchers**

The results highlight common gaps and recommendations for future work identified by both public health researchers and practitioners in Arizona and Colorado. Both groups mentioned insufficient data for disease vectors. Additionally, both of these groups highlighted poor communication and collaboration across states, organizations, and groups. This means that there is a great deal of work all over the country to promote vector surveillance but there is a missed opportunity to collaborate and further organizational goals.

In efforts to address the lack of reliable disease vector data, both groups suggested more surveillance and research efforts. As far as mosquitoes are concerned, current data collection can include factors such as vegetation cover, canopy cover, and patterns in flowering plants. An additional recommendation was the creation of predictive models for certain vector species. However, there are vector species, such as the brown dog tick, for which it will be difficult to predict activity since their life cycles are driven by photoperiods rather than climatic conditions.

Both researchers and practitioners made recommendations on how to improve communications related to vector surveillance. The first recommendation was to support existing programs and technological applications by providing extra hands and resources rather than creating an entirely new product. One suggestion was a citizen science project, which could accommodate more vector species and more people in diverse locations. This will also create more opportunities for engagement with community members about disease vectors.

One respondent recommended that once we have products to disseminate, we might reach out to several national organizations that host monthly conference calls, including Council of State and Territorial Epidemiologists, National Association of County and City Health Officials (NACCHO), America Planning Association, and National Environmental Health Association.

Another recommendation emerged for regular regional meetings between various practitioners and researchers. One such example was the inaugural Southwest One Health Symposium held in Flagstaff, AZ in August 2019. This event brought together diverse researchers and practitioners to encourage a comprehensive discussion on One Health research and work in the American Southwest. One of the staff members at the USA-NPN attended this event and was able to better understand where the potential applications of phenology for public health. Such events allow researchers and practitioners to establish collaborative research, advance data sharing efforts, identify stakeholders to their products, identify overlapping projects, and reduce redundancy in their work. Moreover, organizations interested in collaborative efforts can attend these symposia and identify potential areas of involvement. Table 6 below demonstrates potential areas of collaboration that were identified during the symposium and via our discussions with researchers and practitioners.

**Table 6.** Areas of collaboration identified at One Health Symposium and interviews.

| **Public Health Concern** | **Potential Areas of Collaboration** |
|---|---|
| West Nile Virus | • Creation of forecasts of mosquito activity to maximize the efficiency of trapping for the *Culex tarsalis* mosquito species for rural counties.<br>• Observe timing of mourning dove nesting to determine mosquito abundance since mosquitoes feed on nestlings.<br>• Using Christmas Bird Count Data for avian relative abundance.<br>• Incorporate mosquito data into the Environmental Public Health Tracking portal. NPN would need metadata to carry this out.<br>• Use NEON mosquito datasets to assist in modelling work and assist in developing an app that vector control can use. |
| Rabies | • Observe bat migration timing and its relevance to potential rabies cases.<br>• Observe whether there is a pattern with seasons such as fall and winter. |
| Valley Fever | • Could use climate data to model valley fever spread. It seems that valley fever is associated with drought and high temperatures. |
| Canine River Blindness | • Observe the time of year that black fly is most active. This could help to warn people of the disease. |
| Ticks | • Use climate variables such as maximum and minimum temperature, diurnal range, and land cover (percent forest, percent scrub) to develop models that predict distributions. |

| | |
|---|---|
| Plague | • Observing the emergence and presence of prairie dogs could help in understanding their influence in plague. |
| Hantavirus | • Observing the hosts (*Peromyscus maniculatus*) activity time periods can ensure early prevention actions for Hantavirus. |
| Lyme disease | • Understanding the relationship between growing degree days, ticks, and the occurrence of Lyme disease. |
| Critical parasite hosts | • Understanding reservoirs that could have phenological stages of interest such as bird nesting |
| Pollen | • Pollen's impact on asthma, high risk areas etc.<br>• Pollen forecasts for each day would be helpful.<br>• Collaborate with CDC health and tracking portal staff to pull NPN data into the Portal<br>• USA-NPN create long-term annual projections of Si-x on a decadal scale |

For continuation of the survey of the needs of underserved communities related to disease-vector information, we recommend continuing to collaborate with the DEI project. By tagging onto a pre-existing and approved project, the disease vectors project would not need a new IRB approval process, which requires a substantial amount of time and paperwork. We would suggest a focus on multiple libraries – especially those at the University of Arizona, the Pima County Library, and Sam Lena library. We would suggest limiting the questions to 2-3 questions to maintain the purpose of the initial survey. We would also suggest a Google Forms survey format linked to an Excel sheet where responses can be automatically saved.

# CONTRIBUTIONS AND ACKNOWLEDGEMENTS

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