



Mosquito Census

Tracking New Zealand's Mosquitoes Using Citizen Science

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The Mosquito Census: Tracking New Zealand's Mosquitoes Using Citizen Science

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Submitted to:

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I. Abstract

To improve the availability of ecological data, we designed and recommended a submission process and accompanying website for the Mosquito Census, a project for the National Museum of New Zealand Te Papa Tongarewa that promotes citizen science and biosecurity. Our website will facilitate the submission of physical specimens and provide scientists with a database to archive and access mosquito distribution and ecology data. We conducted surveys and interviews to inform our suggestions for efficient specimen submission and future outreach programs to improve mosquito and biosecurity literacy.

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III. Authorship

This project group of Katherine Long, Andrew Moore, Anthony Topper, Georgie Wood, and Chase Woodward collectively wrote, reviewed, and revised the entirety of this report. Anthony Topper, applying his computer science background, coded a functional website as a component of the project proposal.

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VII. Executive Summary

Introduction and Background

New Zealand's geographic isolation makes its ecosystems especially vulnerable to invasive species and exotic diseases (Jay, 2003). Addressing these biosecurity threats requires the collection of a large amount of data on the distribution and ecology of endemic, introduced, and exotic species in New Zealand that can only be gained through citizen scientist participation. Of New Zealand's species, our project focuses specifically on mosquitoes due to their potential to harm ecosystems and spread disease if not monitored (Southern Monitoring Services, Ltd., 2018). Our goal was to recommend a collection system and accompanying website to assist citizen scientists submitting physical mosquito specimens to Te Papa's Mosquito Census.

Biosecurity management can intercept exotic species and diseases with the potential to destabilize ecosystems and drive native species to extinction (Brockerhoff, 2009). Native mosquitoes, however, also play important roles in New Zealand's ecosystems as pollinators and as a vital component of local food chains (J. Kasper, personal communication, February 18, 2019). To protect New Zealand's ecosystems and public health, mosquitoes must be monitored.

Dealing with biosecurity threats requires the collection, management, and publication of ecological data. In the past, such data was collected solely by scientists, but with the advent of the Internet, citizen scientists are contributing to ecological data collection (Kobori et al., 2016). This ecological data must not only be collected, but be freely accessible, in order to promote research (Michener, 2015).

Te Papa's Mosquito Census will track and document the distribution of the sixteen mosquito species present in New Zealand. Unlike most animals, mosquito species cannot easily be identified without the use of a microscope (J. Kasper, personal communication, February 18, 2019). For this reason, the Mosquito Census will rely on citizen scientists to submit physical specimens for mosquito specialists to identify. This data will allow Te Papa to not only track endemic and introduced species' geographical distribution, but also to potentially discover and respond to exotic arrivals before they can establish themselves.

Methodology

We interviewed mosquito specialists and professionals from iNaturalist, NZBEL, Find-A-Pest, the Mückenatlas, the University of Otago, the New Zealand Ministry for Primary Industries, and the New Zealand Ministry of Health. We worked closely with domain experts within Te Papa specializing in public programming, exhibitions, graphic design, marketing outreach, creative development, digital channels, and resource management. Interview feedback and suggestions were used to rule out existing input portals, improve the specimen submission form, construct a list of system requirements for the website, and evaluate the feasibility of identification numbers for submissions. Insight from our interviews was also used to formulate ideas for marketing the Mosquito Census to a larger audience, decide how to transition website development, consider a public health perspective, and identify potential sources of funding. These suggestions were also considered in addressing logistics, privacy, sensational media, and marketing and outreach.

We surveyed museumgoers at a temporary exhibit before opening the survey up to Reddit and Twitter users. Respondents shared information on demographics, their knowledge pertaining to biosecurity and mosquitoes in New Zealand, the Mosquito Census website interface, and their likelihood to participate in the Mosquito Census.

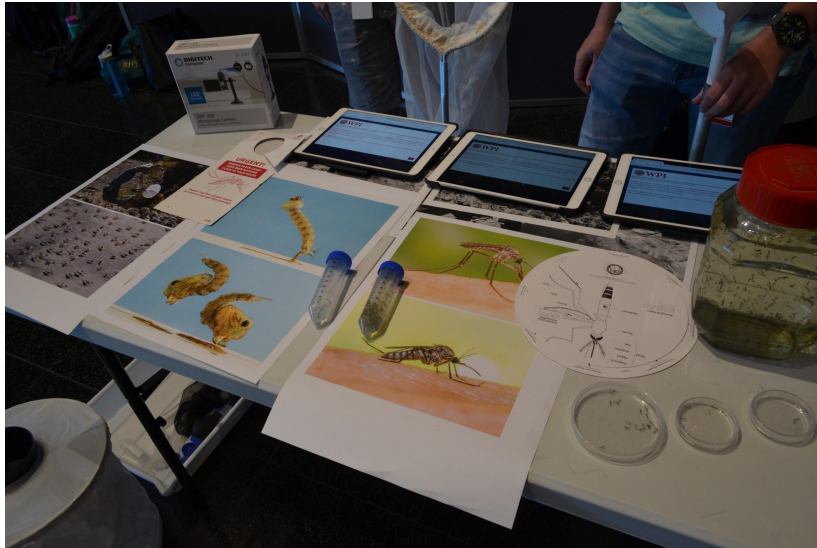
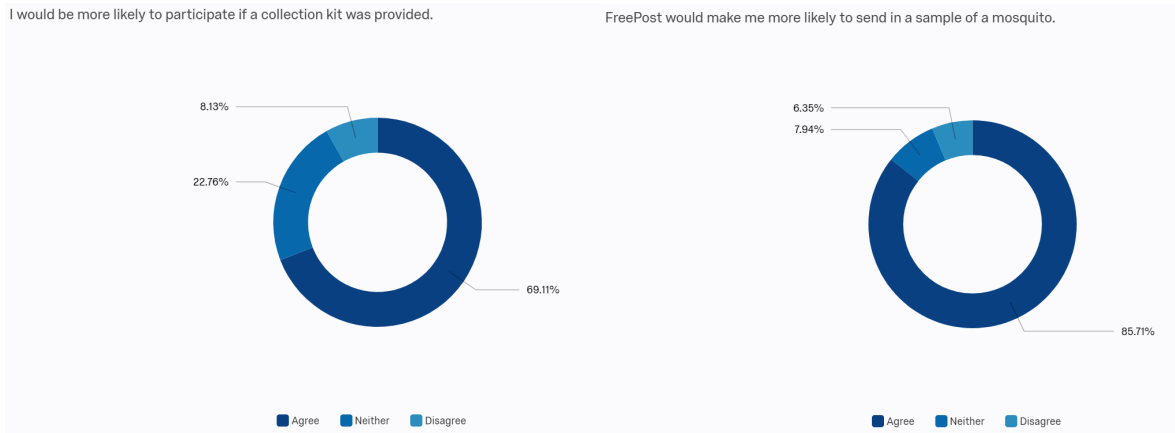


Figure VII.1: Our temporary exhibit

We designed a website for the Mosquito Census. The front-end focused on user interactions and graphic design choices while informing visitors about the project. The back-end consisted of the underlying system responsible for recording, storing, cataloging, uploading, and accessing mosquito specimen records. At a second temporary exhibit, we informally interviewed and observed museumgoers as they navigated the Mosquito Census interface and examined the online submission form to obtain feedback to assess the front-end and the functionality of the website.

Results

From our interviews with mosquito specialists, we refined our recommendations for the specimen submission process. We found the estimated maximum number of identifications possible to be ten identifications per specialist per day. We also determined what fields need to be present in the submission form to ensure the usefulness of the data collected. We found that the majority of survey respondents would be more likely to participate in the Mosquito Census if they were provided collection kits and could utilize FreePost as seen in Figures VII.2 and VII.3.



Figures VII.2 and VII.3: Combined online and in-person survey responses

We also determined that no existing platform satisfies the needs of the Mosquito Census. While iNaturalist does not satisfy the input portal and back-end database needs of the Mosquito Census, this platform provides a way for the data that is collected and identified through the Mosquito Census to be shared with an existing citizen science community. Publicizing Mosquito Census data on iNaturalist is both possible and achieves our goal of making ecological data easily accessible to all.

We discussed methods of marketing the Mosquito Census with experts from Te Papa. Our surveying showed a lack of public knowledge about mosquitoes. Approximately one third of survey respondents supported the eradication of all mosquito species, underscoring a lack of awareness of the benefits of native mosquito species. Due to this misconception, we analyzed different ways of elevating mosquito literacy while also promoting the Mosquito Census. These include lesson plans for teachers, a mention of the Mosquito Census in the upcoming natural history exhibition, and articles on the Te Papa website. Finally, researchers from the Mückenatlas advised us on how to maintain a positive image and encourage participation in the Mosquito Census.

We created a website prototype addressing requirements derived from our surveys and interviews. It contains information about New Zealand's mosquitoes, a map of previous specimen submissions, and details about the collection and submission process. It also has both a paper and online submission form with the fields required by the Mosquito specialists.



Figure VII.4: The homepage of the website prototype

Recommendations

Based on our results, we are recommending that Te Papa utilize the website interface for the Mosquito Census that was created by our team.

After conducting user testing, we recommend that the prototype be modified for the next version created by the museum to reduce confusion for users. These changes include a menu bar on the top of the site or a sidebar that shows users their progression through the website as well as the removal of the arrows on the front page.

Since free sharing of data is one of the goals of our sponsor, we recommend constructing the website in a way that makes collaborating with third parties easier. We specifically recommend sharing the Mosquito Census data with iNaturalist, as their platform corresponds with the structure of our website. We also included a map in the design of the website. We suggest that this function remain on the website so that citizen scientists can see the data directly on the finished Mosquito Census website.

Based on survey results, we are also recommending that the Mosquito Census utilize FreePost, drop-off locations, and collection kits. Implementing these would help decrease barriers of participation for citizen scientists.

In addition, our results showed that citizens generally lack knowledge of mosquitoes and their importance in the ecosystem. Therefore, we recommend that Te Papa continue to spread awareness for the project as well as the importance of mosquitoes through public outreach and exhibitions. We are recommending an exhibit design to be featured in the new nature exhibition opening this year. We are also recommending that the public outreach team conduct school visits and share a curriculum that can be used in schools or in homeschooling that can teach children about the importance of mosquitoes and call out for submissions to the Mosquito Census.

Since exotic mosquitoes are a health and safety risk, we recommend that all information provided on the Mosquito Census be checked over by Ministry of Health (MoH) and Ministry for Primary Industries to

ensure it would not cause panic amongst New Zealand citizens. In the case that any media outlet does write a sensational or falsified story on the Mosquito Census, we recommend that the MoH and Te Papa communications teams work together to make a plan for responding to the media.

Conclusion

The goal of our project was to help Te Papa gather data on the distribution and ecology of New Zealand's mosquito populations. We recommended an intuitive collection system and accompanying website interface to enable the submission of physical specimens to mosquito specialists. Through interviews and surveys, we determined that the Mosquito Census website and online submission form will be the most effective method to gather data on and amass collections of New Zealand's mosquito populations. This will assist in future entomology research and public outreach, future citizen science natural history data collection projects, as well as help prevent or effectively respond to potential mosquito-related biosecurity problems

Chapter 1: Introduction

Biosecurity is defined as, “the exclusion, eradication, or management of pests and diseases that pose a risk to the economy, environment, cultural and social values, including human health” (MPI, 2016). Biosecurity concentrates on preserving environmental and human health. The introduction of invasive species can lead to the decline and even extinction of native species. A decline in native species can spell disaster for the global ecosystem (Brockerhoff, 2009).

New Zealand’s biological and geographical isolation and consequent ecological vulnerability amplify the biosecurity risk posed by introduced species (Jay, 2003). Throughout 80 million years of isolation, New Zealand benefited from low amounts of pests and disease (Nelson et al., 2015). An exponential increase in travel and trade has created more opportunities for invasive species to potentially travel to New Zealand (MPI, 2016). The distribution of native flora and fauna may be permanently altered by the spread of these intentionally and unintentionally introduced species, with the potential of some native species populations decrease in numbers (J. Kasper, personal communication, February 18, 2019).

In order to improve biosecurity in New Zealand, accurate and substantial data must be collected and made publicly accessible (Thomson et al., 2018). Information on occurrence, distribution, and ecology of native, introduced, and exotic species in New Zealand is necessary to inform biosecurity policy decisions. A community-driven citizen science project known as iNaturalist tracks a variety of species through photographic submissions. Boasting 15.7 million submissions thus far from all over the globe, they have taken major strides towards increasing access to biodiversity data (“iNaturalist”, 2019).

One important biosecurity risk is the introduction of exotic mosquito species to New Zealand. These mosquitoes can out-compete native species by depleting resources, as well as potentially be vectors for human diseases (Southern Monitoring Services, Ltd., 2018). In order to manage this risk, experts as well as citizen scientists must track mosquito species across the country. Unlike most other animals, the specifications and expertise required to identify mosquito species require physical specimens for morphological examination, as opposed to typical photograph-dependent visual recognition (J. Kasper, personal communication, February 18, 2019). Using a photo-dependent platform like iNaturalist to track them, therefore, is not feasible. The National Museum of New Zealand Te Papa Tongarewa’s Mosquito Census initiative seeks to track both native and introduced species of mosquito in addition to detecting exotic mosquito arrivals before they have a chance to establish themselves.

The goal of our project is to recommend a collection system and accompanying website interface to enable submission of mosquito specimens to Te Papa’s Mosquito Census initiative. Enlisting the untapped populations of citizen scientists throughout New Zealand in non-conventional data collection will enable entomologists to create an extensive mapping of mosquito species that can be used by researchers to improve biosecurity (Kobori et al., 2016). The Mosquito Census initiative approaches this by coordinating with iNaturalist, the Mückenatlas, New Zealand Biosecure Entomology Laboratory, and Ministry for Primary Industries while addressing the logistics of a necessary alternative citizen science method based on the submission of physical specimens.

Chapter 2: Background

2.1 Biosecurity

Biosecurity is the prevention of harmful, infectious, quarantined, or invasive species from entering an ecosystem (Nelson et al., 2015). These species may damage an ecosystem by consuming too much of another species' resources, or by preying on species that have evolved without the need for defense mechanisms. They may also carry diseases that pose a threat to native organisms, undermining an area's biodiversity. Biodiversity can be defined as the variety of life in a particular habitat (Cardinale et al., 2012). The effects of biodiversity loss cascade through the intricate food web interactions which mediate ecosystem functioning, reducing the stability of those ecosystems (Cardinale et al., 2012).

Species are becoming extinct at a rate 1,000 to 10,000 times higher than they would barring human influence (i.e. the "natural extinction rate") (World Wildlife Fund, 2017). Instability at this scale can largely be attributed to the unintentional introduction of invasive species (Brockerhoff, 2009). However, species introduction is not the only threat to biodiversity. Land use conversion, or transitions between forest, grassland, cultivated land, and urban land, directly induces habitat loss and fragmentation (de Chazal & Rounsevell, 2009). Variations in temperature, precipitation, and wind over time due to climate change also play a role in decreasing endemic species richness. An accurate assessment of biodiversity decline must reflect the intertwining impacts of each of these major elements (de Chazal & Rounsevell, 2009). One role of our sponsor is to shine a light on the impact of exotic and introduced invertebrate species on both biosecurity and biodiversity.

In 1999, a study funded by the Australian Quarantine and Inspection Service was conducted to analyze the risk of invasive weeds in New Zealand and Australia. Weed management is a good example of biosecurity, as weeds spread uncontrollably and outcompete native plants in obtaining nutrients. The study discusses 370 taxa present in New Zealand and outlines a tool that can help agriculturalists, botanists, and conservationists screen for invasive species by scoring plants based on their "weediness" (Pheloung, Williams, and Halloy, 1999). This screening can prevent the importation of harmful species, and prevent further spread of existing exotic species, both of which fulfill the goal of biosecurity.

2.1.1 Biosecurity in New Zealand

New Zealand's diverse biological systems developed over the past 80 million years in the, "longest period of isolation of any non-polar landmass on the planet" (Nelson et al., 2015). New Zealand's biological isolation is a cause of significant ecological concern in this era of exponential globalization (Jay, 2003). Prior to human interaction, New Zealand benefited from low amounts of pests and disease. With human interaction, intentional and unintentional species introductions have plagued New Zealand's ecosystems. Underscoring the great significance of conservation is the fact that an estimated 52% of the terrestrial and aquatic species in New Zealand are endemic, meaning they are found nowhere else in the world (Nelson et al., 2015). Endemic species are often highly localized, and many species have experienced population extinctions, range retraction, and lineage loss. (Rawlence, Kennedy, Anderson, 2015). New Zealand is a unique environment and such drastic changes can irreparably damage its ecosystem.

2.1.2 Biosecurity 2025

The Biosecurity 2025 initiative, created by the Ministry for Primary Industries (MPI), outlines goals that seek to protect New Zealand's biological ecosystems and consequently promote the health and well-being of its citizens. The initiative lays out a series of safeguards to prevent harmful pests from entering the country and to counter dissemination of existing harmful species (MPI, 2016). Pre-border checks are initiated as far back as overseas shipping ports, where sourced goods are inspected for potentially dangerous pests ranging from insects to fungi. Our focus in particular is on mosquitoes, which are incredibly easy to accidentally carry into the country (J. Kasper, personal communication, February 18, 2019). The goal of the initiative is to help intercept new introductions, and to contain dangerous species before they can spread.

Biosecurity 2025 also stresses the importance of easy data access. Government agencies, border patrol, and surveillance programs alone cannot protect New Zealand from harmful species. Public information from researchers and citizen scientists provides a wider scope of monitoring that can help protect the nation's environment. One goal of the initiative is that everyone in New Zealand's population of 4.7 million can be their own biosecurity risk manager (MPI, 2016). With increases in mail parcels, shipping containers, and air passengers to New Zealand (MPI, 2016), there is a heightened risk of invasive pest introductions. The primary sector, or industries that depend on collection of natural resources, loses \$1 billion per year due to invasive pests, the same pests that kill nearly 25 million native birds per year. Evidently pests can cause significant damage to the environment and economy. MPI seeks to mobilize every citizen to protect the balance of ecosystems and overall health of New Zealand's native species.

2.1.3 Mosquitoes as a Biosecurity Risk

Mosquitoes are small flying insects in the family Culicidae. The females of this family extract blood from other animals, including humans, in order to reproduce. In addition to their rash and itch-causing saliva, they can also be vectors of disease, making them not only a nuisance but also a public health risk.

Currently there are sixteen established species of mosquito in New Zealand, across six different genera (Southern Monitoring Services, Ltd., 2018). These mosquitoes can be divided into two groups: native and introduced. All of the thirteen native species are endemic. The three introduced species (*Aedes australis*, *Aedes notoscriptus*, and *Culex quinquefasciatus*) were established in New Zealand from as recently as 50 years ago to as long as 170 years ago (Landcare Research, 2004). However, thanks to increased border surveillance, no new exotic mosquito species have been established in New Zealand in the past 50 years (EHINZ, 2018).

As vectors of diseases such as West Nile Virus, dengue fever and malaria (Southern Monitoring Services, Ltd., 2018), introduced species of mosquito pose a risk to biosecurity. The primary hosts of West Nile Virus are birds, so if vector mosquitoes such as the already established *Cx. quinquefasciatus* were to become carriers, New Zealand's native bird population could be at risk of extinction (Landcare Research, 2004). In Hawai'i, several species of birds have already gone extinct from the introduction of this mosquito because of its ability to spread avian malaria (Rich, 2015).

Since 1950, ten species of exotic mosquito have been intercepted at the New Zealand border (Landcare Research, 2004). One of these, *Aedes aegypti*, is the primary vector for yellow fever and dengue fever throughout the world (Southern Monitoring Services, Ltd., 2018). This species has been intercepted at the border fourteen times since the year 2000 (Jessamine, 2016). For the sake of public safety and the health of New Zealand's ecosystem, it is critical that these invasive mosquitoes be intercepted before they establish themselves in the country.

In the history of New Zealand, there has been one successful eradication of an established introduced species of mosquito. Native to Southern Australia, *Aedes camptorhynchus* is an aggressive biter and known to carry Ross River virus, as well as other viruses and parasites (Southern Monitoring Services, Ltd., 2018). This species was first discovered in New Zealand at Hawke's Bay in 1998 after several complaints to the local city council about swarms of aggressive mosquitoes (Kay & Russell, 2013). Once the mosquito was identified, several parties including the Ministry of Health and the Ministry of Agriculture and Forestry (now MPI) started the effort to eradicate this mosquito from the country. The project lasted until 2010 and ultimately cost the nation over NZ\$70 million (Kay & Russell, 2013). This sort of eradication, while effective, is very expensive. It is much more cost-effective to prevent invasive mosquitoes from establishing themselves in the first place.

2.1.4 Benefits of Mosquitoes

Despite their reputation as disease vectors, mosquitoes play an important role in the overall health of ecosystems. Of roughly 3,500 mosquito species in existence, only a couple hundred are considered pests (Fang, 2010). Mosquitoes occupy essential ecological roles and services as prey for predators and as pollinators for plants. Adult male mosquitoes extract energy from the nectar of thousands of plant species. In fact, several tropical crops are pollinated by mosquitoes. Furthermore, plant growth is stimulated by mosquito larvae conversion of waste to nutrients and nitrogen (Fang, 2010). Interbreeding among native and invasive species could disturb fragile food chains by removing a primary food source for many species of fish, insects, spiders, salamanders, lizards, and frogs, initiating a rippling effect with major fallout (Fang, 2010). From flora to fauna, the contamination or elimination of mosquito species "would be detrimental to ecology" (Fang, 2010).

2.2 Ecological Data

Insufficient information on mosquito locality and ecology inhibits the abilities of researchers and decision-makers to recognize and respond to biodiversity loss and biosecurity threats. Filling this research gap necessitates collection of data by citizen scientists throughout the country in addition to ongoing research by entomology experts.

In order to protect and evaluate ecosystems, scientists must first be able to obtain and access ecological data. Ecological datasets, consisting of sighting records and specimen collections, are the framework upon which researchers measure biodiversity loss and track species populations. From this data, scientists can infer information about the population of a species within a given area, and, subsequently, the general health and well-being of the ecosystem. Biological collection systems are vital to research the effects of resource use on agriculture, horticulture, aquaculture, forestry, wild fisheries, and mining sectors (Nelson et al., 2015).

Generally, environmental and ecological scientists are willing to share data but suffer from a lack of standards, institutional support, and access to large-scale data management tools (Michener, 2015). Data is often submitted in an incomplete manner, not appropriately labeled, or lacking information fields required by different databases (Nelson et al, 2015). Before the Internet, it was difficult to determine what data existed, let alone how to access the data (Porter, 2010). Traditionally, researchers were required to travel to and tour museums, then locate and study physical specimen labels (Brooke, 2000). Data was shared through in-person exchanges or by mailing via the post office (Michener, 2015). The creation and widespread use of various types of software, hardware, and networking infrastructure, especially with regards to the Internet, have facilitated widespread data sharing and consequently remote research and collaboration.

The museums and research institutions charged with collecting and managing New Zealand’s ecological datasets will benefit from enlisting the public to address pressing ecological issues (Michener, 2015). Citizen science is a partnership between volunteers and scientists in which non-specialists are actively engaged in the generation of scientific data (Stilgoe, 2016). Advances in information technology over the past few decades have accelerated the scope and number of citizen science projects internationally (Kobori et al., 2016). Volunteers are seizing the opportunity to make authentic contributions to scientific knowledge and literacy (Bonney et al., 2009). Data gathered by citizen science programs can be used as early warning systems in detecting invasive plant species and other resource-extraction activities (Tredick et al., 2017). Citizen participation enables species identification throughout diverse habitats, on private land and in remote regions, and over a greater period of time (Bonney et al., 2009). The vast quantities of ecological data collected by citizen scientists need to be shared to allow scientists to compare data, augment datasets, and verify results. Data sharing between scientists and citizen scientists enables people to make informed decisions, and provides an opportunity for everyone to learn more about ecology (Michener, 2015). Moreover, inhibiting the sharing of data “widens the gap between developed and developing countries” (Michener, 2015).

2.3 Mosquito Census

The Mosquito Census is a citizen science project developed by our team for the Te Papa Museum with collaboration from specialists and domain experts. The primary aim of the project is to track New Zealand’s local, or native and introduced, mosquito species. A secondary benefit of this project is the possibility of finding occurrences of exotic species so that they can be controlled before they spread.

The Mosquito Census relies on citizen scientists to catch and submit mosquito specimens. Citizen scientists across the nation are encouraged to capture the mosquitoes they encounter in their everyday lives and to send in these samples to the Mosquito Census. The mosquito specimens are identified by mosquito specialists. The goal of the initiative is to obtain a wide variety of submissions from across New Zealand in order to comprehensively map all of the country’s mosquito species.

2.3.1 Sample Verification

Citizen science contributions must be verified in order for them to be used in research. Crall and others (2011) assessed the quality of citizen science data in an invasive species case study. The researchers

concluded that volunteers identified “easier” species just as well as professionals and recommended only relying on citizens to perform easier identifications (Crall et al., 2011). Interviews and focus groups with biodiversity experts showed a strong relationship between how data is verified and future participation from the data collectors; increased feedback from data validators led to increased future participation of citizen scientists (Turnhout, Lawrence, & Turnhout, 2016).

Smartphone applications employing visual recognition software to identify species and automatically record the geographic location of the volunteer have already been successfully implemented (Kobori et al., 2016). Photographs of specimens typically offer a realistic method of assessing the accuracy of a report (Bonney et al., 2009). This method of data verification is frequently utilized in scientific endeavors monitoring threatened, endangered, and exotic species.

The Mosquito Census is motivated by the need for a new method of species identification, paralleling popular approaches for other species, and ultimately contributing to the same publicly accessible biosecurity collections. Physical specimen submission is required because the distinguishing features of mosquito species are only visible under microscope, making photograph-dependent visual recognition nearly impossible (J. Kasper, personal communication, February 18, 2019). Moreover, entomology experts are extremely knowledgeable of mosquito morphology and the subtle distinctions differentiating mosquito species. Non-entomologists, however, frequently mistake flies, gnats, bees, wasps, and other insects for mosquitoes (J. Kasper, personal communication, February 18, 2019). Due to the sensitivity inherent in publicizing information on disease vectors, specialist verification of species occurrences will be a necessary precaution. Manual verification by experts, although less efficient than popular approaches, is therefore the most appropriate technique for the Mosquito Census.

2.3.2 Data Users

Specific geographic and ecological data on mosquitoes in New Zealand is hard to come by, so mosquito researchers often struggle to obtain the quantity of data they need (J. Kasper, personal communication, February 18, 2019). This information is even more difficult to access for non-specialized third parties, because datasets often serve only to back up the owning organization’s own research rather than to contribute to the field (Liz et al., 2018). The long-term operation and success of the Mosquito Census are dependent upon the combined efforts of Te Papa, the Ministry for Primary Industries, and the Ministry of Health, and researchers at New Zealand universities such as Massey and Victoria University, and New Zealand Biosecure Laboratories.

2.3.3. Stakeholders

The National Museum of New Zealand Te Papa Tongarewa is implementing a Mosquito Census because of its commitment to preserving and enhancing accessibility to knowledge of the natural environment. Growth of its physical specimen collection, available for future DNA tests, is another motivator for Te Papa’s involvement. Te Papa’s expertise with “curation, communication, and providing access to resources,” uniquely qualifies it to spearhead this data collection initiative (Kobori et al., 2016). Museum stewardship of physical biological collections provides essential legal protections, supports exhibition and outreach, and enables site-specific taxonomic research (Nelson et al., 2015). In an effort to enhance transparency and collaboration, Te Papa upscaled digitization of collection items to its own Electronic

Museum (EMu) database from 3,100 items in 2016 to 25,000 items in 2017 (Williams & Foote, 2018). This dissemination of taxonomic collection information throughout academic spheres in New Zealand has directly supported the discovery of several new species (Williams & Foote, 2008). Collaboration with existing databases will promote data accessibility beyond academic spheres. A 45% increase in unique local users on the Te Papa Museum's website from 2017 to 2018 reinforces the viability of popularizing citizen scientist contributions to resources for amateur and academic research (Williams & Foote, 2018).

The Ministry of Health (MoH) is a particularly involved stakeholder in the Mosquito Census project due to its official role in increasing awareness of, knowledge of, and protection from mosquitoes (MoH, 2019). Moreover, the Ministry of Health enforces the International Health Regulations (IHR) 2005 to which New Zealand is a signatory. The IHR was created to “prevent, protect against, control, and provide a public health response to the international spread of disease [including] the control of disease vectors such as mosquitoes” (Sally Giles, personal communication, February 14, 2019). The New Zealand Ministry of Health has taken steps toward increasing mosquito biosecurity, “including the implementation of mosquito surveillance programmes and control measures, in particular at international maritime and aviation ports” (Sally Giles, personal communication, February 14, 2019). For example, larvae and adult mosquito traps are placed in international airport terminals throughout the country (MoH, 2019). The Mosquito Census will provide the data necessary to inform an effective response in the event that invasive mosquitoes elude airport surveillance and border interception efforts. The Ministry of Health is also interested in discerning what changes, if any, there have been to New Zealand's unique mosquito population. This information will be considered in evaluating the “likelihood and threat of an exotic mosquito population establishing and spreading within New Zealand” (Sally Giles, personal communication, February 14, 2019).

As the creator of the Biosecurity 2025 initiative, Ministry for Primary Industries (MPI) is committed to protecting New Zealand from biological threats and to achieving a more resilient and biosecurity-focused New Zealand (MPI, 2019). The Mosquito Census and MPI share a focus on community engagement, growth, sustainability, and management of biosecurity risk.

2.4 Existing Ecological Databases

Most existing databases are not optimally utilized because proprietary data is bartered between academic institutions instead of being treated as a commodity (Nelson et al., 2015). Currently, there are several institutions globally employing a variety of methods to store and access ecological data freely. These databases typically encourage nationwide ecological data collection, management, and sharing.

2.4.1 Mückenatlas

The Mückenatlas, or Mosquito Atlas, a citizen science project implemented in Germany in 2012, currently holds over 22,000 mosquito specimens submitted by citizen scientists and catalogued by specialists. Its webpage is straightforward, easy to use, and encourages participation. Active monitoring enables the database to serve as a warning system for invasive species; since 2007, the Mückenatlas has identified four invasive mosquito species (Walther & Kampen, 2017). Although there are far fewer invasive than native mosquitoes reported, the data has helped researchers to track spatial occurrences (Walther & Kampen, 2017). Researchers are also able to detect the reproduction sites of some of the

invasive species, which is very important to public safety (Walther & Kampen, 2017). The Mückenatlas is an example of the successful implementation of species surveillance through citizen science (Walther & Kampen, 2017). Archived data allows researchers to map and detect changes in mosquito populations and distributions (Walther & Kampen, 2017).

Unlike New Zealand, Germany is not geographically isolated and, therefore, exotic mosquitoes can enter the country through its land borders. Germany therefore faces different biosecurity threats. Additionally, Germany has a population of 82.91 million, while New Zealand has a population of 4.97 million. The Mückenatlas has the potential to draw a much larger audience of citizen scientists. The Mückenatlas provides a useful reference for the Mosquito Census as their process and website interface have proved successful in acquiring citizen science participation.

2.4.2 iNaturalist and Find-a-Pest

iNaturalist is a community-driven citizen science project, created by Scion, that allows anyone to submit photos of species they encounter in the wild (iNaturalist, 2019). These photos are connected to the location where they were taken and then identified by the user to the best of their ability (even if the identification is just “plant” or “bird”), and other iNaturalist users either confirm the identification or suggest a new one. The entries to iNaturalist can then be used to gather taxonomic information on species distributions, biology, and variation (Michonneau, 2015). iNaturalist’s community focus is an inspiration for the Mosquito Census because geographic diversity of data is difficult for professionals to achieve on their own.

Since 2014, iNaturalist has grown to a community of nearly 428,000 observers, submitting over 15.7 million observations of 196,550 different species identified by approximately 63,000 identifiers (iNaturalist, 2019). At the moment, iNaturalist only accepts photographic submissions which, as stated earlier, are usually impossible to use to identify mosquitoes.

Scion has more recently begun working on a mobile app named Find-a-Pest. Similar to iNaturalist, it is a community-driven project where photos of species are submitted and identified to amass valuable data for research. Find-a-Pest, however, focuses specifically on “pests.” The objective of the project is to spot invasive species as they make their way into a country, before they are fully introduced into an ecosystem. Again, Find-a-Pest only utilizes photographs of submissions and does not allow for physical specimens to be sent in. The data and submission locations gained from the app also feeds into iNaturalist and are plotted on the iNaturalist map.

2.4.3 NZBEL

The New Zealand BioSecure Entomology Laboratory (NZBEL), specializes in entomology, border health, biosecurity, and vector control. In addition to offering entomology identification and recommendations to the Ministry of Health, NZBEL manages the National Mosquito Surveillance Database composed of all of the Ministry of Health’s mosquito sampling results. On the NZBEL web page, links to specific datasets and information regarding mosquitoes can be found. However, the data collections are fragmented among a hierarchy of organizations. As a protector of environmental and public health, and an ally in biosecurity risk management, NZBEL endorsed the Mosquito Census effort, excited by the prospect of accumulating

sufficient information on mosquito distribution (Southern Monitoring Services, Ltd., 2018). An NZBEL representative will be one of the mosquito specialists receiving and classifying specimens submitted by citizen scientists for the Mosquito Census project.

2.4.4 Atlas of Living Australia (ALA)

Several institutions around the world have developed a variety of methods to store and access ecological data. The ALA was created in 2007 with the goal of collecting, managing, and sharing the extensive biodiversity data available in Australia (Blackburn, La Salle, & Doherty, 2014). Its creators originally gathered data from museum collections and spent extensive amounts of time digitizing this data. The ALA began with physical collections but continues to grow exponentially through the addition of more museum collections and citizen science. Just three years after its launch in 2010, the Atlas of Living Australia contained over 42 million records compiled from 147 collections and over 700 datasets from 18 different partners (Blackburn, La Salle, & Doherty, 2014). The Atlas of Living Australia currently boasts over one and a half billion downloads (CSIRO, 2011). The developers appealed to a large audience ranging from primary school students to postgraduate researchers with the use of different add-ons and features (Balbin & Williams, 2018). The Atlas of Living Australia currently has over 40,000 registered users who contribute ecological data and is ever expanding its audience (CSIRO, 2011).

The ALA and the Global Biodiversity Information System developed a software to enable the collection and accumulation of biological and ecological data (CSIRO, 2011). Balbin and Williams (2016) claim the Atlas of Living Australia is easily scalable due to the structure of the database and the culture surrounding the collection of data. The Atlas of Living Australia has been successful in linking diverse collections and providing data on all the species in Australia from a wide variety of data providers such as museums, community groups, universities, individuals, and governmental departments, largely due to considerable government funding (Nelson et al., 2015). The availability of the software has stimulated a recent emergence in Atlases of Living in more than ten different nations, including Costa Rica, which has amassed over 7 million records since its launch in 2016 (“The Living Atlases Community”, n.d.).

2.4.5 Atlas of Living Aotearoa

The development of a system capable of long-term management of ecological data is essential to avoid redundancy, manage massive amounts of data, and achieve meaningful progress in dealing with emerging environmental and biosecurity issues (Kobori et al., 2016). Accessibility to standardized ecological data is helping to bring forth evidence-based decision making in policy and management, but New Zealand currently lacks a database that centralizes all ecological and biological data (Balbin & Williams, 2018).

With over 70,000 endemic plant and animal species, New Zealand is one of the most biologically diverse nations in the world (Broke, 2007). Despite recent efforts in New Zealand to convert taxonomic data to digital formats, taxonomic collections are still not easily accessible to members outside of the organizations that maintain the records (Nelson et al., 2015). Currently, New Zealand has roughly 20% of its 12 million specimens available electronically (Nelson et al., 2015). An increased need for access to specimens, images, and data requires new systems for analyzing and integrating research (Schindel & Cook, 2018). A centralized repository of information that caters to New Zealand’s specific biosecurity needs is critical for advancing ecological research and policy decisions to mitigate biodiversity loss (Bik,

2017). Te Papa is seeking to implement an Atlas of Living Aotearoa modified from the Atlas of Living Australia and building on the Mosquito Census project. Rather than merely using Australia's existing system, Te Papa wants to create an independent platform based on New Zealand's unique ecological situation.

Chapter 3: Methodology

The goal of our project was to recommend a collection system and accompanying website interface to enable submission of physical mosquito specimens to Te Papa’s Mosquito Census initiative. We used an iterative design process to formulate recommendations regarding both the layout and features of the Mosquito Census website, as well as details of the submission process.

To achieve this goal, our team identified the following objectives:

1. Identify Needs of Mosquito Specialists and Citizen Scientists
 - Evaluate Successes and Failures of Existing Projects
2. Iteratively Design Prototype Interface
3. Promote Public Outreach

In order to achieve these objectives, we interviewed various experts, designed a prototype interface, tested these interfaces in a temporary exhibit, surveyed museumgoers, proposed an exhibit for the new nature space, and created a proposal containing a recommendation for developers.

Figure 3.1 illustrates the general timeline our group followed to complete our objectives.

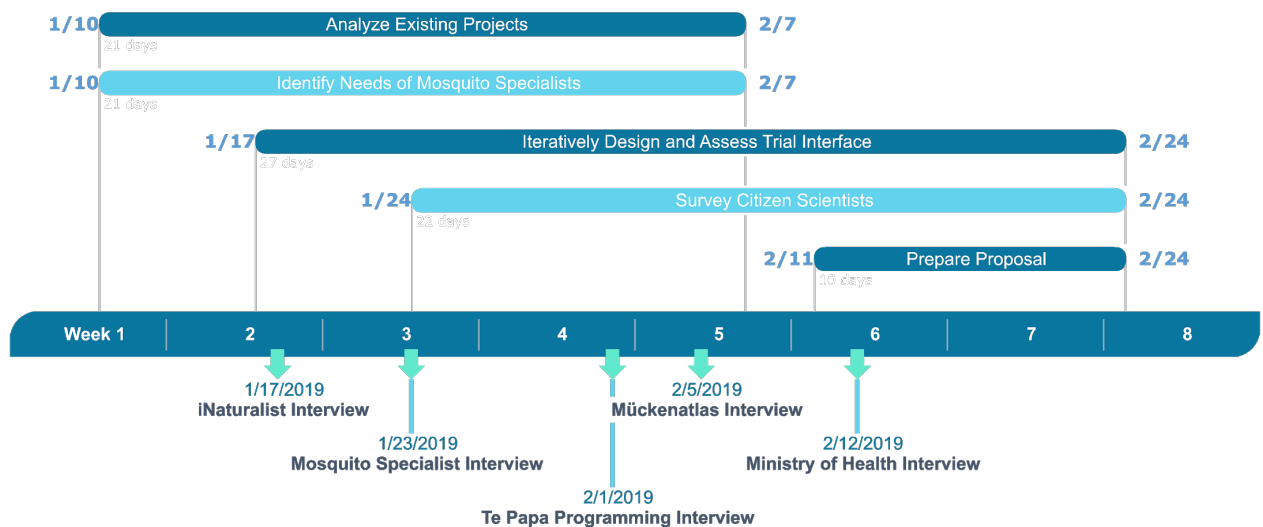


Figure 3.1: Gantt Chart of project timeline

3.1 Interviewing Experts

We conducted a series of face-to-face interviews with mosquito specialists, professionals supporting existing databases, and other experts, supplemented with email and Skype conversations, to identify the needs of the Mosquito Census. Face-to-face interviews ensured that all, or almost all, of the questions posed to informants were answered (Bernard, 2002). Interviewer clarification of word choice yielded highly accurate data (Bernard, 2002). Follow-up questions and additional probing enhanced the depth and quality of responses. To foster a friendly environment, while still ensuring thorough documentation, we

selected two to three group members to attend select interviews. We streamlined our interview process by sharing meeting agendas and interview questions in advance whenever possible. We requested consent to document each meeting or conversation when appropriate. Important quotations and points of consideration were recorded in shorthand, then converted to digital transcripts immediately after each interview. In follow-up correspondence, we shared any direct quotations we hoped to include in our final recommendations, and asked informants if all statements were used in the correct context, with the intended meaning. We then asked if there was anything the informants would like to add, having had time to reflect on the conversation, and asked who else we should interview. The transcripts were subsequently analyzed to determine consensus themes, pros and cons of existing systems, and features to prioritize during the development process. Our sponsor provided us with contact information and introductions to several notable scientists and political figures both within New Zealand and abroad. Conducting face-to-face interviews with some of these contacts was not feasible due to geographic separation and the time constraints inherent in these professionals' schedules. We therefore engaged in email contact or Skype interviews whenever necessary.

We utilized the social science research method of coding to organize interview transcripts in addition to data and quotations extracted from Qualtrics surveys (see section 3.2) and to link this data to broader ideas relevant to the Mosquito Census initiative. Frequently repeated phrases and concepts from meetings like ecological data, biosecurity, and mosquito literacy functioned as deductive codes. Inductive codes, on the other hand, emerged while reviewing survey responses and interview transcripts. Working in pairs, codes were identified, reviewed, then evaluated. Finally, quotations evidencing specific themes were grouped together to facilitate data analysis. The most frequently and least frequently used codes were identified to infer priorities of various parties. Umbrella categories were created to unite related codes. The codebook is included in Appendix I. This process of organizing and connecting data assisted us in addressing the research question, and formulating recommendations for a Mosquito Census initiative to motivate citizen scientist participation and amass accurate and substantial ecological data.

Through interviews, we gained distinct insights from mosquito specialists, domain experts within Te Papa, and professionals supporting existing databases including iNaturalist, the New Zealand BioSecure Entomology Laboratory (NZBEL), Find-A-Pest, and the Mückenatlas. As shown in Table 3.1, these individuals were able to give us different insights on the project. Mosquito specialists at NZBEL refined the structure of citizen scientist specimen submission forms in addition to preservation and packaging methods. Domain experts within Te Papa specializing in public programming, exhibitions, graphic design, marketing outreach, and resource management guided us toward a realistic and comprehensive final proposal to inform the developers and to guide marketing and outreach for the Mosquito Census launch. Representatives of existing databases elaborated upon their own challenges in areas such as media, advertising, politics, and overcoming unexpected obstacles. These collective insights enabled us to identify stakeholder motivations and needs, essential functional and design-based features, and how to successfully engage New Zealand citizens in biosecurity risk management.

Who did we interview?	When?	What did we want to accomplish?
Steve Pawson (Scion Research Leader: Entomology) Jonathan Rudge (MPI Senior Communications Advisor) Julia Kasper (Te Papa Curator: Invertebrates) Susan Waugh (Te Papa Head of Science)	January 17, 2019	Evaluate iNaturalist and Find-a-Pest with regards to the needs of the Mosquito Census
Sherif Ammar (University of Otago PhD Student) Carolyn Edgecumbe (NZBEL Taxonomist) Mariana Musicante (NZBEL Principal Entomologist) Roz McKenzie (NZBEL Taxonomist) Also in attendance: Julia Kasper	January 23, 2019	Recommendations for sample submission form. Feasibility of identification numbers for submissions.
Kate Button (Te Papa Senior Public Programming Advisor) Adrian Kingston (Te Papa Digital Channels Manager) Daniel Crichton-Rouse (Te Papa Senior Digital Editor) Eleanor Holland (Te Papa Public Programming) Scott Ogilvie (Te Papa Museum Educator) Also in attendance: Julia Kasper	February 1, 2019	Ideas for marketing the Mosquito Census to a larger audience. How to handle transition of website development.
Doreen Walther (Zalf Biologist) Nadja Pernat (Zalf PhD Research Student: Mückenatlas) Also in attendance: Julia Kasper	February 5, 2019	Info on Mückenatlas approach regarding Mosquito Atlas logistics, privacy, sensational media, rationale, and marketing and outreach.
Sally Giles (Ministry of Health Senior Advisor) Also in attendance: Julia Kasper	February 12, 2019	Public health perspective on the Mosquito Census project.
Adrian Kingston (Te Papa Digital Channels Manager)	February 13, 2019	Input on Te Papa Museum website requirements
Bas van Druten (Te Papa Experience Designer)	February 19, 2019	Input on Mosquito Census exhibit design

Table 3.1: List of interviews with professionals

3.2 Conducting Surveys

Boasting over 1.5 million annual visitors, The National Museum of New Zealand Te Papa Tongarewa was the ideal venue for reaching a large population of potential citizen scientists in a short period of time (Williams & Foote, 2018). While at Te Papa, we asked museumgoers to complete our survey by either approaching unoccupied visitors or by attracting people to our temporary exhibit and asking interested parties to complete our survey. The latter method proved to be more successful, and allowed us to receive specific input and converse with survey respondents. Creating a small, temporary exhibit in Te Papa allowed us to showcase our design and inform museumgoers about the Mosquito Census project (see Fig. 3.2). While the primary purpose of these interactions was to accumulate survey responses, a very important secondary purpose was to initiate a conversation about pests and diseases in New Zealand. This, in the long term, will hopefully encourage museumgoers to examine their actions in relation to the management of biosecurity risks and encourage them to participate in the Mosquito Census. Ultimately, we utilized a combination of both methods to maximize responses. Figure 3.2 displays our temporary exhibit at Te Papa; additional images can be found in Appendix E.

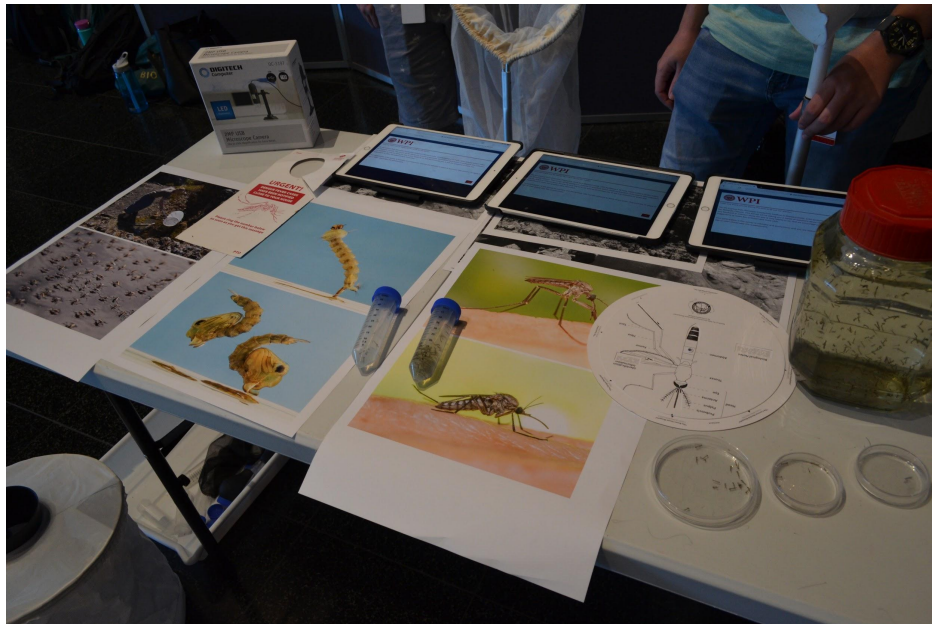


Figure 3.2: Temporary exhibit set-up

We administered the questionnaire on tablet computers through Qualtrics, allowing the data to be logged electronically. Responses collected in this format were especially easy to analyze, due to the fact that they were already digitized. The final survey we distributed contained two different sections. The first part of the survey addressed demographic questions and the respondents' knowledge pertaining to biosecurity in New Zealand, and the second showed a mockup of the interface and asked their likelihood of participation in the Mosquito Census. Questions included how often respondents notice mosquitoes, how they would describe the term "biosecurity," and what factors would make them more likely to contribute to the Mosquito Census. The full museumgoer questionnaire is located in Appendix A. The accumulation of information pertaining to demographics and knowledge about biosecurity and mosquitoes was organized through analysis through Qualtrics and coding of responses, as we described earlier, to

determine consistent themes throughout. Data collected through the first part of our survey provided information important to making future recommendations for public outreach.

Before we administered any questionnaires, we pretested the questions with Te Papa employees including specialists and interns, who are local university students, as well as other students from WPI. This pretest gave us feedback on the structure and content of our questions as well as the effectiveness of the questions themselves. The questionnaire was then modified before being administered to museumgoers. In addition, after the first day of surveying the survey was modified again based on the results of the survey. On the first day of surveying in Te Papa we walked around individually and approached visitors asking them to take our survey. Based on the initial responses we worked to improve the survey by looking at how much time it took a participant to complete the survey and if they had any clarifying questions about the survey. We then reviewed the questionnaire responses and analyzed the information that each response gave us. Based on this we condensed the survey and modified the questions to get the best results possible. A new survey was created and distributed. The results from the first two iterations were stored as reference but were not utilized in the final analysis.

Since the interests of museumgoers are varied, there was a need to acquire a large number of responses to form a consensus opinion (Bernard, 2002). Taking this into consideration, we decided to use social media to gain more responses after the pretest was performed and the survey was amended. The survey was posted on Reddit on the New Zealand page in order to obtain responses from a broader audience. The survey was also posted in the Twitter page for Te Papa, allowing us to reach more museumgoers and more people interested in Te Papa. By utilizing social media, we were able to expand the sample population that our survey reached.

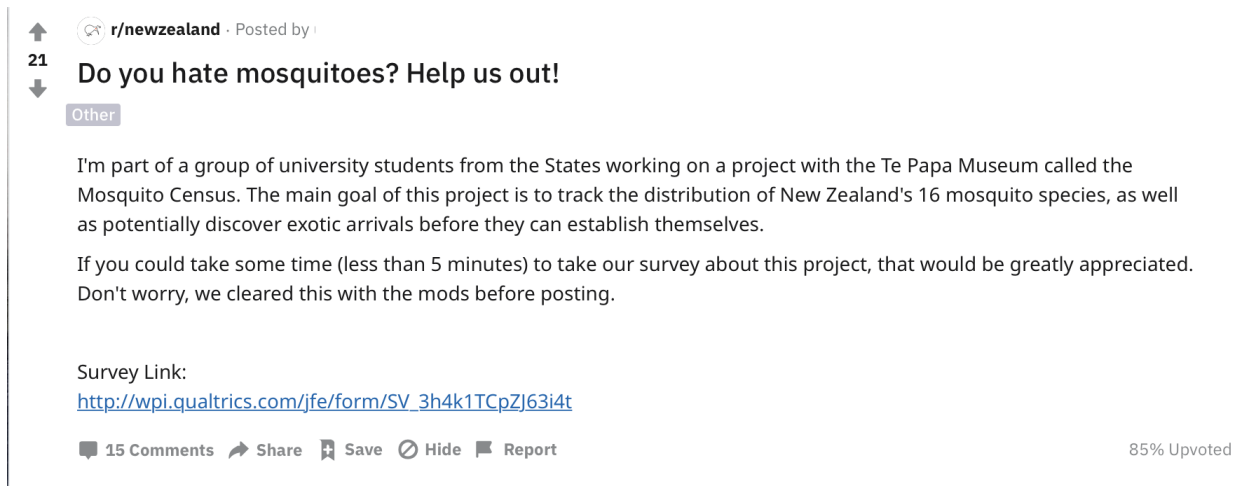


Figure 3.3: Post made on Reddit to advertise our survey

3.3 Designing an Interface

The Mosquito Census website prototype consisted of two distinct dimensions: the front-end and the back-end. The front-end consisted of the website's interactions with users as well as its graphic design. The back-end consisted of the underlying system of recording, storing, uploading, and accessing records of mosquito specimens.

We began by using information from our interviews to construct an initial list of requirements including the functional features necessary to accomplish Te Papa's objectives. Our initial requirements revolved around two major parts of the system: an interface to advertise the platform and to inform visitors about our project and about mosquitoes, and a database to store mosquito submission records.

The requirements of the front-end depend on many factors, as the website has a wide target audience. The website must appeal to all demographics and skill levels, ranging from anyone interested in learning about insects to enthusiasts wanting to submit mosquito samples. We began prototyping this interface in HTML (hypertext markup language) with CSS (cascading style sheets) styling and JavaScript logic. This combination of technologies is how nearly all modern websites operate. HTML defines what visual elements are present on the page. Then, CSS defines how those elements appear. Finally, Javascript, an extensive, well-supported, and well-documented scripting language, defines dynamic behaviors for visual elements. We used some open source third party libraries to speed up our prototyping process, including jQuery and Bootstrap.

A preliminary design was created for the interface and updated based on feedback gained through surveys and interviews which helped to create a final design. We constructed a layout that could satisfy multiple kinds of end-users, including those interested in submitting specimens, but also casual visitors seeking to learn more about mosquitoes. Our design process took this variation into consideration. Additionally, we needed to keep the mosquito specialists informed as well. We constructed a separate database component for them to view and catalog submission information.

The back-end database was built using MongoDB, which is regarded as an efficient and fast database system, using a complicated set of tools to optimize how entries are stored (Banker, 2011). MongoDB uses a document-style format, meaning each record is entered as an independent piece of information, which does not need to follow a consistent schema. This is more flexible than how records are stored in Microsoft Excel.

3.4 Analyzing Functionality of the Website Interface

A second temporary exhibit at Te Papa focused on the functionality of the website interface. The exhibit attracted interested parties and allowed us to conduct informal interviews and observe museumgoers navigating our website. We encouraged museumgoers to test the trial interface and took note of what the users spent the most time on and what parts of the website seemed to confuse them the most. We made sure to record this data, along with any feedback, after each encounter. This feedback was then compiled into one document and coded so that we could identify the most frequent criticisms and adapt our website interface based on this user testing.

Chapter 4: Results and Discussion

Through surveys and interviews, we gained a broader understanding of the requirements of the Mosquito Census. Our survey received 162 responses in total: 40 from in-person surveys at the museum, and 122 from online social media posts. We created a proposal recommending front-end design and back-end specifications for the Mosquito Census website, logistical solutions for linking submissions to mosquito specialists and their identifications to iNaturalist, marketing strategies and outreach programs, and an exhibit for the new natural history exhibition at Te Papa. The Mosquito Census website includes instructions on capturing and submitting mosquito specimens, profiles on mosquitoes in New Zealand, and links to educational resources and existing databases. To the domain experts in marketing and outreach, we communicated survey results indicating baselines of mosquito literacy and biosecurity literacy as well as ideal demographics to target.

4.1 Mosquito Census Requirements

In order to accumulate accurate and substantial citizen scientist records documenting mosquito occurrence, distribution, and ecology throughout New Zealand, barriers to participation must be removed.

4.1.1 Logistics of Physical Specimen Submission

Although collection kits would streamline the process of catching and submitting the mosquitoes, alleviating barriers to participation, a lack of funding has prevented similar projects from supplying interested communities with collection kits. Nadja Pernat, a PhD student evaluating the effectiveness and explanatory power of Mückenatlas data, recalled the distribution of matchboxes adorned with the Mückenatlas logo which served as both advertisements and potential containers for specimen submission (Personal communication, February 5, 2019). Interviewees from various institutions recommended a range of possible containers including, for example, a toothbrush case, a glasses case, and a contact lens container. Although a multitude of objects found at home could serve as vessels for mosquito specimens, survey respondents shared that they would be more likely to participate if a collection kit was provided. As seen in Fig. 4.1, 69% of respondents agreed that collection kits would make them more likely to participate in the Mosquito Census.

I would be more likely to participate if a collection kit was provided.

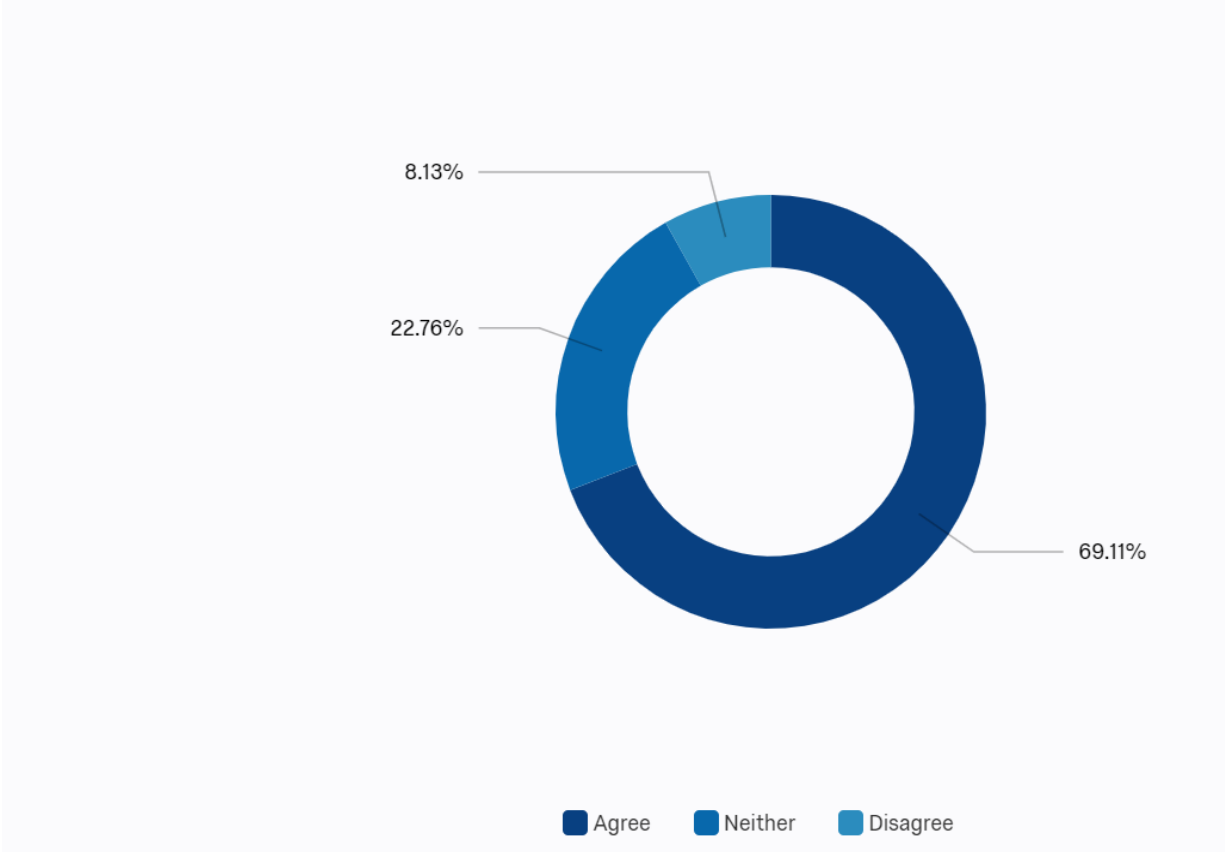


Figure 4.1: Survey results regarding collection kits (n=123)

We addressed inconveniences associated with transporting a physical specimen to the mosquito specialists located in Wellington. Despite our concerns, Pernat and Walther stated that citizen scientist coverage of postage costs had not deterred submissions to the German Mückenatlas (Personal communication, February 5, 2019). Walther admitted, “in fact, we do not know how many people willing to contribute do not submit,” yet only one reimbursement request was made in over 20,000 submissions (Personal communication, February 5, 2019). During our interview with the New Zealand mosquito specialists, we discussed the idea of utilizing local libraries as drop-off locations, and one specialist suggested that we also consider veterinarians’ offices. The majority of survey respondents noted that a drop-off center for specimens would make them more likely to participate as shown in Fig. 4.2. Alternatively, a FreePost account linked to a P.O. Box in Wellington would enable citizens to submit specimens free of charge, while providing a convenient pick-up location for the mosquito specialists. Survey respondents indicated that FreePost would make them more likely to participate as 86% shared this sentiment (see Fig. 4.3) One respondent told us that they would not be as inclined to participate in the Mosquito Census since it “requires sending away the sample which is time consuming.”

A drop off center for samples would increase my likelihood to participate.

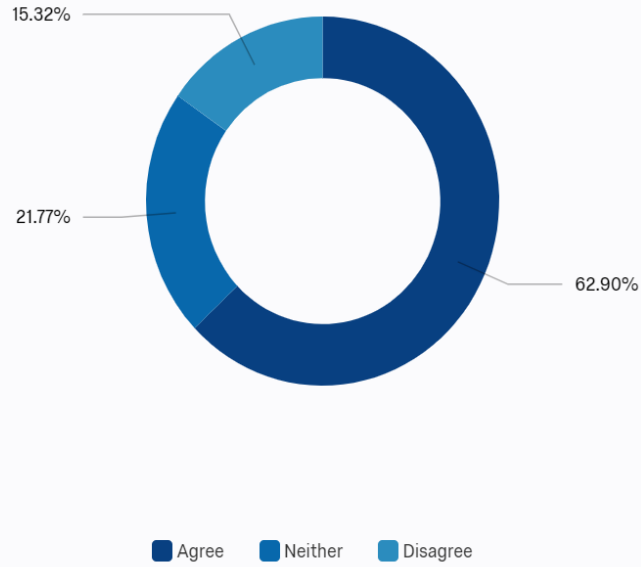


Figure 4.2: Survey results regarding drop-off locations (n=124)

FreePost would make me more likely to send in a sample of a mosquito.

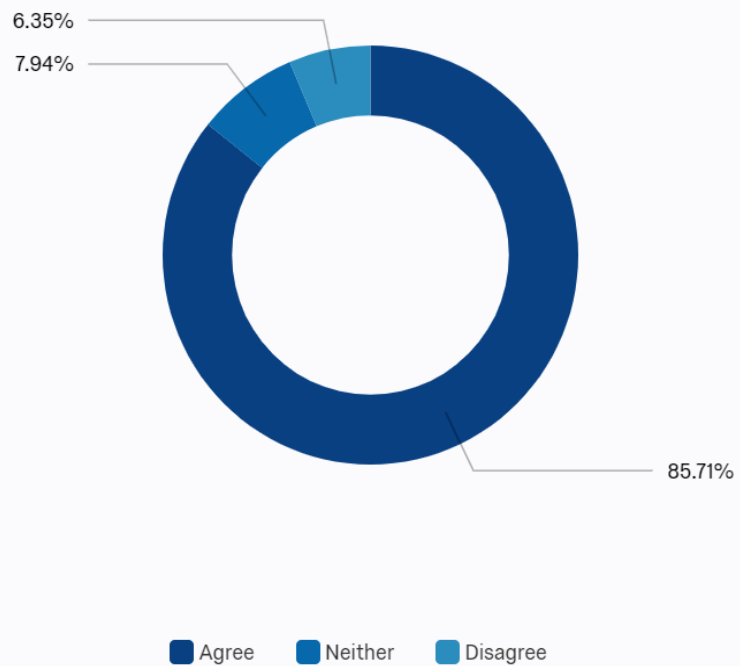


Figure 4.3: Survey results regarding FreePost (n=126)

Mosquito specialists from NZBEL including Dr. Musicante, a principal entomologist, as well as Sherif Ammar, a mosquito specialist PhD student at the University of Otago, discussed information fields that they would like to see on a submission form. All attendees agreed that the location and time of the mosquito's capture were of utmost importance but disagreed on how this data should be formatted.

Sherif Ammar commented that it would be beneficial for researchers to know the date and time of submission, humidity, and temperature at the time of submission, habitat, and region. Steve Pawson, a research leader and forest entomologist employed by Scion, suggested that citizen scientists include a photograph of the specimen and a photograph of the habitat in which the specimen was captured (personal communication, January 28, 2019). To the contrary, the mosquito specialists pointed out that it would be easier for data analysis purposes for citizen scientists to select a habitat from a list of options (e.g. forest, meadow, indoors). Moreover, the specialists offered to photograph the mosquitoes with laboratory microscopes, capable of achieving a much higher level of detail than citizen scientists' smartphones, and attach the pictures to the submissions.

Doreen Walther and Nadja Pernat mentioned that a paper submission form could increase participation, especially from those without access to the Internet or a smartphone (personal communication, February 5, 2019). We found, however, that 98% of respondents reported that they preferred an online form to a paper form (see Figure X). New Zealand citizens' sentiments towards technology are perhaps different than those of German citizens.

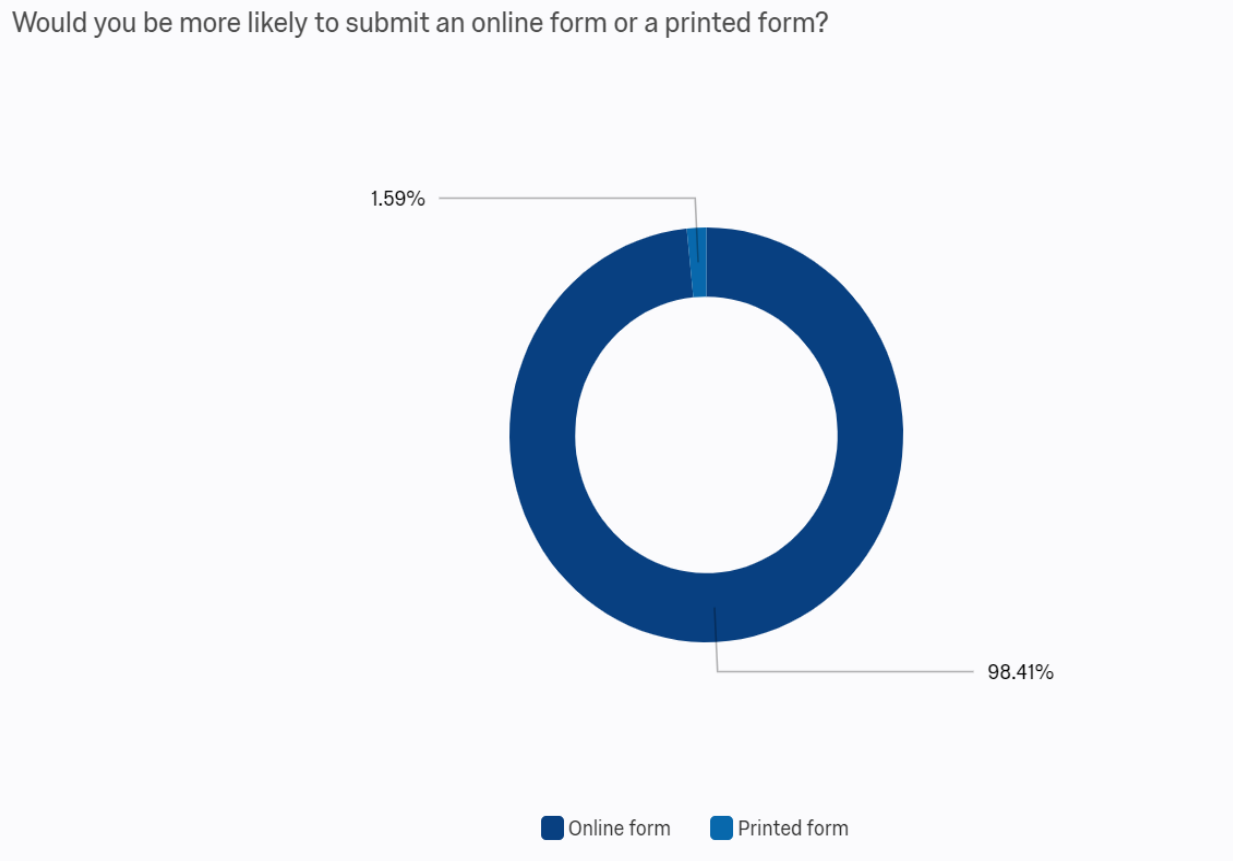


Figure 4.4: Survey responses regarding paper vs. online forms (n=126)

4.1.2 Logistics of Identification

The scope of the Mosquito Census is defined by the availability and resources of the mosquito specialists. The Mückenatlas receives one to two submissions per day in the winter months, but this number skyrockets to fifty to one hundred per day in the summer months (N. Pernat, D. Walther, personal communication, February 5, 2019). Despite this inundation, only one mosquito specialist is responsible for completing identifications, and the identifications are done in her spare time. With half the number of mosquito species, triple the number of mosquito specialists, and less than one twentieth the population of Germany, New Zealand's numbers indicate a certainly manageable scale for establishing a Mosquito Census. We expect the number of submissions to be somewhere around twenty submissions per week, with summer months having more submissions than winter months (J. Kasper, personal communication, February 22, 2019). The specialists' estimate of being capable of ten identifications per person per day is more than enough to cover the expected number of submissions. Automating data entry and transmission processes further increases the efficiency of the Mosquito Census, alleviating the specialists' burden.

There are a few considerations regarding the specimens themselves. Around 25% of the specimens submitted to the Mückenatlas are not mosquitoes (N. Pernat, D. Walther, personal communication, February 5, 2019). However, these specimens can still be useful for collections, and the Mückenatlas does their best to relay the correct species to the submitter anyway. Additionally, people frequently submit squashed or unidentifiable mosquitoes. These rarely can be identified, and thus cannot contribute to their research.

Following the identification of the mosquito, the Mückenatlas pins the mosquito for museum, university, and researcher collections (N. Pernat, D. Walther, personal communication, February 5, 2019). Local researchers can benefit from similar processes, as mosquito collections for studies in New Zealand are lacking (J. Kasper, Personal communication, 2019).

4.1.3 Input Portal Considerations

After specimens are collected and identified, the information must be stored. Representatives from the Mückenatlas underscored the importance of creating a meticulous database to ensure the preservation of all records. Using a third party database would be much less time-consuming and more cost-effective on Te Papa's part, but only if such a database existed that completely satisfies the needs of the Mosquito Census. Existing input portals including iNaturalist and Find-A-Pest were carefully considered as a third party that would then display the data for the world to see. Pawson graciously facilitated a trial comparison between iNaturalist and Find-A-Pest a week before Find-a-Pest went live. We assessed both platforms and created comprehensive pro and con lists. The full lists can be found in Appendix D. However, to ease analysis, the most relevant pros and cons are listed in the tables below in Tables 4.1 and 4.2.

Abbreviated Pro-Con Assessment of iNaturalist

Pros	Cons
Observation reports mapped to illustrate geographic distribution of species	No intermediary step between submission and publication
Gives credit to citizen scientist contributors	Relies on pictures for identification
Photos attached to species submissions	

Table 4.1: Abbreviated pro-con assessment of iNaturalist

iNaturalist, as a data sharing platform featuring a distribution map and accrediting citizen scientists for their efforts, matches the desired database format for the Mosquito Census. Pawson stated, “iNaturalist has no way of delaying anything related to the observation, you hit submit and it is live on the website” (personal correspondence, January 28, 2019). Unfortunately, without an intermediary step withholding submissions from automatically and instantaneously becoming available worldwide, this platform neither considers the need for a mosquito specialist to identify submissions nor exhibits the sensitivity to potential biosecurity threats required by the Mosquito Census. Media releases and a response strategy should be prepared before publicizing the discovery of an exotic species in New Zealand, yet iNaturalist as a submission platform does not allow this. Additionally, the website relies solely on photographs for species identification, which is not suitable for mosquitoes.

Abbreviated Pro-Con Assessment of Find-A-Pest

Pros	Cons
Informative species factsheets	Not all mosquitoes are pests
Photos attached to species submissions	No intermediary step between submission and publication
	Not anonymous
	Funding not guaranteed past June
	No reward or recognition for contributing
	No physical submissions

Table 4.2: Abbreviated pro-con assessment of Find-a-Pest

Although Find-A-Pest is a biosecurity-focused application, the significance and quantity of its cons illustrate that it is not the ideal Mosquito Census input portal. First and foremost, not all mosquitoes are pests, and therefore the premise of the name would misrepresent New Zealand’s endemic mosquito species (J. Kasper, Personal communication, 2019). Additionally, an intermediary triage phase, a distribution map, privacy, sustainability, and citizen scientist recognition are vital elements to be realized in the finalized Mosquito Census. Pawson noted, “Find-a-Pest allows you to delay, but not edit, the publication of the observation until you have added an identification, however you cannot yet add a new

image to it” (S. Pawson, personal correspondence, January 28, 2019). This delay does not satisfy the needs of the Mosquito Census. While less significant than the other cons listed, Pawson himself advised that iNaturalist would be a “less risky option” due to the lack of guaranteed funding (S. Pawson, personal correspondence, January 28, 2019).

4.1.4 Data Sharing Capabilities

Although iNaturalist’s submission process does not satisfy the need of the Mosquito Census, as the community cannot identify mosquitoes from a picture, the data collected by the Mosquito Census can still be put into the iNaturalist database. This process is shown in Figure 4.5. Because the free sharing of data is very important to our sponsors, submitting complete records on iNaturalist will allow widespread access. The Mosquito Census submission process allows for the intermediary steps required for mosquito identification and management of exotic species, and sharing the identification data on iNaturalist promotes the community aspect of citizen science. We found that the best way to share data while also preserving the sense of community in iNaturalist would be to have the submitter connect their iNaturalist account to their Mosquito Census submission. Once identified, the submission would be logged into iNaturalist along with its identification via the submitter’s iNaturalist account name.

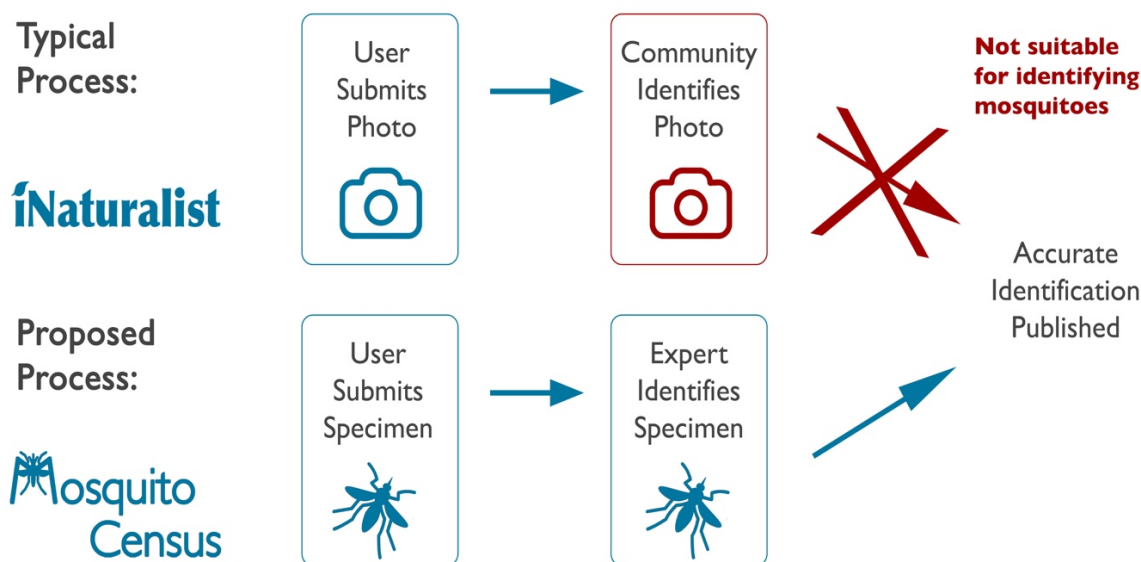


Figure 4.5: Submission process of iNaturalist and the Mosquito Census

The Mosquito Census data must be able to mesh with both iNaturalist and Te Papa’s own collections. With the prototype code, the data can easily be exported to a standard .csv file then uploaded to various platforms including EMu, Te Papa’s private digital collection database, and iNaturalist. In order to determine what information types were required by EMu, we catalogued a variety of insects. Through this process we learned that individually digitizing specimen records is difficult and time consuming. Modifying the output from the Mosquito Census data to be compatible with any software is straightforward as long as we know what fields that software requires.

Adrian Kingston, the Digital Channels Manager at the museum, mentioned that the Te Papa website currently uses the museum’s own framework. He suggested that in order to increase confidence in the program, the Mosquito Census should be a part of Te Papa’s official website. Kasper added that a Mosquito Census page within the Te Papa website will ensure that the project pops up quickly on searches and will be easy for people to find. Constructing the Mosquito Census on the same back-end framework will allow for its seamless incorporation into Te Papa’s website. In addition, Adrian Kingston mentioned that extensive documentation will help him and his team take over construction of the website after our team’s departure. This documentation will also assist them update the website in the future.

4.2 Citizen Scientist Involvement

The Mosquito Census cannot function without citizen scientists to collect mosquitoes. In order to motivate participation, we needed to learn more about their baseline knowledge, privacy concerns, and interest level.

4.2.1 Mosquito and Biosecurity Literacy

An assessment of the target audience’s baseline knowledge of mosquitoes and biosecurity will direct public programming efforts to advertise the Mosquito Census. According to Kate Button, manager of public programs at Te Papa, surveying could, “identify gaps in public knowledge,” and thus inform public programming. Common misconceptions regarding mosquitoes could negatively affect Mosquito Census involvement. For example, a mere five survey respondents knew that only three of New Zealand’s sixteen mosquito species were introduced, and 68% of the respondents thought that over half of New Zealand’s mosquito species were introduced (see Fig. 4.6).

How many of New Zealand's 16 mosquitoes are introduced?

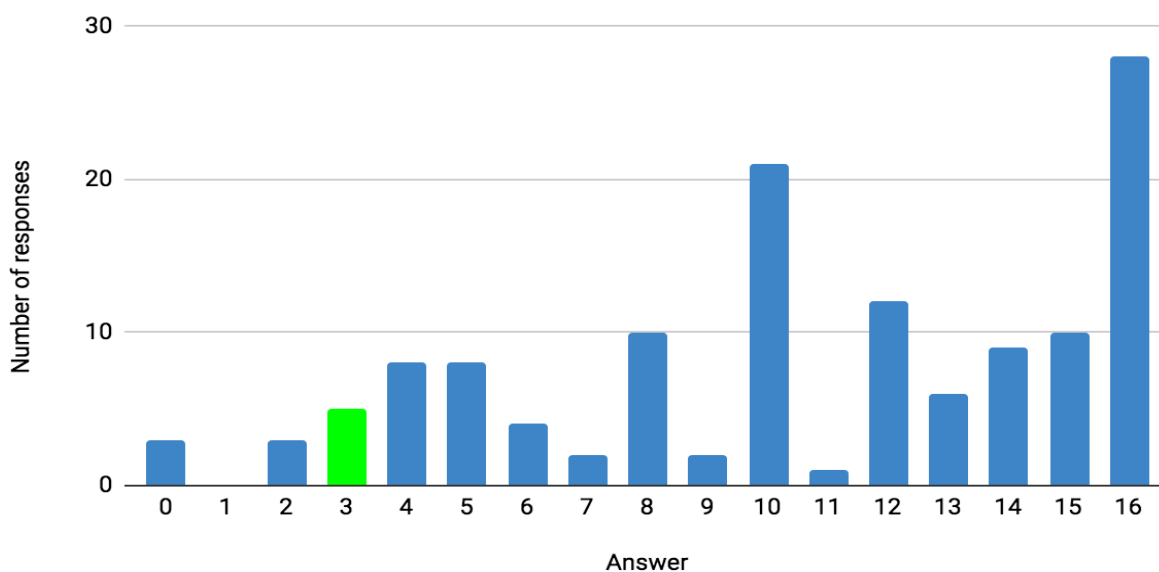


Figure 4.6: Respondents’ guesses of how many introduced mosquito species New Zealand has

Furthermore, survey respondents were by and large unaware that the thirteen endemic mosquito species are bird biters and pollinators incredibly useful to New Zealand, while its three introduced species are

responsible for most human bites. Public programming specialists could raise awareness of mosquito-borne diseases, biosecurity in New Zealand, opportunities for career paths for young people, and the benefits of mosquitoes in our ecosystem if such information gaps are identified. Our survey also asked how mosquitoes should be dealt with in New Zealand and asked the respondents to check all applicable options. Fifty-two respondents supported the eradication of all mosquito species in New Zealand and fifty-six respondents supported the eradication of only introduced mosquito species. Seventy-seven respondents preferred that researchers monitor distribution patterns of mosquitoes throughout New Zealand, eighty-two respondents believed that the border should be monitored for invasive mosquito species, and ten respondents thought that researchers should not interfere with natural patterns. The project also aligns with the Ministry for Primary Industries (MPI) goal of establishing a baseline of New Zealanders' knowledge about existing mosquito species in New Zealand.

MPI is one of many stakeholders interested in raising public knowledge of biosecurity. We found that most survey respondents considered biosecurity to be “keeping New Zealand safe and free of invasive species.” Respondents also mentioned that biosecurity is the “protection of the population, environment and ecosystems from pathogens and invasive species.” Campaigns improving the mosquito and biosecurity literacy of the target audience will prepare potential citizen scientists for the launch of the Mosquito Census. As one survey respondent worded it, “if it helps the eco balance of our country, then I want to help.” Yet another respondent emphasized the importance of biosecurity in New Zealand, stating, “it is vitally important to protect NZ from exotic invaders as we have a unique environment.”

4.2.2 Privacy and Public Image

Stringent European privacy laws motivated the Mückenatlas to require physical consent signatures, to allow the use of pseudonyms, and to keep mosquito data proprietary. Considering 66-70% of submissions are from citizens' own homes or backyards, the Mückenatlas elected to dissociate participant data from submission data (N. Pernat, D. Walther, personal communication, February 5, 2019). Furthermore, they feel their use of paper submission forms and paper thank you letters evoke a feeling of trust among participants. Citizens may contribute to the Mückenatlas without going through the trouble of connecting to the Internet, downloading an application, and creating yet another account. Due to biosecurity reasons and ministry sponsorship, the Mückenatlas records are only for research at this point and not publicly accessible. The ministry owns the database and prefers to perform risk analysis prior to releasing data. Doreen Walther and Nadja Pernat noted that they do not display the species found on their annual distribution maps due to privacy concerns (Personal communication, February 5, 2019).

Maintaining a positive public image is vital to the longevity of the Mosquito Census initiative. Te Papa will establish a relationship with media outlets, including prominent newspapers and radio stations, early on in order to avoid any misunderstandings or misquotes. Walther and Pernat said that, “the media is more or less our best friend,” and the reason people constantly submit specimens to the Mückenatlas (N. Pernat, D. Walther, personal communication, February 5, 2019). Pawson noted that one main focus of Find-A-Pest is monitoring introduced species, and that there are hopefully no new exotic species being brought into the country (S. Pawson, personal correspondence, January 28, 2019). Emphasizing this focus detracts from sensationalizing exotic species. We found that the German strategy to manage public image consists of requesting to review articles before they are published, advertising successes and going to the media with important discoveries and positive mosquito news, and preparing a press release in the event of a panic. The misrepresentation of scientific findings to incite public reactions has been such that our

correspondents at the Mückenatlas, “do not release data on submission of invasive species or potential vectors not cross-checked in the field, ... since in those cases control might be necessary” (N. Pernat, D. Walther, personal communication, February 5, 2019). This reserves time to develop a “plan B” in case sensational media is later propagated or in the event that information is leaked in the wrong way (J. Kasper, personal communications, 2019). Distribution maps of all mosquito species reported throughout Germany each year are, “made available to the public after publication of the data,” while, “authorities will be informed immediately in the case of local reproduction of invasive species” (N. Pernat, D. Walther, personal communication, February 5, 2019).

Although it is unlikely that an exotic mosquito will be discovered in the New Zealand interior due to its border surveillance program and geographical isolation, a slight delay to allow authorities to respond to the potential biosecurity threat is one reason the Mosquito Census requires an intermediary step between input portal and global public access. A possible solution for the Mosquito Census would be to not display any exotic submissions on the map until the Ministry for Primary Industries and Ministry of Health begin to handle the situation, and even then “fuzz” the location data so the exact location can’t be determined.

The Ministry of Health is supporting the Mosquito Census “by providing entomology services, and contributing funds to develop promotional material (a short video clip)” (Sally Giles, personal communication, February 14, 2019). In addition, the Ministry of Health Communications team will work closely with Te Papa and Ministry for Primary Industries Communications staff to ensure consistent and appropriate messaging for the Mosquito Census. They will also support social messaging and provide appropriate responses to any media interest.

4.2.3 Encouraging Participation

The sustainability of the Mosquito Census is also dependent upon determining the rationale behind citizen scientist contributions and rewarding participants to encourage future engagement and sustain positive public perception. Kasper hypothesized that during peak summer months, people are annoyed with mosquitoes and more likely to become involved. Around two thirds of respondents who live New Zealand notice mosquitoes often in their everyday lives (see Fig 4.7). Contributions to iNaturalist are largely motivated by its community-based structure. Pawson stated iNaturalist moderators have formed a tightly-knit community by staying in touch with contributing citizen scientists (S. Pawson, personal correspondence, January 28, 2019). Of those surveyed, however, only 10% had heard of iNaturalist (see Fig. 4.8). Some 20-25% of contributors to the Mückenatlas are repeaters (N. Pernat, D. Walther, personal communication, February 5, 2019). The Mückenatlas’ thank you letter informs participants of the species and breeding habits of the mosquito identified, while noting how helpful it would be if the submitter caught more mosquitoes from their region to allow the Mückenatlas to perform comparisons with previous years. For the Mosquito Census, specialists emphasized that having submissions over a broad distribution would be helpful for future research rather than multiple submissions from the same exact area. To gauge whether people would be interested in sending in multiple samples, the survey asked how many times if at all could the respondents see themselves submitting to the census. As shown in Fig. 4.9, respondents were most likely to submit between 1 time and 2-4 times.

How often do you notice mosquitoes in your daily life?

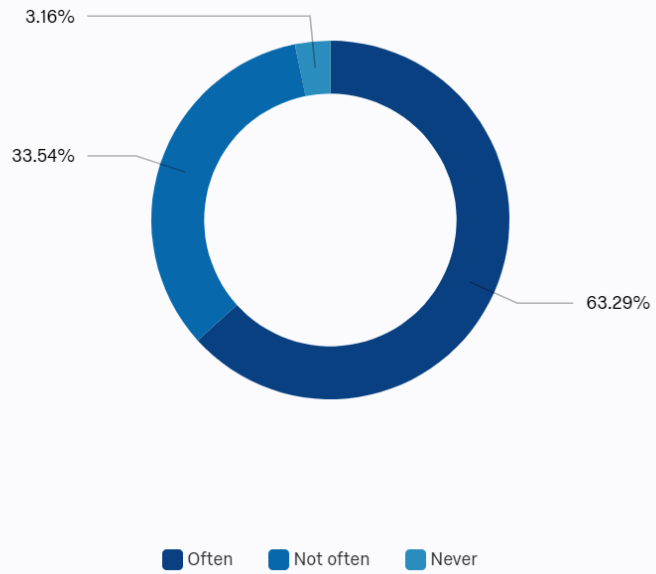


Figure 4.7: Survey responses regarding noticing of mosquitoes (n=115)

Have you heard of iNaturalist?

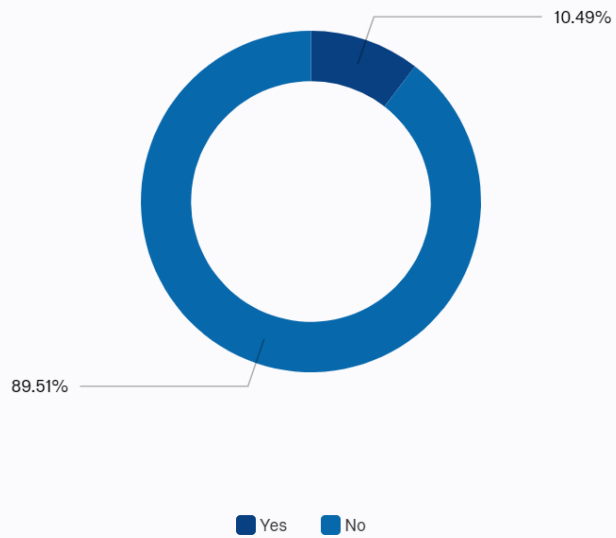


Figure 4.8: Percent of survey respondents who have heard of iNaturalist (n=162)

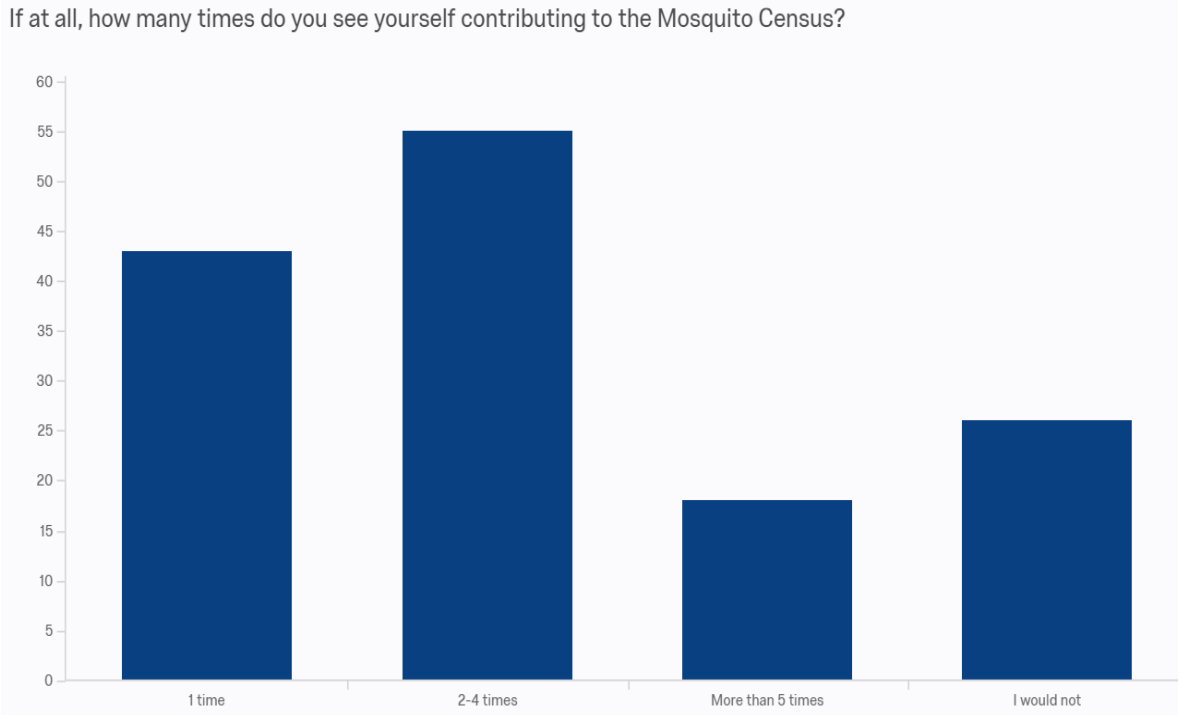


Figure 4.9: Survey responses regarding future participation (n=142)

4.2.4 Marketing and Outreach

Marketing campaigns and outreach programs may persuade anyone on the fence to participate in citizen science data collection (J. Kasper, personal communication 2019). One survey respondent noted that they “don’t know enough about the importance of [the Mosquito Census] and what it impacts to know why [to submit].” Dr. Kasper, recognizing the logistics involved in submitting a physical specimen, noted that in order to engage the youngest generation of potential citizen scientists, the Mosquito Census must first appeal to their parents. The parents then can assist and engage the children in collecting and submitting the specimens. One survey respondent noted, “my kids enjoy engaging with insects and very much dislike being bitten by mozzies so I would likely include them in the activity and it would feel good to be helping.”

The Mosquito Census will only succeed if citizens of diverse regions participate; Kasper stated she is worried that repeated submissions from the same people would fail to illustrate the distribution patterns of mosquito species throughout New Zealand. One survey respondent noted, “I’m likely to be seeing the same species over and over so it may not be useful to keep collecting more except to show presence over time.” Publicizing the important roles that mosquitoes play as pollinators and in the nutrition web may pique the curiosity of those individuals on the fence about contributing to a citizen science project. The survey shows that 44% of respondents would be either somewhat likely or very likely to send in a specimen to the Mosquito Census (see Fig. 4.10).

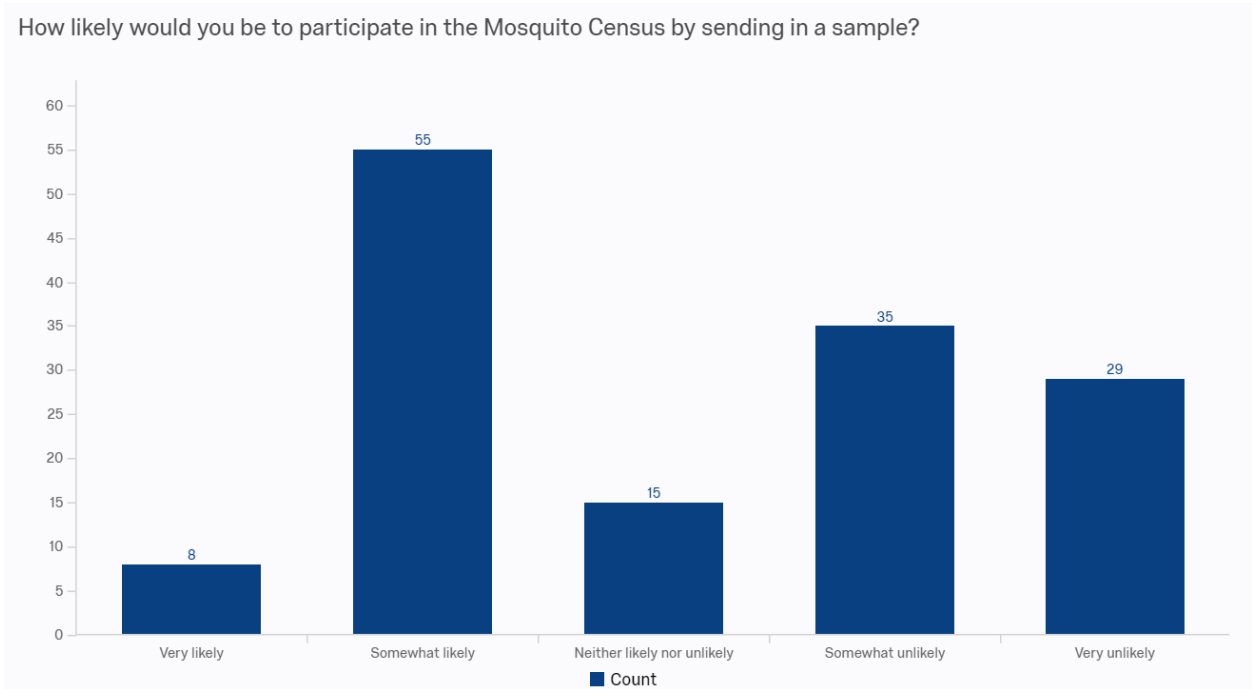


Figure 4.10: Survey respondents' likelihood of contributing to the Mosquito Census (n=142)

The unveiling of the Mosquito Census is scheduled for the beginning of summer 2020, leaving Te Papa ample time to boost mosquito and biosecurity literacy and to elevate public interest in the objectives of the Mosquito Census. While surveying and chatting with museumgoers at Te Papa, we realized the untapped potential of homeschool communities and retirees. Participating in the Mosquito Census “could be a fun activity to do with my children,” said one respondent. Fig. 4.11 shows the breakdown of the survey respondents age with their likelihood to participate. The greatest likelihood of participation based on percentage is for the age range of 46-55. It is also important to note that the majority of each age range choose likely to participate except for 18-25 year-olds and 65+ year-olds. Marketing for the Mosquito Census should take into account the preferred news sources and interests of these demographics. With this information, Te Papa can get an idea of how to market the Mosquito Census and the best way to spread mosquito literacy.

		How likely would you be to participate in the Mosquito Census by sending in a sample?					Total
		Very likely	Somewhat likely	Neither likely nor unlikely	Somewhat unlikely	Very unlikely	
In what age group do you fall?	18-25	2 4.44%	12 26.67%	7 15.56%	13 28.89%	11 24.44%	45 100.00%
	26-35	1 2.94%	14 41.18%	4 11.76%	11 32.35%	4 11.76%	34 100.00%
	36-45	3 10.34%	13 44.83%	2 6.90%	6 20.69%	5 17.24%	29 100.00%
	46-55	2 14.29%	8 57.14%	1 7.14%	2 14.29%	1 7.14%	14 100.00%
	56-64	0 0.00%	7 58.33%	0 0.00%	2 16.67%	3 25.00%	12 100.00%
	65+	0 0.00%	1 12.50%	1 12.50%	1 12.50%	5 62.50%	8 100.00%
	Total	8 5.63%	55 38.73%	15 10.56%	35 24.65%	29 20.42%	142 100.00%

Figure 4.11: Cross table of age and likelihood of participation

Respondents who selected that they would be unlikely to participate shared why they would not participate. Some common reasons include the “amount of effort and time required,” that “mosquitoes are hard enough to kill, let alone catch” and that they “don't often see them [mosquitoes].” On the other hand, a respondent who said they were likely to participate stated that “it is fun and I get to contribute to science.” Another said, “I would like to see mosquitoes get a bit more under control.” From identifications in Te Papa’s online collections to invasive diseases to endangered native species, there are several access points for advertising the Mosquito Census. For example, we met multiple teachers during our in-person surveys at Te Papa Museum, who recommended that we create a lesson plan for students. Creating a lesson plan to go with a mosquito hunt would be a great way to involve teachers and homeschoolers.

According to Te Papa’s marketing team, marketing via newspaper or radio is the best way to reach such widespread potential participants, while outreach fosters long-term interest. Kasper emphasized the potential for overlap between public programming and collecting specimens, suggesting citizen science school programs for children. Mückenatlas representatives published teacher instructions to inform students of their project (N. Pernat, D. Walther, personal communication, February 5, 2019). Scott Ogilvie, Museum Education Specialist, agreed that extending training to schools could yield “heaps” of specimens. Teacher lesson plans incorporating mosquito and biosecurity literacy, educational outreach programs, and bio-blitzes are exciting opportunities to engage younger audiences. Engaging with children can foster an enduring interest in taxonomy and ecology (MPI, 2016). In the past, Kasper has volunteered in schools, turning pipetting larvae into a competition or illustrating the spread of viruses with cranberry juice and glitter. She proposed hands-on family and young adult field trips to teach participants how to distinguish mosquitoes from other insects and how to catch mosquitoes for the Mosquito Census.

We engaged in participant observation during a mosquito hunting exhibition to Moa Point outside Wellington, capturing both adult and larvae *Opifex fuscus* specimens. The coastal views and energy release of mosquito hunting could motivate future collections. On the other hand, mosquito hunting is improved by patience, equipment, and knowledge of mosquito habitats and habits. Without Kasper to direct us to the most popular pools, show us how to avoid scaring the swarms of adults into the rocks, and

demonstrate proper use of the collection equipment to capture larvae or vacuum adult mosquitoes from a net to a test tube, we could not have collected a fraction of the specimens we did. 30% of survey respondents indicated that they would be interested in participating in a mosquito hunt led by a specialist. From participating in this expedition and analyzing survey responses, we found that access to a mosquito specialist and to collection equipment was tremendously helpful for first-time mosquito hunters. More pictures of this mosquito hunt can be found in Appendix G.



Figure 4.12: Dr. Kasper transferring larvae into a container during the mosquito hunting expedition

4.3 The Website Prototype

We drafted a fully-functional prototype of the website, including a submission form, a map of submissions, and a database to store them.

A new visitor first sees the landing page (see Fig. 4.13), which contains large graphics and bright colors.



Figure 4.13: Landing page of the website prototype

The landing page features a button labelled “I found a mozzie [mosquito],” which leads to the submission form. When a user is ready to submit a mosquito specimen, they can fill out the online form or download the paper version and print it out. Alternatively, if they have not yet found a mosquito, they can simply scroll down and view some information on mosquitoes, written by our team with the help of Julia Kasper (see Fig. 4.14). This section discusses the threat of exotic mosquitoes, while clarifying that this is not currently a problem in New Zealand, as to avoid concern. The text then discusses the overall purpose of the Mosquito Census, which is broader than simply hunting exotic species and talks about the various other research areas that can benefit from the data we collect.

Mosquitoes in New Zealand

Did you know that there are approx. 3,000 different mosquito species worldwide? New Zealand is the natural home of 13 of them. They only occur here - nowhere else in the world (endemic species) - and are mainly bird biters. Three foreign species have been introduced to New Zealand between 80 and 200 years ago. If you get bitten, it is likely one of those 3, as they like human blood.

The Threat

Have you heard of Malaria, Dengue or Zika? In some other countries these diseases can be transmitted via mosquito bites. So far we are lucky: We have no human diseases that are transmitted by mosquitoes in NZ and we don't have the mozzie species that are able to do so – just yet! Traveling and incoming goods could bring exotic mosquitoes to New Zealand. Underutilized habitat and little local competition with our few endemic mozzie species as well as climate change would offer some exotic species great exploitation potential. That's why international air and seaports are constantly monitored for mosquitoes and shipping containers are regularly checked by [MPI](#) and [MoH](#) to help protect our environment and our health. We can do our part by discovering the kinds of exotic species that may already inhabit our island.

Purpose of this Project


Biosecurity helps to protect our environment and our health... Ko tatou – this is us... We can do our part by discovering helping to find exotic species by. But more than that, we can help to understand the distribution of our native flora and fauna and how it changes with the spreading of introduced species to understand potential breeding habitat and distribution potential of exotic species. Help us to find out which mosquito species are living in your neighborhood and bring them on the map. Find out how

Figure 4.14: Mosquito information section of the website

Mosquito Species

Here are some mosquito species that exist in New Zealand.


– *Aedes notoscriptus*



Common Name	Striped mosquito
NZ Status	Introduced
Genus: <i>Aedes</i>	Subgenus <i>Finlaya</i>

Aedes notoscriptus were introduced to New Zealand through shipping in the 1920s. It is a vector of dog heartworm (*Dirofilaria immitis*) in Australia. Preventing new arrivals of this species decreases the chance of disease agents being introduced to the native population. They reach peak numbers during warmer months, and they prefer to bite in the evening and early morning. Their physical characteristics include: lyre shaped scutal pattern, bright white stripes on very dark legs, and banded proboscis.

+ *Culex pervigilans*



+ *Culex quinquefasciatus*




Figure 4.15: Mosquito species information

The user can scroll down further to see a catalog of existing mosquitoes in New Zealand (see Fig. 4.15). Each mosquito has its own description beginning with a brief history and a taxonomic description for each species. The description also includes the status of that mosquito in New Zealand, which may be *introduced*, meaning it did not live here before being carried in by humans, *endemic*, meaning it only exists natively in New Zealand, or *exotic*, meaning it does not yet dwell in New Zealand.

The site also features a map of our public database records (see Fig. 4.16), which are the submissions that have been properly identified and published by the mosquito specialists. This would enable users to visualize where each type of mosquito has been found, as well as where people are submitting from.

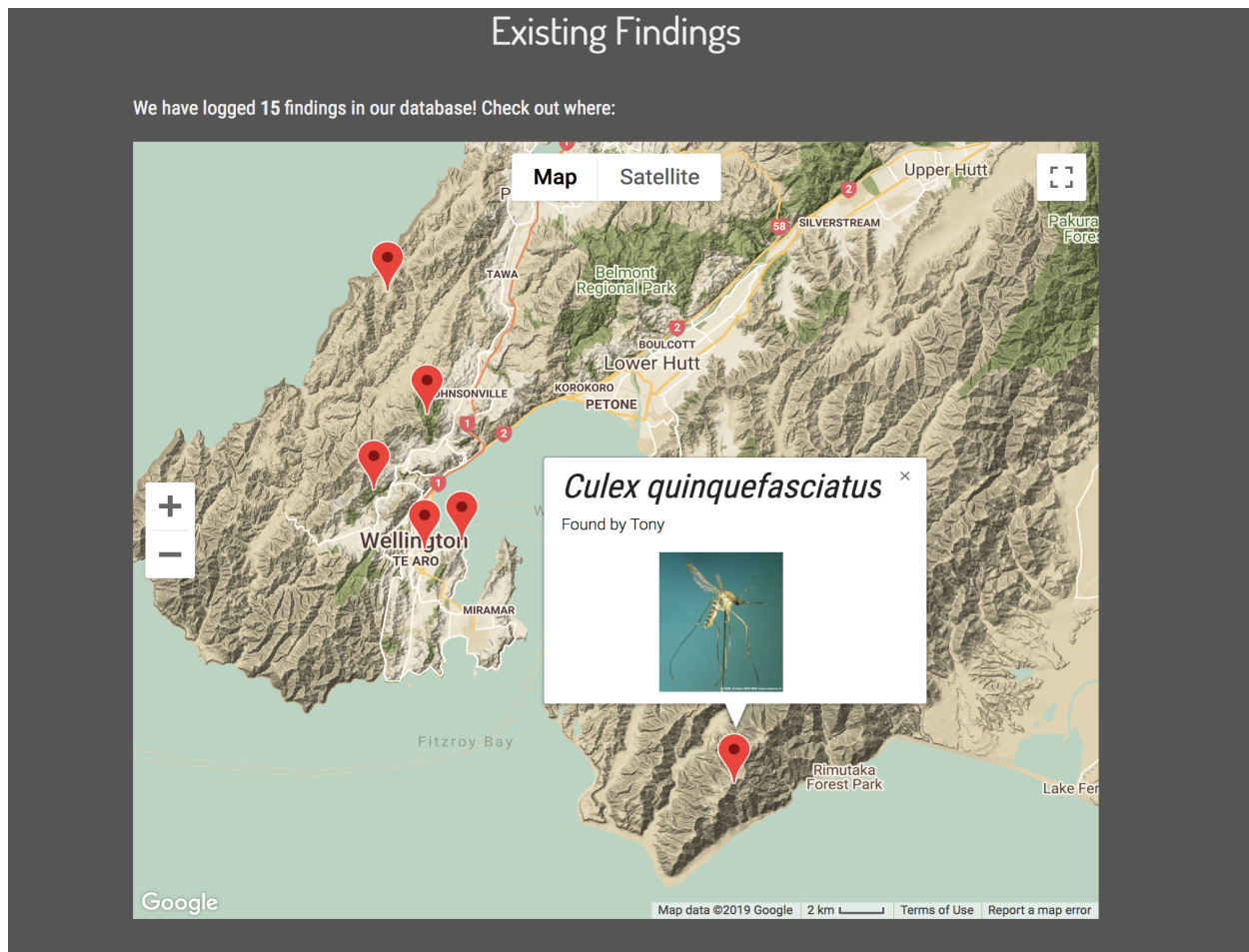


Figure 4.16: Findings map

The website also contains links to existing platforms that have helped the Mosquito Census (see Fig. 4.17).

Who Else is Involved?




Mückenatlas	iNaturalist	Find-A-Pest
 Mückenatlas <i>Jede Mücke zählt!</i>		
https://mueckenatlas.com	https://www.inaturalist.org	Find-A-Pest
<p>The Mückenatlas is a mosquito tracking platform already successfully operating in Germany!</p> <p>Similar to our Mosquito Census, the Mückenatlas encourages everyone to submit samples of mozzies for identification.</p>	<p>iNaturalist is a global platform for "naturalists", or anyone excited by biology and nature, to discover plants and animals around them!</p> <p>With its growing community, iNaturalist records thousands of observations of wildlife.</p>	<p>Find-A-Pest is a mobile application that allows users to report findings of dangerous critters.</p> <p>Many forms of weeds, diseases, and other pests can be tracked, helping to keep New Zealand safe and healthy.</p>

Figure 4.17: Links to collaborators

The website also hosts the submission form for the mosquito findings that are sent to the Mosquito Census (see Figs. 4.18-4.20). A user first fills out this form, which asks them for basic contact information, and details on where and when they found the mosquito. If they are using a mobile phone, the website can access their current location through the web browser. If the submitter happens to still be in the same location as where the mosquito was caught, they can simply click the “found it now” button. This will save their location information and enter in the information automatically. The form also asks the submitter to guess which mosquito species they found. This guess is not considered in our evaluation of the specimen, but is meant to make the process more engaging for the user. The form also presents the submitter with an option to remain anonymous, rather than have the finding published in their name. Alternatively, the user has the option to be attributed under a pseudonym.

Finally, the submission form asks the user whether or not they want to have their submission directly uploaded to iNaturalist under their account name following the submission’s identification. The user can log in to iNaturalist, and give permission to the Mosquito Census to submit the information on their behalf to their account. This is done using a protocol known as OAuth, which is a widely-trusted and secure means of giving third parties limited and temporary access to an online account (Leiba, 2012). The iNaturalist submission, however, is completely optional.

Once the information on the form is filled out, the user can submit the specimen. The user is issued a sample number, which can be written on the submission package before sending it in. This will allow the physical specimen to be linked with the information from the form. The submitter then receives an email thanking them for their contribution. Once the mosquito has been identified by a mosquito specialist, the submitter receives an automated email, thanking them again for their contribution and informing them of which mosquito species they found.

X

Submit a Mosquito Sample

I just found the Mosquito now! Autofill all info based on where I am.

FOUND IT NOW

OR

Fill out the details of your finding!

Your Name

Anthony Topper

Your Email

ajtopper@wpi.edu

WHEN did you find this Mosquito?

2019-01-31 12:00


In what habitat did you find this Mosquito?

Backyard
▼

Figure 4.18: Beginning of submission form

WHERE did you find this Mosquito?
 Tell us approximately where you found the Mosquito. Don't worry if you're not exactly sure where.

Click on the map to select a place!



Lat 41.2901 S

Lon 174.7823 E

Just for fun!

What species do you think this Mozzie is?

Culex quinquefasciatus
▼

Figure 4.19: Submission form prompt for location and a guess for the species

Permissions

I consent to being credited for the discovery, including mention of my name to 3rd party distributors, such as [iNaturalist](#)

Would you like to be cited under a different name?

Pseudonym

If you'd like to link your submission on [iNaturalist](#), click here:

Figure 4.20: Prompts for privacy and linking with an iNaturalist account

Once the user submits the form, they are directed to a page that displays a simple set of instructions on how to submit their specimen. The three-step process describes how to catch (Fig. 4.21), preserve (Fig. 4.22), and send in (Fig. 4.23) their specimen.

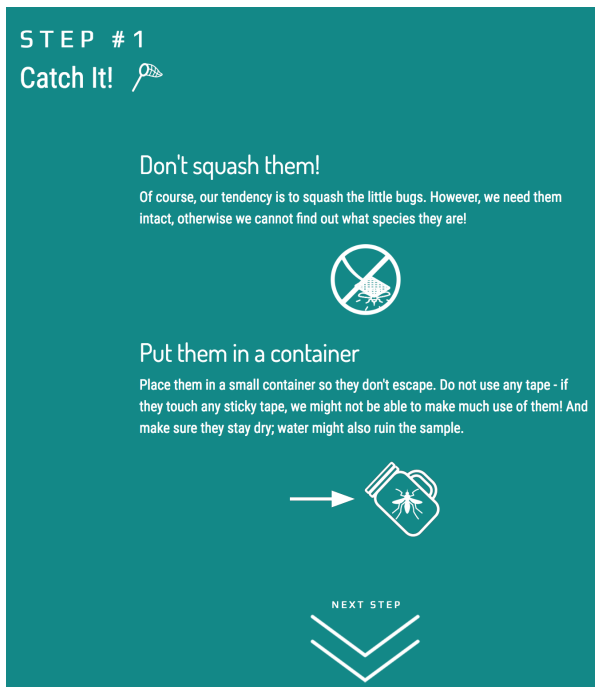


Figure 4.21: Step one of the submission process: "Catch it"

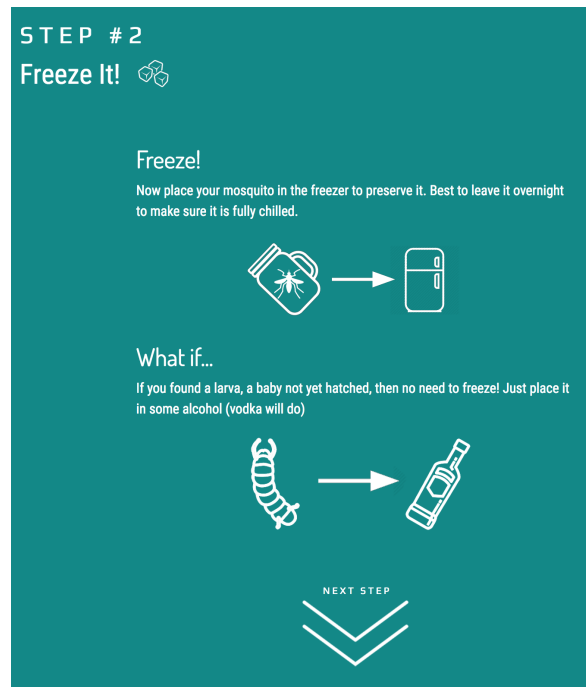


Figure 4.22: Step two: "Freeze it"

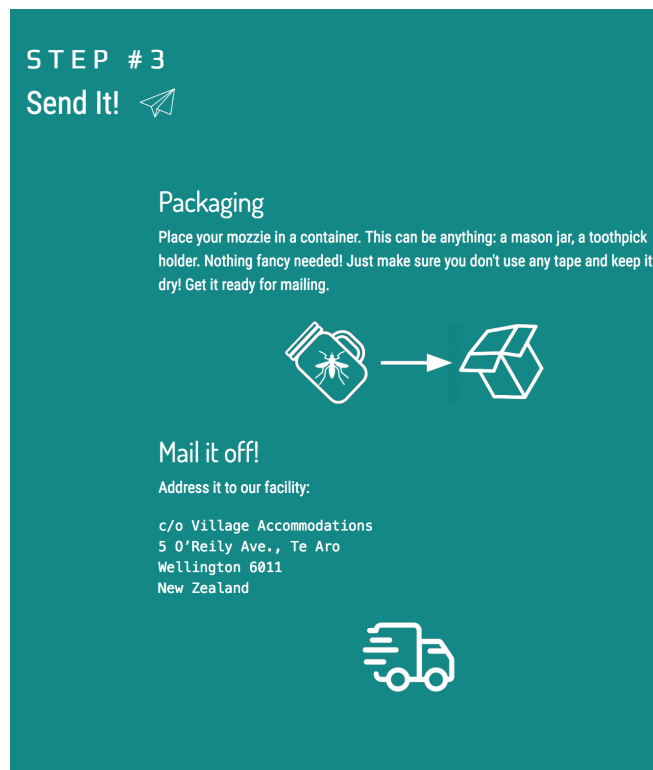



Figure 4.23: Step three: "Send it"

The Mosquito Census website also provides a paper alternative to the online form which can be printed out and sent in the parcel containing the specimen (see Fig. 4.24).



<http://mosquito.demo.anthonytopper.com>

Mosquito Finding Submission

Personal Information

Name	Email
Phone	

Personal Information Use (**CHECK ONE**)

Do you consent to including your name in your submission? Your name will be published along with your record. If not, you will remain anonymous; your contact info will only be used to follow up with you once your sample is identified.

YES, give me attribution for this record

NO, keep my information private

Finding Information

When did you find this Mosquito? (e.g. "Afternoon on 2nd Feb")

Where did you find this Mosquito?

This does not need to be specific. You may provide an address, or a general area (e.g. "In Alexandra Park")

In what environment was this Mosquito? (**check all that apply**)

Forest Backyard Indoors Other (describe below)

Final Instructions

Thank you for filling out all this info! Now all you need to do is send in your sample. Please make out the post to the following address:

c/o Village Accommodations
5 O'Reilly Ave., Te Aro
Wellington 6011
New Zealand

Figure 4.24: Paper submission form

A back-end interface (see Fig. 4.25) was also created for the mosquito specialists to access the online submission records. The back-end displays a table of all the submissions, including each sample number, as well as a drop-down that elaborates more detail. The back-end also shows a map of where the submission was found, and allows the specialist to enter information regarding the age and gender of the specimen, as well as the species identification. The website also automatically calculates weather information, including temperature and humidity, based on the submission's location and time. Specialists can mark each submission as incomplete, in progress, complete, unidentifiable, or that it was not a mosquito. The results can be sorted by this status allowing for submissions that have already been completed to be hidden.

+	COMPLETE	596482	Anonymous	Culex quinquefasciatus	https://www.inaturalist.org/observations/19959021
+	COMPLETE	412452	Tony	Culex quinquefasciatus	https://www.inaturalist.org/observations/19959008
+	INCOMPLETE	643649	Anthony Topper	Culex pervigilans	https://www.inaturalist.org/observations/19956296
-	COMPLETE	819986	Anthony	Culex pervigilans	https://www.inaturalist.org/observations/19936154

Images

Choose Files No file chosen

Location

Weather

Based on the time and location of the submission

Temperature 17.89°C

Humidity 78%

Details

Gender
Female

Age
Larva

Figure 4.25: Submission viewing interface for specialists

4.3.1 Feedback from User Testing

After performing user testing, we determined that the menu feature on our original prototype website caused confusion amongst users and was often overlooked. The current layout of the menu can be seen in Figs. 4.46-4.27. Users suggested placing the menu on the side or top of the page so that they could access the menu at any point. Displaying a sidebar showing the user's progression or a top menu for pages cleared up any confusion about scrolling through the website. Users also noted that the scrolling feature was not intuitive, as there was an arrow on the home page (pictured in Fig. 4.26) but not on every page. Lastly, some users found that factsheets would only unfurl if the user clicked directly on the name of the species, which became slightly confusing. These drop-down menus, as seen in Fig. 4.28, were fixed to allow users to view the factsheet by clicking anywhere on the bar.



Figures 4.26 and 4.27: The current menu design of the prototype

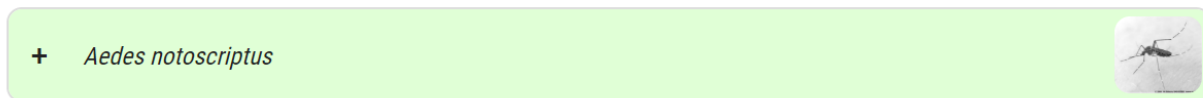


Figure 4.28: Species information drop-down menus

4.4. Discussion

4.4.1. Mosquito Census Requirements

The submission process is an integral part of the Mosquito Census, as the physical specimens are needed for identification and tracking spatial occurrences. This submission process will be used almost exclusively by people who are not entomologists, and it is unlikely that the participants will have submitted a specimen before. Because of this, the submission form must be user friendly while still including necessary fields for the mosquito specialists.

Part of the vision for the Mosquito Census is not only to create a database, but also to submit our data to the already successful iNaturalist. One of the most important aspects of iNaturalist is the sense of community, which is why we will encourage the submitter to share their name or a pseudonym (“iNaturalist”, 2019). The importance of data privacy was stressed by Walther and Pernat (Personal communication, February 5, 2019). Although New Zealand does not have the strict data privacy laws that Germany has, the Mosquito Census must allow submitters to remain anonymous or post under a pseudonym. With this, the Mosquito Census strikes the balance between fostering a strong sense of community and preserving the privacy of its users by providing the option to remain anonymous.

Providing the date, time, and location of capture along with specimens allows the Mosquito Census to determine temperature and humidity data for the area that the mosquitoes were found. This will assist researchers in determining the types of climates that New Zealand’s mosquitoes thrive in. As climate change continues, this data can inform scientists on which species’ habitats are shrinking or growing.

4.4.2 Citizen Scientist Involvement

Currently public knowledge about mosquitoes is lacking. Our surveys show that a bulk of respondents were not aware of the existence of mosquitoes endemic to New Zealand. Additionally, we found that the respondents were not well informed of the important role mosquitoes play in the broader ecosystem. We believe that increased awareness of the benefits of mosquitoes, and appreciation for those bird biting

species endemic to New Zealand, will augment interest in mosquitoes and strengthen support for the Mosquito Census. Participation in the Mosquito Census requires public awareness of the value of contributions to this project. Through our interviews, we discussed several means of promoting the Mosquito Census as a citizen science project, each with different target audiences. Drawing from survey demographics, informal interviews, and its popularity with mothers in New Zealand, Facebook is a valuable portal through which we could reach homeschool communities and families interested in the Mosquito Census. Our survey respondents from the museum and on Reddit and Twitter do not reflect the wider population of citizen scientists who could potentially contribute to the Mosquito Census. These platforms reached mainly younger audiences familiar with social media. Expanding to Facebook would reach a broader demographic and therefore yield more accurate and representative data.

Measuring and increasing public awareness of mosquitoes is of global importance; there are 3,000 species of mosquitoes throughout the world. The steps we are taking to market the Mosquito Census as a citizen science platform can also be used elsewhere to promote similar programs. The Mosquito Census requires citizen scientists to physically catch a mosquito, fill out a form, and mail in their specimen, which requires effort on the part of the submitter. Our recommendations on how to increase participation in this project could be useful for other projects in the future that also require significant effort from participants.

4.4.3. The Website Prototype

Our prototype website demonstrates one possible way to fulfill the Mosquito Census project's requirements. Te Papa has its own digital content team that is planning on launching the project's website as a subsidiary page within the main Te Papa website. As a result, it must remain consistent with the site's overall branding and structure. The design will also likely evolve as certain features change in popularity. Therefore, there will be some significant design changes from what our prototype presents. We will simply recommend the prototype that we developed with modifications to make the website compatible with Te Papa as well as general improvements that users shared with us.

Chapter 5: Recommendations

By conducting interviews with entomology, biosecurity, and database specialists and surveying museumgoers, Reddit users, and Twitter users, we have gathered data on the creation, production, and marketing of the Mosquito Census. We gained additional insights on the website through prototype iterations and user testing. These finding-driven recommendations will facilitate the launch and long-term success of the Mosquito Census.

5.1 Website

The full website recommendation, including code, front-end features, and back-end features, can be found in Appendix J. Functionality and design priorities will be discussed below.

Based on our observations and surveying of museumgoers who tested our website, we are recommending that the museum replicate the layout of our updated interface. Besides the confusion about the menu and homepage layout, users found the website straightforward and easy to use. The website should progress from: submission form; information about mosquitoes; information on species found here in New Zealand; map of the submissions; directions on how to catch and submit the mosquito specimens.

One requirement defined in this project was the ability for the website to be compatible with a third party database. As discussed in our results we looked at Find-a-Pest and iNaturalist primarily. We are recommending that the Mosquito Census be linked to iNaturalist as it would be the best way to publicly display the data by submission and mapping. Because 90% of survey respondents were not familiar with iNaturalist, we recommend that a map showing identified submissions also be displayed on the Mosquito Census website.

To fulfill the needs of the specialists, we recommend that the website be implemented as a static front-end client with a dynamic server-less back-end. This means the visual components of the website can be hosted on very cheap and simple infrastructure. Our webpage will be embedded into the main Te Papa website, meaning it will be in the context of Te Papa's branding. The top bar of the page will be the same as the main website's navigation menu. All of our content will be simply displayed in the main body of the page. The back-end component, however, is more complicated. The database of mosquito findings needs to have a large set of features in order to be useful. It needs to be able to record findings from the online submission form, and has to be able to display all the submissions for the mosquito specialists to view. It also needs to be secure, so that only specialists can view all the information. This is an incredibly important requirement, as users are entering personal information into the form.

To save costs, we recommend that the infrastructure be constructed using server-less components. Our site was built with more simple tools, for the sake of rapid prototyping. For maintaining the system in the long-term, it is important to consider cost and scalability. Many back-end database services that currently exist use large servers that are constantly online. They are large computers that are always ready to read from and write to the database. This is not cost effective, however, because it is expensive to run these computers even when nothing is happening. We thus recommend avoiding this approach. Software architects at AWS (Amazon Web Services) have created a new way to develop this kind of software in a more efficient manner. They provide a set of services that can perform individual operations, and only run

our software as long as it takes for these operations. Thus, it would only be necessary to pay for the system as long as it is being actively used. For example, if a mosquito expert wants to view the current list of findings in the database, AWS would quickly execute the code needed to get information from the database. After that, the code would finish executing and AWS would only charge for the short amount of time needed to run this code (Castro et al., 2017). This approach is known as server-less design, as there are no server computers that are constantly running.

We also would recommend including a contact form in future versions of the site, so that visitors can ask questions. The three mosquito specialists agreed that they can handle up to ten responses per week, meaning that a total of thirty questions per week can be answered. (J. Kasper, personal communication, February 5, 2019)

5.2 Submission process

One goal of the project is to encourage all citizens to become citizen scientists and to remove barriers that might prevent those citizen scientists from participating. In order to appeal to as much of the population as possible, we are recommending that both an online form and a paper form be made available. Only two respondents to the survey choose paper forms over online forms out of 162 respondents who answered this question. However, taking into account the survey bias, and the fact that the survey was distributed mainly online with fewer in person responses, we still recommend a paper form be made available. The form should include relevant fields like the date, time and location of the mosquito catching as well as more detailed fields like the habitat it was caught in.

We recommend that funding from the Ministry of Health (MoH), if approved, be allocated to providing FreePost for submitters to the Mosquito Census due to the overwhelmingly positive response that survey respondents had to the option of free postage. MoH also supported the idea of FreePost, as it would help to remove barriers from public participation. We recommend that drop-off locations be added in areas such as museums, libraries, and veterinary offices. These drop-off sites should also provide paper copies of the submission form. Additionally, due to positive survey responses, we are recommending that, if funding allows, collection kits are distributed. The collection kits could be as simple as a net and a test tube with the Mosquito Census logo printed on them. With these collection kits, citizen scientists will not be discouraged by any difficulties in catching a mosquito and packaging and submitting the specimen.

5.3 Public Outreach

The success of the Mosquito Census is dependent upon citizen scientist participation. In order to influence participation, we recommend that Te Papa's natural history exhibit, opening in May of 2019, have a display to market the Mosquito Census. We created a mock display that can be seen in Fig. 5.4. The exhibit could be in their citizen science section or be advertised along with the exhibit displaying the story of certain mosquitoes.



Figure 5.1: Exhibition Display Mock-up.

Considering such a large majority of survey respondents did not have a good grasp on the importance of mosquitoes in the ecosystem, the information on the website must be of high priority. We recommend that the text be reviewed by professional entomologists, the Ministry of Health, and the Ministry for Primary Industries in order to ensure that all information is accurate and helpful in increasing mosquito literacy in New Zealand. MoH has agreed to provide funding for an informative video clip to be made for the website (S. Giles, personal communication, February 13, 2019). We recommend that this video clip be animated and go over the necessary steps in order to catch and send in a mosquito to the census, while being light hearted and funny in order to capture the viewer's attention. According to a study done in 2018, 3.5 million people in New Zealand are using social media, with Facebook being the most popular (Carney, 2018) Facebook videos focus on relevant content and target different audiences by creating a connection with the viewer (Carney, 2018). Above assisting in the submission process, we recommend this video to be used as advertisement, assuming the funding is available, on social media platforms such as Facebook.

During the development of our project, we were made aware, in multiple cases, of the potential for sensational media about biosecurity related matters. In order to reduce this risk, we recommend Te Papa museum, MoH, and MPI communication teams stay in close contact. If the three organizations prepare for any possible news story about delicate matters, such as disease, it would be beneficial to all parties. To ensure time for additional preparation if an exotic species is discovered in the country through the Mosquito Census, we suggest that the specialists do not immediately publicize data that could cause alarm. Instead, reporting this finding directly to MoH so they can prepare a response would be the safest option.

Chapter 6: Conclusion

The goal of our project was to help Te Papa gather data on the distribution and ecology of New Zealand's mosquito populations. We recommended an intuitive collection system and accompanying website interface to enable the submission of physical specimens to mosquito specialists. Through interviews and surveys, we determined that the Mosquito Census website and online submission form will be the most effective method to gather data on and amass collections of New Zealand's mosquito populations. The results of our research indicate that the creation of a Mosquito Census with the features we recommend will increase the amount of data on New Zealand's mosquito populations. This will assist in future entomology research and help prevent or effectively respond to potential mosquito-related biosecurity problems. On a broader scale, the mosquito Census will serve as a trial run for the Atlas of Living Aotearoa and potential reference for similar form citizen science projects. In doing so, it will contribute to the mobilization of New Zealand's citizens to protect biodiversity and preserve biosecurity according to MoH's Biosecurity 2025 initiative.

Chapter 7: Reflections

For all five of us, this project has been an unforgettable experience. We all would like to take a moment and reflect on the impacts this project has had on our life.

7.1 Chase Woodward

This project has not only given me the opportunity to travel outside the east coast of America, but has given me the skills and confidence to work and write with a group and cooperate with major government organizations.

7.2 Katie Long

I am immensely grateful for the memories forged and lessons learned during my travels throughout New Zealand. My knowledge and confidence have grown, and my writing, research, and communication skills have improved, as a result of this experience.

7.3 Georgie Wood

Through the work I did on this project, I had the chance to learn about ecological issues around the world more specifically in New Zealand. I am grateful for the opportunity to explore the beautiful country of New Zealand and for how this experience has helped me to grow as a person. This project helped me develop skills on how to collaborate with others and work with government agencies which will help me to feel confident and prepared for the future.

7.4 Andrew Moore

Working on this project has been an experience that I will never forget. I learned a lot about what it takes to work in a team for a long period of time, and I was able to do that while also taking advantage of all this beautiful country had to offer. Living abroad for this long really made me realize not only what life is like in New Zealand, but also what I appreciate most about being home in the U.S. Working with Katie, Georgie, Chase, and Anthony has been a true pleasure; as a team we really meshed well together. I hope that one day I will again have an opportunity to do great work with great people in a great place like Wellington.

7.5 Anthony Topper

My experience here in New Zealand was invaluable; our project team was effective, and the work fascinating. I hope this project will impact others as much as it impacted me.

References

- Balbin, L., & Williams, K. (2016). Towards a national bio-environmental data facility: Experiences from the Atlas of Living Australia. *International Journal of Geographical Information Science*, 30(1), 108-125. Retrieved from <https://browzine.com/articles/56213553>
- Banker, Kyle (2011). *MongoDB in Action*. Manning Publications Co. Retrieved from <https://dl.acm.org/citation.cfm?id=2207997>
- Bernard, H. R. (2002). *Research methods in anthropology* (3rd ed.). Walnut Creek, CA: AltaMira Press.
- Bik, H. M. (2017). Let's rise up to unite taxonomy and technology. *PLoS Biology*, 15(8): e2002231. doi: 10.1371/journal.pbio.2002231
- CSIRO. (2011). *The Atlas of Living Australia*. Retrieved from <https://web.archive.org/web/20130121114220/http://www.csiro.au/en/Outcomes/Environment/Biodiversity/The-Atlas-of-Living-Australia.aspx>
- Blackburn, R., La Salle, J., & Doherty, P. (2014). Revolutionising the mapping of nature: The Atlas of Living Australia. *AQ - Australian Quarterly*, 85(2), 19. Retrieved from http://go.galegroup.com/ps/i.do?id=GALE%7CA366082933&v=2.1&u=mlin_c_worpoly&it=r&p=STOM&sw=w
- Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience*, 59(11), 977-984. doi:10.1525/bio.2009.59.11.9
- Brockhoff, E. (2009). Impacts of exotic invertebrates on New Zealand's indigenous species and ecosystems. *Feathers to Fur*, special issue of *New Zealand Journal of Ecology* (2010) 34(1), 158-174. Retrieved from <https://newzealandecology.org/nzje/2916.pdf>
- Brooke, M. d. L. (2000). Why museums matter. *Trends in Ecology & Evolution*, 15(4), 136-137. Retrieved from [https://doi.org/10.1016/S0169-5347\(99\)01802-9](https://doi.org/10.1016/S0169-5347(99)01802-9)
- Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., . . . Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, 486(7401), 59-67. doi:10.1038/nature11148
- Carney, M. (2018). *NZ social media statistics 2018*. Retrieved from <http://socialmedia.org.nz/ccOSo>
- Castro, P., Ishakian, V., Muthusamy, V., & Slominski, A. (2017, June). Serverless programming (function as a service). In *2017 IEEE 37th International Conference on Distributed Computing Systems (ICDCS)* 2658-2659. Retrieved from <https://ieeexplore.ieee.org/abstract/document/7980271>
- de Chazal, J., & Rounsevell, M. (2009). Land-use and climate change within assessments of biodiversity change: a review. *Global Environmental Change*, 19(2), 306-315. Retrieved from <https://doi.org/10.1016/j.gloenvcha.2008.09.007>

- Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J., & Waller, D. M. (2011). Assessing citizen science data quality: An invasive species case study. *Conservation Letters*, 4(6), 433-442. doi:10.1111/j.1755-263X.2011.00196.x
- Environmental Health Indicators New Zealand (EHINZ). (2018). *Exotic mosquitoes established in New Zealand*. Retrieved from <http://www.ehinz.ac.nz/assets/Factsheets/Released-2018/EHI-ExoticMosquitoesEstablishedInNewZealand2006-2017-released201804.pdf>
- Fang, J. (2010). Ecology: A world without mosquitoes. *Nature*, 466(7305), 432. doi:10.1038/466432a
- iNaturalist. (2019). Retrieved from <https://www.inaturalist.org/pages/help>
- Jay, M. (2003). Biosecurity, a policy dilemma for New Zealand. *Land Use Policy*, 20(2), 121-129. Retrieved from <https://www.sciencedirect.com/science/article/pii/S0264837703000085>
- Jessamine, S. (2016). Exotic mosquito larvae detected at Auckland airport. Retrieved from <https://www.health.govt.nz/news-media/media-releases/exotic-mosquito-larvae-detected-auckland-airport>
- Kay, B. H., & Russell, R. C (Eds.). (2013). *Mosquito eradication: The story of killing Campito*. Collingwood, Victoria, Australia: CSIRO Publishing.
- Kobori, H., Dickinson, J., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., . . . Miller-Rushing, A. (2016). Citizen science: A new approach to advance ecology, education, and conservation. *Ecological Research*, 31(1), 1-19. doi:10.1007/s11284-015-1314-y
- Landcare Research. (2004). *Mosquitoes in New Zealand*. Retrieved from <https://www.landcareresearch.co.nz/science/plants-animals-fungi/animals/invertebrates/invasive-invertebrates/mosquitoes>
- Leiba, B. (2012). OAuth web authorization protocol. *IEEE Internet Computing*, 16(1), 74-77. Retrieved from <https://ieeexplore.ieee.org/abstract/document/6123701>
- The Living Atlases Community. (n.d.). Retrieved from <https://bioatlas.se/the-living-atlases-community/>
- Liz, K., Hay K., Maidment, J., Ballantyne, N., Beedoe, L., Walker S. (2018, November 28). Feeling lucky: the serendipitous nature of field education. *Social Work Research in New Zealand* Retrieved on February 15, 2019 from <https://socialworkresearchnz.wordpress.com/2018/11/28/feeling-lucky-the-serendipitous-nature-of-field-education/>
- Michener, W. (2015). Ecological data sharing. *Ecological Informatics*, 29(1), 33-44. Retrieved from <https://doi.org/10.1016/j.ecoinf.2015.06.010>
- Michonneau, F., & Paulay, G. (2015). Using iNaturalist to learn more about echinoderms. *The News Journal of the International Society for Reef Studies*, 30(1), 29-31. Retrieved from <https://francoismichonneau.net/articles/Michonneau+Paulay2015-iNaturalist.pdf>
- Ministry for Primary Industries (MPI). (2016). *Biosecurity 2025: Protecting to grow New Zealand*.

- Retrieved from https://natlib-primo.hosted.exlibrisgroup.com/primo-explore/fulldisplay?docid=NLNZ_ALMA21315258750002836&context=L&vid=NLNZ&search_scope=NLNZ&tab=catalogue&lang=en_US
- Nelson, W., Breitwieser, I., Fordyce, E., Bradford-Grieve, J., Roskruge, D., Webb, C. (2015). *National taxonomic collections in New Zealand*. Retrieved from <https://royalsociety.org.nz/assets/Uploads/Report-National-Taxonomic-Collections-in-New-Zealand-2015.pdf>
- Southern Monitoring Services, Ltd. (2018). *NZBEL*. Retrieved from <https://www.smsl.co.nz/NZBEL.html>
- Pheloung, P. C., Williams, P. A., & Halloy, S. R. (1999). A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management*, 57(4), 239-251 doi://doi.org/10.1006/jema.1999.0297
- Porter, J. H. (2010). A brief history of data sharing in the US long term ecological research network. *The Bulletin of the Ecological Society of America*, 91(1), 14-20. Retrieved from <https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/0012-9623-91.1.14>
- Rawlence, N. J., Kennedy, M., Anderson, C. N. K., Prost, S., Till, C. E., Smith, I. W. G., . . . Waters, J. M. (2015). Geographically contrasting biodiversity reductions in a widespread New Zealand seabird. *Molecular Ecology*, 24(18), 4605-4616. doi:10.1111/mec.13338
- Rich, C. (2015). Avian malaria and the endemic birds of Hawaii. Retrieved from <http://www.discoverconservation.org/avian-malaria-endemic-birds-hawaii/>
- Schindel, D. E., & Cook, J. A. (2018). The next generation of natural history collections. *PLoS Biology*, 16(7), e2006125. doi:10.1371/journal.pbio.2006125
- Stilgoe, J. (2016, November 8). Is citizen science the future of research or a recipe for bad science? *The Guardian* Retrieved from <https://www.theguardian.com/science/political-science/2016/nov/08/is-citizen-science-the-future-of-research-or-a-recipe-for-bad-science>
- Tredick, C. A., Lewison, R. L., Deutschman, D. H., Hunt, Timothy A. N. N., Gordon, K. L., & Von Hendy, P. (2017). A rubric to evaluate citizen-science programs for long-term ecological monitoring. *Bioscience*, 67(9), 834-844. doi:10.1093/biosci/bix090
- Thomson, S. A., Pyle, R. L., Ahyong, S. T., Alonso-Zarazaga, M., Ammirati, J., Araya, J. F., . . . Zhou, H. (2018). Taxonomy based on science is necessary for global conservation. *PLoS Biology*, 16(3), e2005075. doi:10.1371/journal.pbio.2005075
- Turnhout, E., Lawrence, A., & Turnhout, S. (2016). Citizen science networks in natural history and the collective validation of biodiversity data. *Conservation Biology*, 30(3), 532-539. doi:10.1111/cobi.12696

- Walther, D., & Kampen, H. (2017). The citizen science project 'Mueckenatlas' helps monitor the distribution and spread of invasive mosquito species in Germany. *Journal of Medical Entomology*, 54(6), 1790-1794. doi:10.1093/jme/tjx166
- Williams, E., & Foote, A. (2018). *Te papa annual report 2017 - 2018*. Retrieved from https://www.tepapa.govt.nz/sites/default/files/te_papa_annual_report_2017-18_0.pdf
- World Wildlife Fund. (2017). *How many species are we losing?* Retrieved from http://wwf.panda.org/our_work/biodiversity/biodiversity/

Appendix A: Full Questionnaire



Hello and thank you for taking the time to fill out our survey!

We are a group from Worcester Polytechnic Institute in Massachusetts, USA facilitating a Te Papa citizen science project called the Mosquito Census. This survey will be asking you a series of questions about citizen participation in ecological data collection. Any feedback or criticism along the way is very helpful to us, and we encourage you to ask any questions or share any suggestions to make this questionnaire more clear.

Your participation in this survey is voluntary and anonymous, and you are welcome to leave at any point. Only persons 18 years of age or older should take this questionnaire.



Do you live in New Zealand or are you visiting?

- Live in New Zealand
- Visiting

In what age group do you fall?

- 18-25
- 26-35
- 36-45
- 46-55
- 56-64
- 65+

Check all of the following that apply to you.

- Subscribe to This Is Us
- Subscribe to EcoMatters
- Participated in a Bioblitz
- Pay close attention to environmental news stories
- Know about New Zealand's Biosecurity 2025 initiative
- Please list (if any) other environmental newsletters you receive or activities you partake in
- None of the above apply to me

Have you heard of iNaturalist?

- Yes
- No

How would you describe biosecurity to someone?

How many of the 16 mosquito species in New Zealand were introduced? If you're not sure take a guess!

How should mosquitoes be dealt with in New Zealand? Check all that apply.

- Monitor distribution patterns throughout New Zealand
- Monitor border for exotic species
- Eradicate all mosquitoes
- Eradicate only introduced species
- Do not interfere with natural patterns

How often do you notice mosquitoes in your daily life?

- Often
- Not often
- Never

The Mosquito Census is a website that enables citizens, like you, to participate in the collection of mosquitoes around New Zealand. This sample can be from anywhere, from your backyard to a park or a trail. Below are images from the website detailing the process of catching and sending in a sample to the Mosquito Census. On the website there will be a form that submitters will fill out providing details like what habitat the mosquito was found in and at what time. Please take a look at the images, as the next few questions will be about the Mosquito Census.



How Can You Hunt Mosquitoes?



1. Catch It!

If you find a mosquito, place it in a small container. This can be anything from a matchbox to a peanutbutter jar. Even though they can be quite annoying, please try not to quish the little bug! If it's one piece it will be much more easy to analyse.



2. Freeze It!

Freeze the sample to preserve it! Place it in the freezer. But if it's a larva, no need to freeze – just place it in some alcohol (vodka will do).



3. Send It!

Mail it off to this address... Or see one of our dropoff locations!

How likely would you be to participate in the Mosquito Census by sending in a sample?

- Very likely
- Somewhat likely
- Neither likely nor unlikely
- Somewhat unlikely
- Very unlikely

For each of the following statements about the Mosquito Census please rate whether you agree or disagree with the statement.

	Agree	Neither	Disagree
Free post would make me more likely to send in a sample of a mosquito.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
A drop off center for samples would increase my likelihood to participate.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would be more likely to participate if a collection kit was provided.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would be interested in participating in a mosquito hunt led by a specialist.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Would you be more likely to submit an online form or a printed version of the form?

- Online form
- Printed form

If at all, how many times do you see yourself contributing to the Mosquito Census?

- 1 time
- 2-4 times
- More than 5 times
- I would not

Why or why not?

Appendix B: Mückenatlas Skype Call Transcript

Transcript of Skype Call with Mückenatlas Representatives Nadja Pernat (NP) and Dr. Doreen Walther (DW) on Tuesday, February 5, 2019, 9:00 - 10:00 pm.

- Us We would like to verify a few statements before we include them in our paper. 'It has never been a problem for the public to cover costs of submitting specimens.'
- NP + DW No, never. Just a single in over 20,000 submissions, who asked for reimbursement. But in fact, we do not know how many people willing to contribute do not submit.
- Us Submissions are around 25% non-mosquitoes.
- NP + DW It is right. Between 20-25%. Depending on the weather conditions.
- Us 50-100 submissions are received per day during peak season.
- NP + DW 50-100 submissions arrive per day in summer, in winter (worst time) 2-3 submissions.
- Us People have a feeling they can trust the project because of paper forms and personalized emails.
- NP + DW Right.
- Us 20-25% of submitters are repeat users.
- NP + DW Right.
- Us 66-70% of submissions are from people's homes.
- NP + DW Right.
- Us We also have a few quotes from our skype call we would like to include with your permission: "the media is more or less our best friend"
- NP + DW Yes.
- Us "Do not want to release data because we don't want a panic"
- NP + DW [changed to:] "Do not release data on submission of invasive species or potential vectors not cross-checked in the field only such findings linked to reproduction in the field will be released since in those cases control might be necessary." Distribution maps are made available to the public after publication of the data. Authorities will be informed immediately in the case of local reproduction of invasive species.
- Us Lastly, you mentioned that you have developed a guideline for teachers in schools to teach about biodiversity a few times a year, and that you go to schools a couple times a year. To what extent does this encourage those students to submit, or is it more to

raise awareness? Does this include hunting for mosquitoes with the students?

NP + DW

No, we published it once in a teachers school-instruction and explain how the project works and what the background is and what pupils can learn. In other activities we go out with students and teach them.

Appendix C: Steve Pawson Correspondence Transcript

Transcript of Email Correspondence with Scion research leader and forest entomologist Steve Pawson (SP) on Monday, January 28, 2019, 3:00 pm.

Us We really appreciated the opportunity to familiarize ourselves with Find-A-Pest, and to compare and contrast Find-A-Pest with iNaturalist. We were really impressed with the success of iNaturalist, especially how passionate and engaged the iNaturalist community is. For our needs iNaturalist is preferable and we look forward to submitting observations to the Mosquito Census project on iNaturalist.

SP Fine, at this stage it would be a less risky option as Find-A-Pest does not have a commitment from stakeholders after about June.

Us Could you confirm that there is no way to delay publicizing submissions to first verify specimens and add a photo from the laboratory before they reach Find-a-Pest and iNaturalist?

SP Currently no. Find-A-pest allows you to delay the publication of the observation until you have added an identification, however you cannot yet add a new image to it. iNaturalist has no way of delaying anything related to the observation, you hit submit and it is live on the website (if in coverage)

Us If a mosquito specialist were to submit specimens to iNaturalist, is there any way for the name appearing on the map to be the name or pseudonym of the citizen scientist?

SP Not that I am aware of but Jon may say otherwise. There are custom fields that allow you to submit all observations from a mosquito specialists account and then have the original observer as another field. However, iNaturalist does not like that approach as I mentioned in Wellington as it means that the observation and any comments/IDs becomes divorced from the observer and are essentially orphaned in the long term. You can use RNAT the R package for interfacing with iNat to capture observations and you could then have a new R-Shiny or other interface using leaflet or something that would allow you to customise what the maps on your website showed.

Us Could you give us more information about if and how MPI and MOH receive and use iNaturalist findings, to ensure a quick response?

SP There is nothing official between MPI/MOH and iNaturalist NZ it relies on the community as a whole to advise observers that they should ring 0800809966 when something is IDed as a threat. Sometimes other people ring in on behalf of users that have not checked their private messages or comments etc. MPI then ring myself or Jon and ask us for contact details. Anything mosquito related that goes to the 0800 number is diverted from the call centre to the MOD diagnosticians [sic].

Appendix D: Full Pro-Con Assessment of Existing Platforms

Pro-Con Assessment of iNaturalist

Pros	Cons
Descriptive information fields within species observation report	No intermediary step between submission and publication
Community feel fosters long-term engagement	Account required
Observation reports mapped to illustrate geographic distribution of species	Overwhelming quantity of submissions
Gives credit to citizen scientist contributors	Data retained even if account deleted
Capability to immediately suggest a species based on user's photograph	Personal data shared with "partners"
Relatively easy to navigate: organization resembles Facebook	

Table D.1: Full pro-con assessment of iNaturalist

Pro-Con Assessment of Find-A-Pest

Pros	Cons
Informative species factsheets including the status of the species	Not all mosquitoes are pests
Shows images of species	Funding not guaranteed past June
Easy to navigate: organization resembles Instagram	Still fixing bugs in coding
National and regional categories	User profile with phone number linked required for submission
Option to log in with google or Facebook	No tutorial
No superfluous or confusing features	No names labelling pictures of species in home screen grid
Logo top and center at all times	Tabs include large amount of text
	No intermediary step between submission and publication
	Not anonymous
	Information fields within observation report are

	not required to be filled in
	No reward or recognition for contributing

Table D.2: Full pro-con assessment of Find-a-Pest

Appendix E: Ministry of Health Correspondence Transcript

Transcript of Email Correspondence with Sally Giles (SG), Senior Advisor at the New Zealand Ministry of Health, on Wednesday, February 13, 2019, 11:30 a.m.

- Us Thank you so much for your time and insights on the Mosquito Census. In addition to working with Dr. Kasper on creating the Mosquito Census, we are required to write a paper describing the project that will be published through Worcester Polytechnic Institute's library. We hope to describe the Ministry of Health's role in preserving New Zealand's biosecurity, why the Ministry of Health is interested in the Mosquito Census, and how the Ministry of Health could support the Mosquito Census. We would like to verify that the following statements and their contexts are accurate and reflect your own and the Ministry of Health's views before we include them in our paper. If there is anything you would like to excise, or anything you could elaborate upon, we would really appreciate your comments and permission!
- Us New Zealand signed an international health regulation agreement promising to contribute to the global minimization of the spread of diseases. Specific articles within this agreement relate to the spread of mosquitoes and other vectors that can carry diseases. The Ministry of Health plays a public health role in creating safe environments through the operational delivery of board of health utilities. The Ministry of Health is involved in keeping vectors out of New Zealand through border surveillance and monitoring in addition to preparing for and potentially managing emerging disease threats.
- SG New Zealand is a signatory to the International Health Regulations 2005 (IHR). The purpose of the IHR is to prevent, protect against control and provide a public health response to the international spread of disease. This includes the control of disease vectors such as mosquitoes. The Ministry of Health is committed to ensuring the IHR requirements are being met in New Zealand including the implementation of mosquito surveillance programmes and control measures, in particular at international maritime and aviation ports.
- Us There are unique mosquito populations in New Zealand, yet not as much entomology resources and expertise as in other countries. The Ministry of Health would be interested to learn what temperature changes might mean for mosquito population movement and where exotic mosquitoes might be able to tolerate living.
- SG There are unique mosquito populations in New Zealand, but due to resourcing and priorities there has been limited recent studies of these. The Ministry of Health are interested in finding out what changes, if any, there have been to the New Zealand mosquito populations. This information will then be used when considering the likelihood and threat of an exotic mosquito population establishing and spreading within New Zealand.
- Us The Ministry of Health communication and media teams would be able to give feedback on the wording of the text on the Mosquito Census website to ensure that the website text connects to climate change and public health in an informative but non-alarming manner. The coms teams of the Ministry of Health and Te Papa need to be linked to ensure sustainability and a unified response to potentially negative media. The MOH would be willing to and able to provide some amount of monetary support for the Mosquito Census, possibly by funding a

FreePost mail box for specimen submissions or an animated clip explaining background on the project and how easy and important it is to contribute.

SG The Ministry of Health is supporting the Mosquito Census by providing entomology services, and contributing funds to develop promotional material (a short video clip). In addition the Ministry of Health Communications team will work closely with Te Papa and Ministry for Primary Industries Communications staff to ensure consistent and appropriate messaging for the Mosquito Census. They will also support social messaging and provide appropriate responses to any media interest.

Appendix F: Pictures of Temporary Exhibit

Survey table at Te Papa Thursday, February 7, 2019, 1:00 - 3:00 pm.

Petri dishes containing larvae *Opifex fuscus*; table set-up; Chase Woodward, Andrew Moore at the table.



Figure F.1: Petri dishes containing *Opifex fuscus* larvae

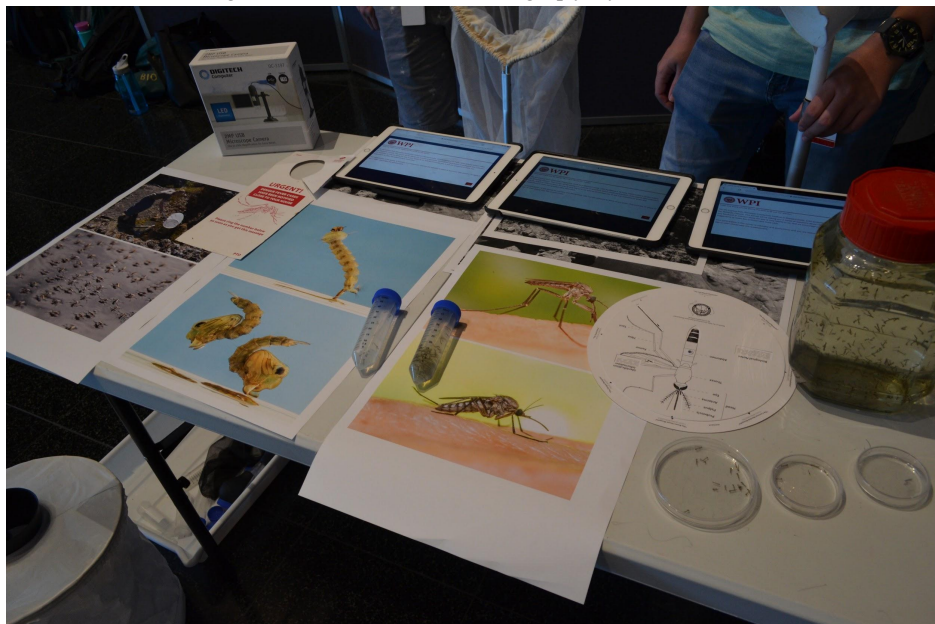


Figure F.2: Exhibit set-up

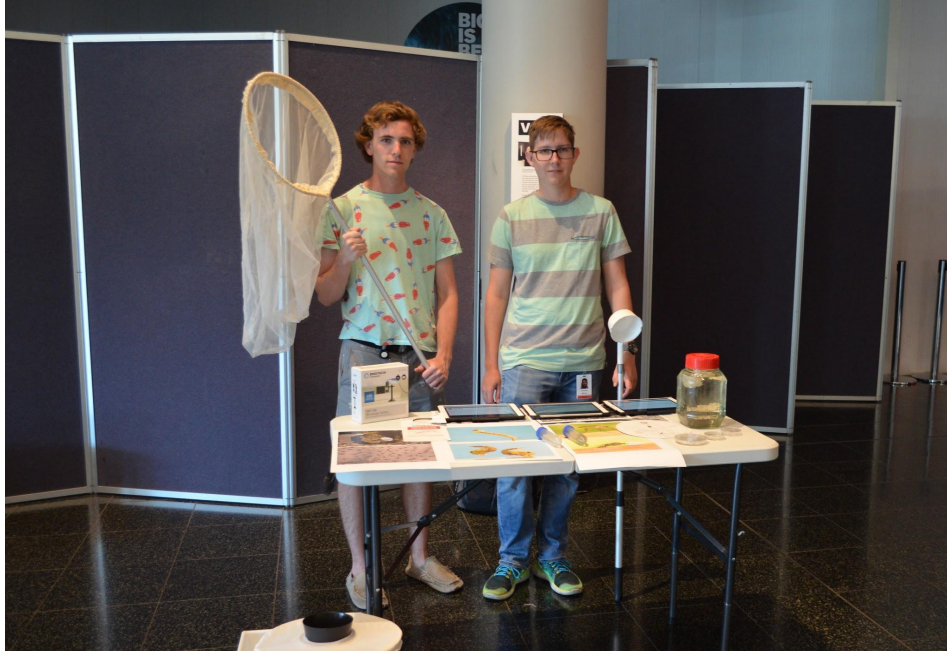


Figure F.3: Chase Woodward (left) and Andrew Moore (right) at the table

Appendix G: Pictures from the Mosquito Hunt

Mosquito Hunting

We engaged in participant observation during a mosquito hunting exhibition to Moa Point outside Wellington. Both adult and larvae *Opifex fuscus* specimens were captured. Photographs documenting this process and a number of the resulting specimens are included below.



Figure G.1: Georgie (top left) collecting larvae from a tide pool while Chase (right) observes



Figure G.2: Our sponsor, Julia Kasper, transferring larvae into a container



Figure G.3: Julia catching adult mosquitoes with a net



Figure G.4: Larvae hitching a ride on Anthony's hand



Figure G.5: Adult males on the pool surface, and larvae and pupae in the water below



Figure G.6: Captured adult mosquitoes



Figure G.7: The natural habitat of *Opifex fuscus*

Appendix H: Infographic

The Mosquito Census

The distribution of our native flora and fauna changes with the spread of introduced mosquito species.

3,000
mosquito species
worldwide



13
mosquito species
call NZ home



3
mosquito species
introduced to NZ



↓
bird biters

↓
like human blood

We can do our part to protect Aotearoa by gathering data on NZ's mosquitoes. Become a citizen scientist today by sending a sample to the Mosquito Census.

Find out which mosquitoes live in your neighborhood!



1. Catch It!



2. Freeze It!



3. Send It!



WPI

Ko Tātou This Is Us
BIOSECURITY 2025

Appendix I: Code Book

Code	Definition
Mosquito Census Requirements	Everything related to requirements for citizen scientists, mosquito specialists, and end users.
Logistics of Physical Specimen Submission	Subcategory: Facilitating the submission of physical voucher specimen.
Logistics of Identification	Subcategory: Mosquito specialist availability and resources.
Input Portal Considerations	Subcategory: Evaluation of existing input portals.
Data Sharing Capabilities	Subcategory: Back-end requirements and functionality to link information to iNaturalist and other partners.
Target Audience Baseline	Everything related to assessing and engaging potential users.
Mosquito & Biosecurity Literacy	Subcategory: Existing knowledge on mosquitoes and biosecurity.
Privacy & Public Image	Subcategory: Protecting users' personal information. Responding to misrepresentations of scientific findings.
Encouraging Participation	Subcategory: Potential citizen scientists' reasons for or against participating in the project. Email responses or rewards after submission to encourage participation.
Marketing & Outreach	Subcategory: Educational outreach programs, specialist assisted mosquito hunting, and press and social media marketing strategies for engaging the target audience.
Website Prototype	Front-end and back-end website features.

Appendix J: Software Documentation

Introduction

The Mosquito Census is a project launched in 2019 that promotes data sharing of information related to biosecurity. It is designed to spread awareness of mosquitoes, and to help expert entomologists understand the existing mosquito populations in New Zealand. It encourages citizens to submit physical mosquito samples via post, so that they can be identified and analyzed. To accomplish all of this, there is a web interface and database that must advertise the project and help to organize internal information.

Overall Architecture

The system consists of a web frontend and backend. A single static HTML/CSS/JS site contains all the public-facing information. The backend infrastructure is hosted separately, for the sake of flexibility. CORS-enabled requests are made to the API, which consists of a simple set of CRUD operations.

Front-End Design

The primary landing page for the website is a single long-scroll card-based layout. Cards are a trending way to display web content and work well for the needs of this project. Due to their simplicity, they allow the site to be completely responsive.

Structure

- Home
 - Landing page — This introduces the site with a vibrant green background and large text. It also clearly shows the navigation menu with a button at the bottom. Additionally, it features a button linking to the submission form.
- About
 - Textual information — This provides an overview of project and the context of mosquitoes in New Zealand.
- Map
 - This is a map of existing findings, pulled directly from the backend database.
- Catching
 - This is a static set of visual instructions on how to submit a mosquito
- Submission form
 - Form for entry of data regarding a mosquito finding. This is inputted directly into the database

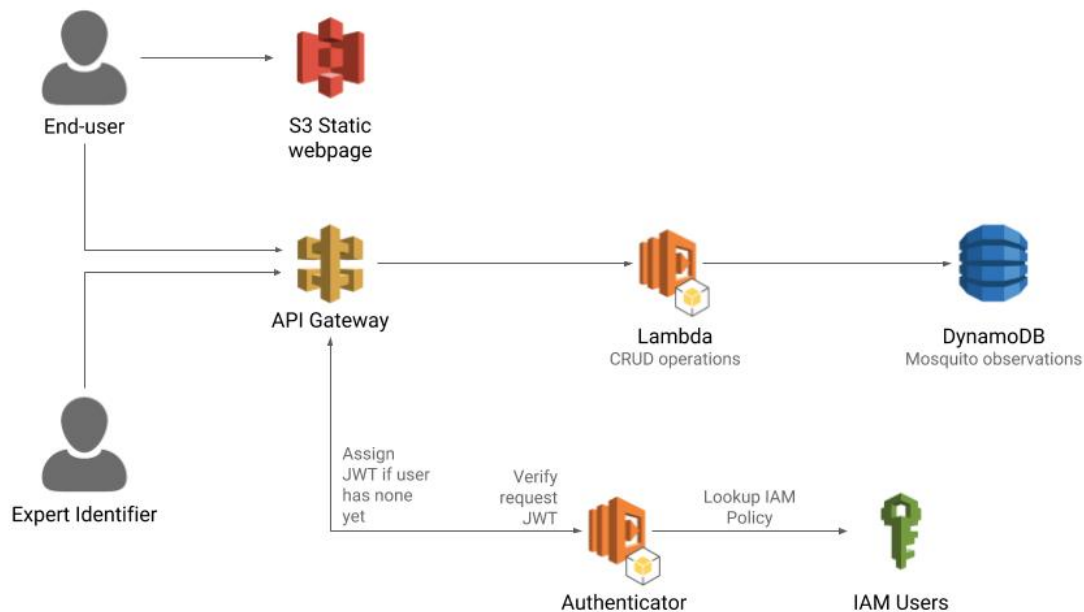
SEO

Search-Engine Optimization is taken into account. Meta-tags in the HTML header include a title and description. However, these are often ignored by more modern search engines. Instead, the page content itself is most considered. Luckily there are blocks of text that contain relevant information, including mosquitoes and the submission process. This text, above most other factors in SEO, will be used by search engines for query matching. Other small details, such as including alt text for images, is also incorporated.

Back-End Architecture

Below is shown a proposed architecture for authenticated data storage. The system is partitioned such that there are two kinds of users, each of which can access a different form of data. An end-user will be able to view all the static content hosted publicly on an S3 bucket. They also will have limited access to records that have been marked as public.

Diagram



Serverless

The advent of serverless cloud technologies has allowed for the development of scalable, reliable, and low-cost backend infrastructure. Using AWS, all API calls go through API Gateway and are processed by Lambda functions. All static content is hosted on S3 with a CloudFront CDN. DynamoDB stores all long- and short-term state information, including the submission records and access tokens.

Schema

All documents follow a roughly consistent schema, which of course is quite flexible depending on available information.

An example document would appear as shown below:

```
{
  "id": "029914",
  "name": "Anthony Topper",
  "email": "ajtopper@wpi.edu",
  "time": "2019-02-05 12:00",
  "habitat": "Forest",
  "location": "-41.12047273081268, 175.08599667968747",
  "species": "Culex pervigilans",
  "credit-consent": true,
  "time-submitted": "Tue Feb 12 2019 12:58:38 GMT+1300 (New Zealand Daylight Time)",
  "weather": {
```

```

"time": 1549278000,
"summary": "Clear",
"icon": "clear-night",
"precipIntensity": 0.0102,
"precipProbability": 0.02,
"precipType": "rain",
"temperature": 19.27,
"apparentTemperature": 19.38,
"dewPoint": 15.99,
"humidity": 0.81,
"pressure": 1016.81,
"windSpeed": 9.8,
"windGust": 14.4,
"windBearing": 350,
"cloudCover": 0.19,
"uvIndex": 0,
"visibility": 10.01,
"ozone": 255.42
},
"status": "complete",
"species_actual": "Culex pervigilans",
"images": ["b38f935f-20da-435e-a670-75091d814854.jpg"],
"gender": "male",
"age": "adult"
}

```

GET /submissions

Retrieves a list of submissions, either by ID or a list of all available submissions in the database. If no access token is specified, the list of entries returned will only consist of those marked as public.

Parameters

Headers

Authorization should be set to a valid access token, otherwise an unauthenticated response with limited information will be returned.

Query string

/submissions?id=###

Query submissions by a particular ID

Returns

```

{"list":[
  {"id":"274102","name":"Anthony Topper","species_actual":"Culex pervigilans","email":"ajtopper@wpi.edu","location":"40.741895, -73.989308","time":"2019-01-22 08:00", ... }
]}

```

POST /submissions

Parameters

Headers

Authorization must be set to a valid access token

Accepts Content-Type: application/json

POST body

```
{"id":"274102","name":"Anthony Topper","species_actual":"Culex  
pervigilans","email":"ajtopper@wpi.edu","location":"40.741895,  
73.989308","time":"2019-01-22 08:00", ... }
```

Returns

```
{"result":"ok"}
```

```
{"result":"error","description":"..."}
```

PUT /submissions

Parameters

Headers

Authorization must be set to a valid access token

Accepts Content-Type: application/json

POST body

```
{"id":"274102","name":"Anthony Topper","species_actual":"Culex  
pervigilans","email":"ajtopper@wpi.edu","location":"40.741895,  
73.989308","time":"2019-01-22 08:00", ... }
```

Returns

```
{"result":"ok"}
```

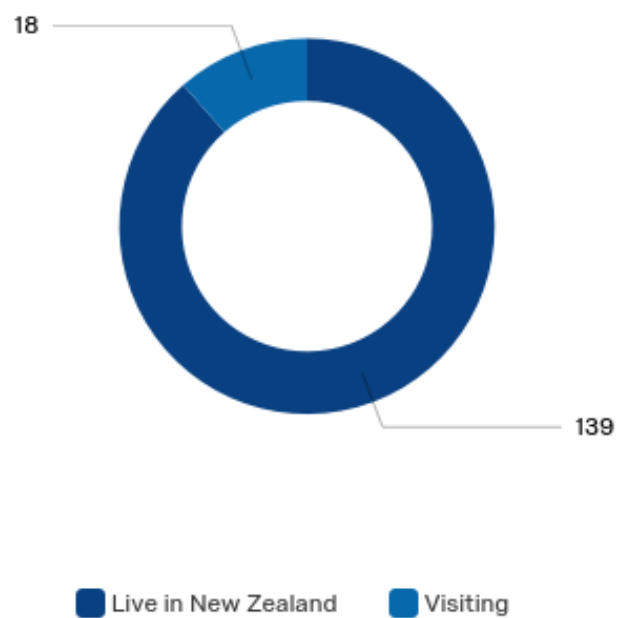
```
{"result":"error","description":"..."}
```

Appendix K: Full Survey Responses

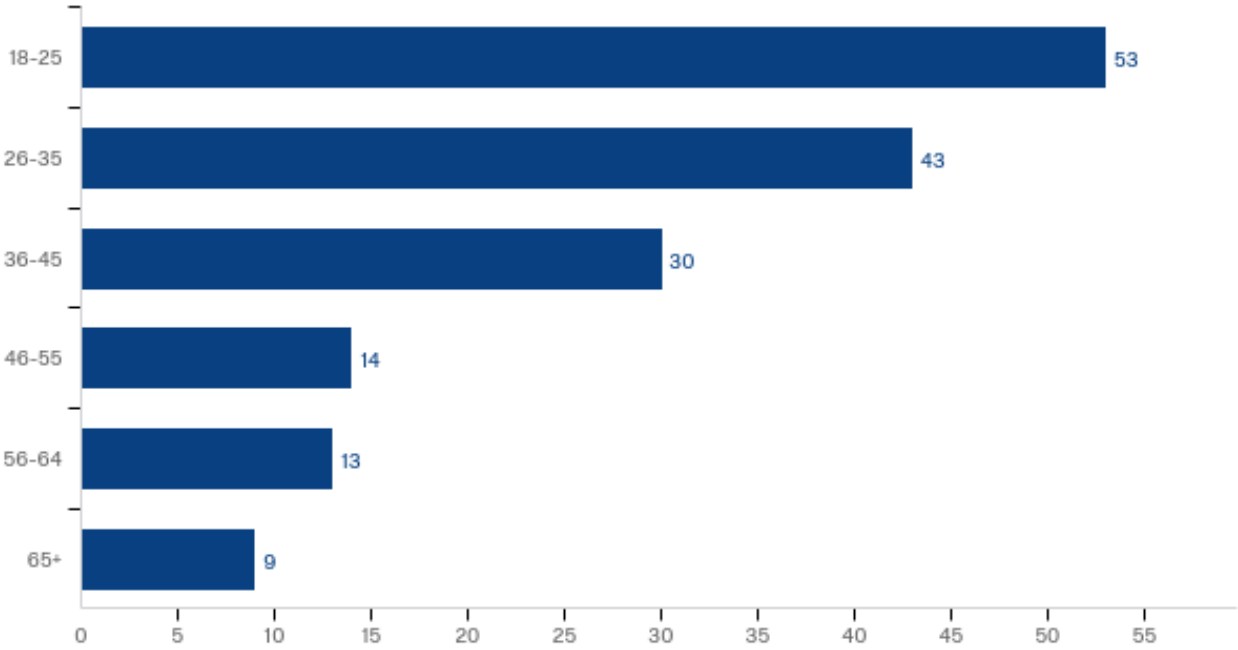
Survey Report

The Mosquito Census

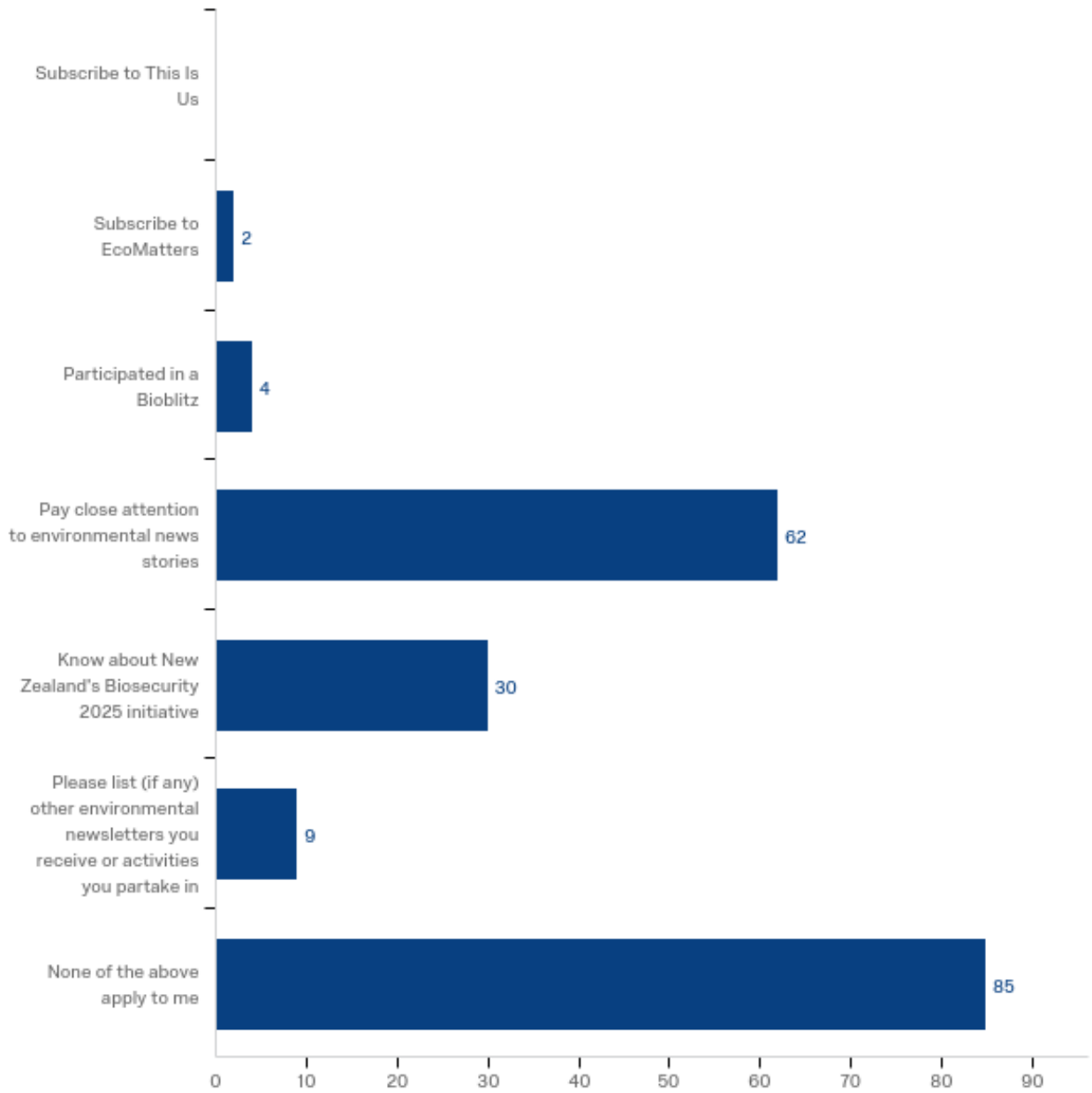
Q1 - Do you live in New Zealand or are you visiting?



Q2 - In what age group do you fall?



Q3 - Check all of the following that apply to you.



Please list (if any) other environmental newsletters you receive or activities you partake in - Text

Greenpeace. Forest and bird

Forest & Bird, NZ Ecological Society.

Fish and game newsletter

Predator free Ngaio, forest & bird

Trapping on the west coast

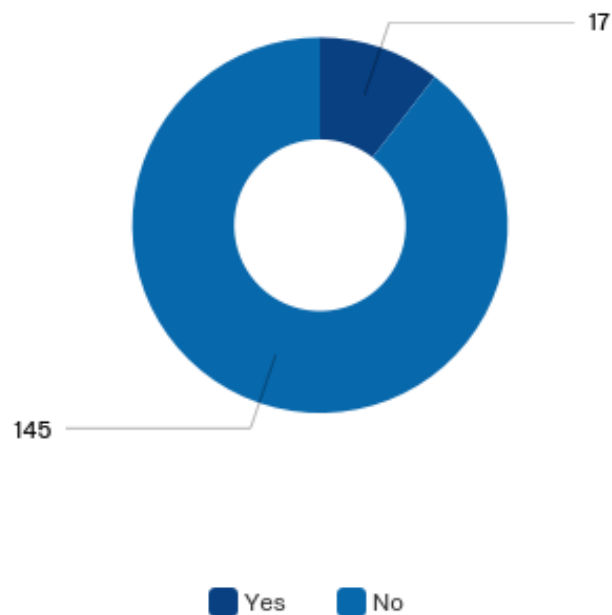
Whatever the mag about the Queens Chain is called.

Predator free taranaki

Forest and bird, kiwicare

Sierra club

Q4 - Have you heard of iNaturalist?



Q5 - How would you describe biosecurity to someone?

How would you describe biosecurity to someone?

Not letting potentially damaging nasties into our ecosystems where they can cause trouble

preventing invasion of foreign species

an underappreciated and vital part of particularly NZ natural, social and economic wellbeing.

Keeping bad bugs out (from microscopic to large).

Keeping disease out of the farm, or country

Want to protect the country from anything invasive

Protecting native species

I don't know if I could

Protecting environment from external threats

Preserving the natural environment seeds

Keeping bad plants and animals and insects out of NZ

Border control of potentially damaging organisms

biosecurity is keeping New Zealand safe and free of invasive species

Ensures that unwanted bugs / fungus / stuff doesn't come into NZ that could harm our environment or any of the products that we export. Probably have got this wrong...

breach of a native ecosystem due to the introduction of a non-native species

Keeping NZ safe from pests and disease. Stopping these from coming through our border.

scary

Initiative to minimize the amount of non-NZ native species (i.e exotic/foreign species) to enter the country

The responsibility of governments to control the introduction and export of flora and fauna across their borders.

Protecting New Zealand from exotic pests that are a potential risk to our native species, to the economy and to people.

making sure that the natural environment is free of pests and diseases

protecting the endemic species and permitted agricultural species of a country from foreign entities

pest control

The control of biological species

defending native species and human livelihood from exotic pests

Protecting native and agricultural species from invasive biological threats.

Stopping pests and diseases crossing the border into our country.

I don't know what biosecurity is, but I assume it has something to do with protecting native species, controlling invasive species, and protecting habitats.

The biosecurity system prevents or manages risks from harmful organisms, like pests and diseases. The biosecurity system helps protect New Zealand's economy, environment, human health, and a range of social and cultural values. It does this by: stopping pests and diseases before they arrive dealing with any if they do enter the country.

To keep and flora/fauna out of our country that may affect the economy and species already here.

Defensive measures to protect native flora and fauna

Securing the native flora and fauna of NZ

Preventing the arrival/establishment/spread of potentially harmful organisms.

Controls relating to biological substances

Ensuring that threats to New Zealand's ecosystem are responded to

Keeping our environment and biology free from pests and disease

Prevention of human interference with the natural biosphere

i wouldn't try

Protecting Isolated and delicate ecosystems

Protection of animals within the country

Protection of the population, environment and ecosystems from pathogens and invasive species.

Keeping diseases and unwanted species out of a country

Regulations to preserve a country's environment

Keeping no wildlife/agriculture/industry safe from foreign pests and diseases

?

keeping safe against natural threats

Making sure foreign species don't enter NZ and harm our native ones

Threats to the country and people from organic matter

Protecting natural diversity in a specific area

Protecting the environment

Keeping out foreign pests

Preventing introduction of unwanted species that will change ecosystems

The protection of environments

Prevented foreign biological threats infect the environment

To prevent the introduction of invasive species and protect the native plants and birds.

The process of keeping invasive species out of a particular environment.

Taking measures to protect the integrity of the local environment

Stopping the introduction of non-native species to the country to maintain the delicate balance of the ecosystem

Ensuring native species and local agriculture is not compromised or damaged by foreign hazards such as pests, parasites, or harmful microorganisms

Enforcing what comes in and out of NZ

Making sure that nothing which could damage NZs ecosystem gets into NZ

Keeping our country safe from unwanted organisms

Protecting the environment against unwanted species -plant/animal/insect

Making sure biological threats don't come in to the country

Stopping biological material from getting where it shouldn't (eg to prevent the spread of diseases or pests)

Preventing unwanted animals/insects/plants from entering the country as well as plant/animal diseases.

control of import and export of living material

Keeping bug and diseases out of New Zealand

Keeping out unwanted species.

Protecting borders stopping foreign organisms entering the country

A way for us to preserve our native ecosystems

Ensuring our natural fauna and flora are protected from invading species

protecting native species from external and internal (disease) threats

Preventing harmful biological agents from entering or spreading throughout the country

Protecting kiwis against harmful species.

In nz it's about protecting our native species and primary industry.

Protecting our environment against foreign invaders

can't bring food in to country

don't let dodgy plants and animals in

Efforts to preserve the natural ecosystem of New Zealand by preventing foreign organisms being introduced.

Protecting natural flora and fauna, and the introduced stuff that makes money.

Protecting the environment

Preservation of natural flora and fauna by preventing exotic pests from coming in

Protection of natural resources from introduced threats.

A programme/series of programmes to deter & discourage the introduction of any new (i.e. introduced) animal or plant species to a specific geographic location, and to eradicate (or control) any species that nevertheless arrive.

Preventing exotic species from entering NZ

Protecting the country from unwanted/damaging pests

Preventing or managing risks from harmful organisms

Keeping biological pests not found in the country outside it, to reduce risk of damage to native flora and fauna

Protecting native wildlife and preserving the current eco-system from foreign species

keeping nonnative species out of the country

The work done to prevent damage to New Zealand's biosphere occurring

it's important to our economy

Ensuring that our ecology isn't negatively effected by outside influences.

They prevent bad things from coming into NZ and ruining our lands

Keeping invasive organisms out of the country and managing the ones that are here already

Rules & methods designed to preserve the flora & fauna from potentially damaging alien biological matter

Keeping unwanted species out of NZ.

Protect the country from diseases and pests that could cause major damage, e.g., stopping them from entering at our borders.

Preventing organic materials and organisms from arriving in NZ that can damage NZs ecosystems or economy

The protection and preservation of our ecosystem's biodiversity.

The regulation and control of introduced species and pests in a country or area

Protecting a thing/place from biological threats

Biosecurity is the protection of our native flora and fauna.

Protecting wildlife and ecosystems from foreign and invasive threats.

Keeping unwanted shit out of nz

Protecting the natural biodiversity of an area

the protection of New Zealand's natural flora and fauna

Ensuring the safety and health of our natural environment. Including native Flora and fauna. Kaitiakitanga

The act of protecting a country's boarders from potentially harmful animals and plants.

Stopping unwanted plants and animals getting into an area.

Keeping bugs and animals in the right place.

Stop invasive species from harming NZ native ones

Protecting the integrity and indigenous species of a country

Protection of natural species, for example by checking for and eliminating any pests that cause harm to existing and especially natural species.

Stopping the spread of unwanted organisms

Maintaining the unique species in NZ

Protecting NZ from invasive species and diseases that could harm the environment for primary industries

Protecting the ecosystem from external threats

Protection of indigenous ecosystems from external risks

The prevention of nonnative species into a country

Not tight enough

The protection of biological and ecosystems.

A system designed to protect our native wildlife and ecosystem

Biosecurity is a collection of procedures and regulations enforced to protect the population and economy from bad animals or biochemical stuff

I don't know

Protect indigenous species by preventing alien organisms from entering

Protection of the borders against microorganisms

Not sure

Protecting species

It is vitally important to protect NZ from exotic invaders as we have a unique environment.

Keeping NZ safe from bio threats

Protecting against biological threats.

Coming into the country, protecting the environment

Prevent unwanted bugs from getting in the country

Protecting our country from external threats to the flora and fauna of New Zealand

Protection of our natural and indigenous environment from introduced flora and fauna

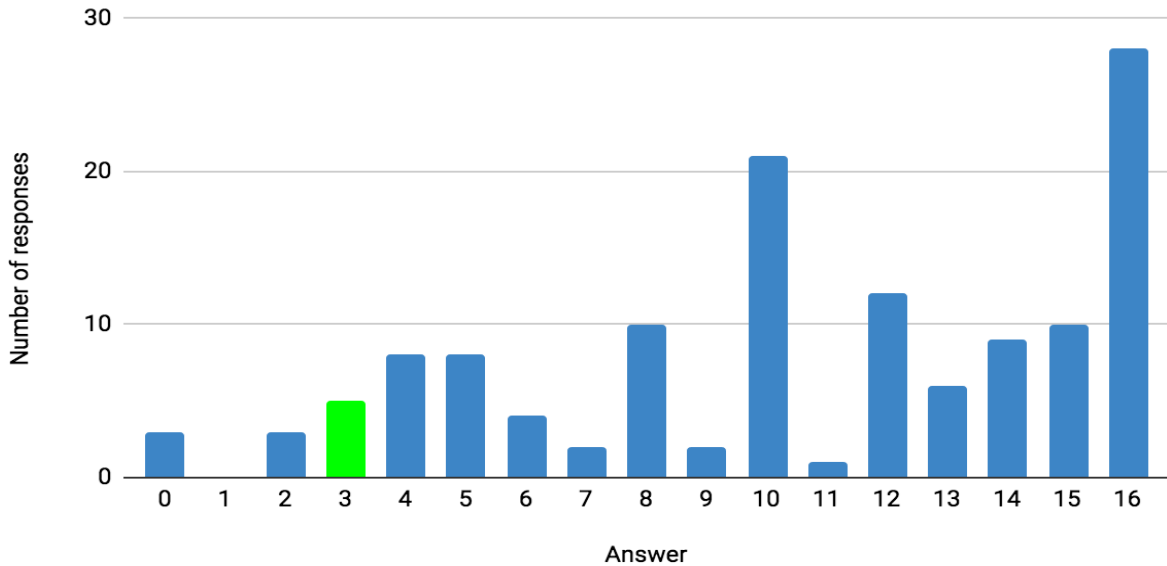
Not familiar with the term

biosecurity is keeping pests out of New Zealand

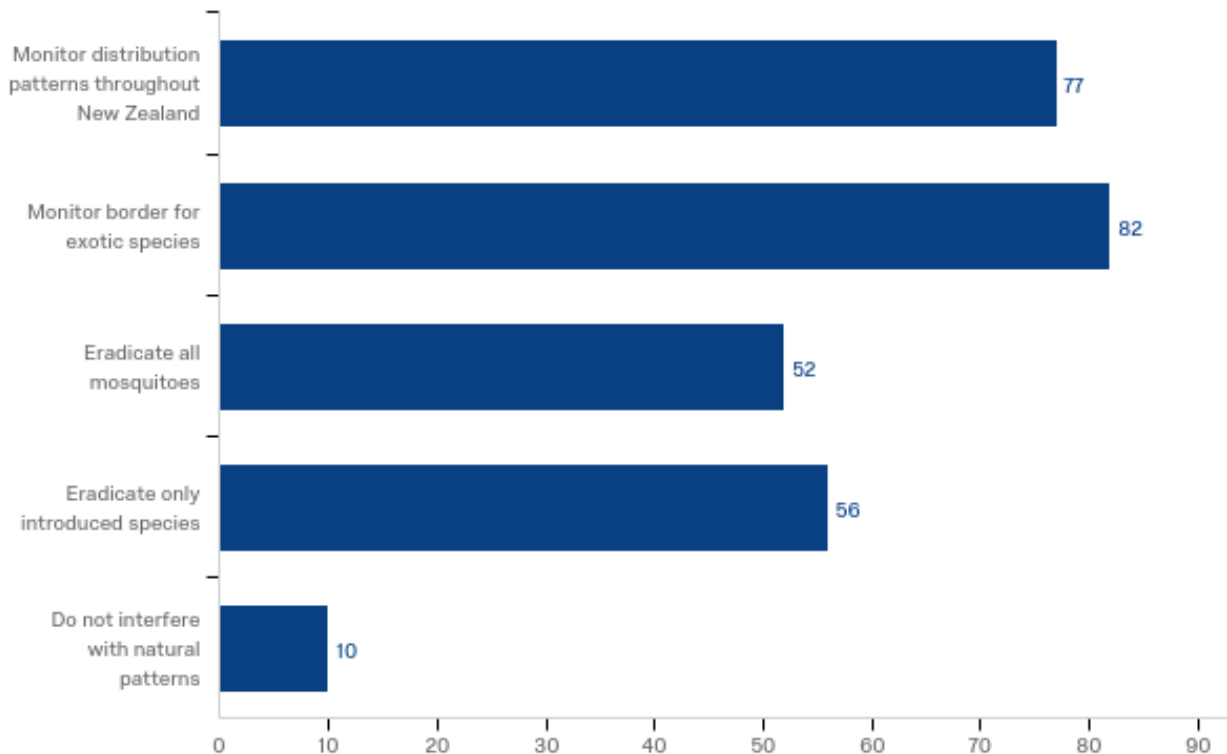
Q6 - How many of the 16 mosquito species in New Zealand were introduced?

How many of the 16 mosquito species in New Zealand were introduced? If you're not sure take a guess!

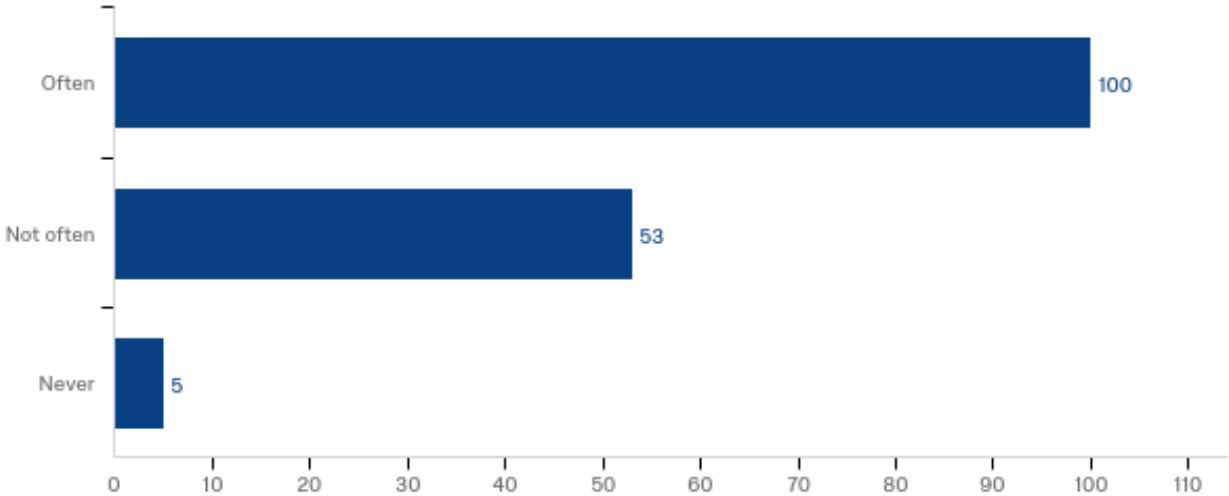
How many of New Zealand's 16 mosquitoes are introduced?



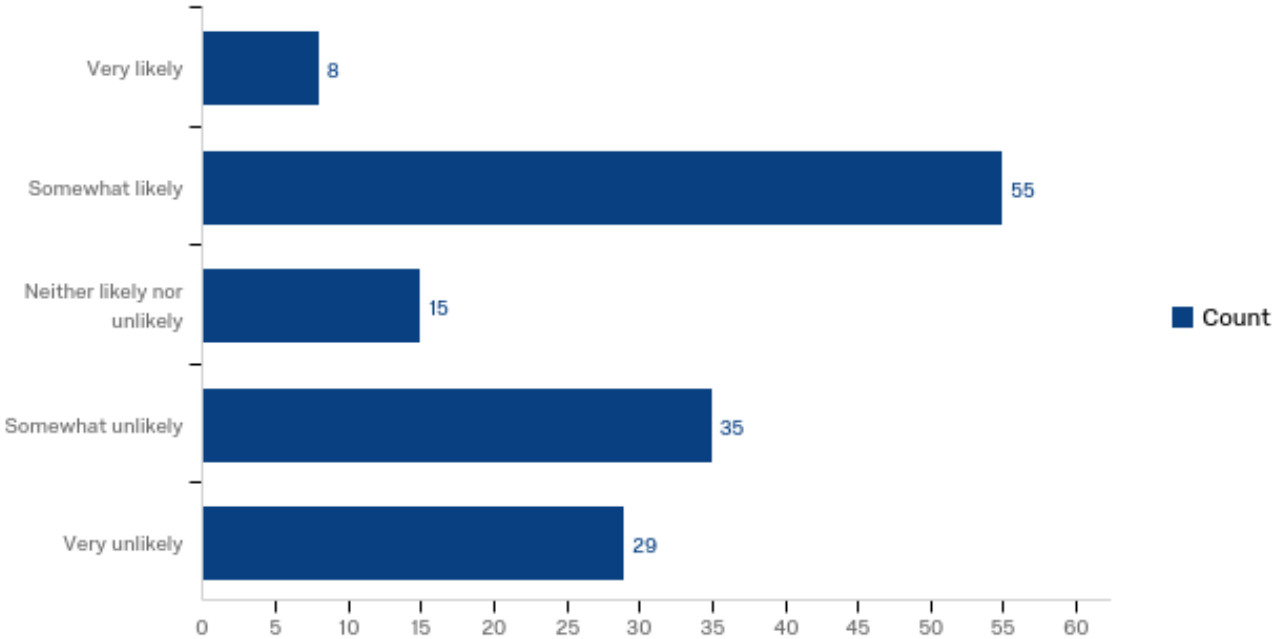
Q7 - How should mosquitoes be dealt with in New Zealand? Check all that apply.



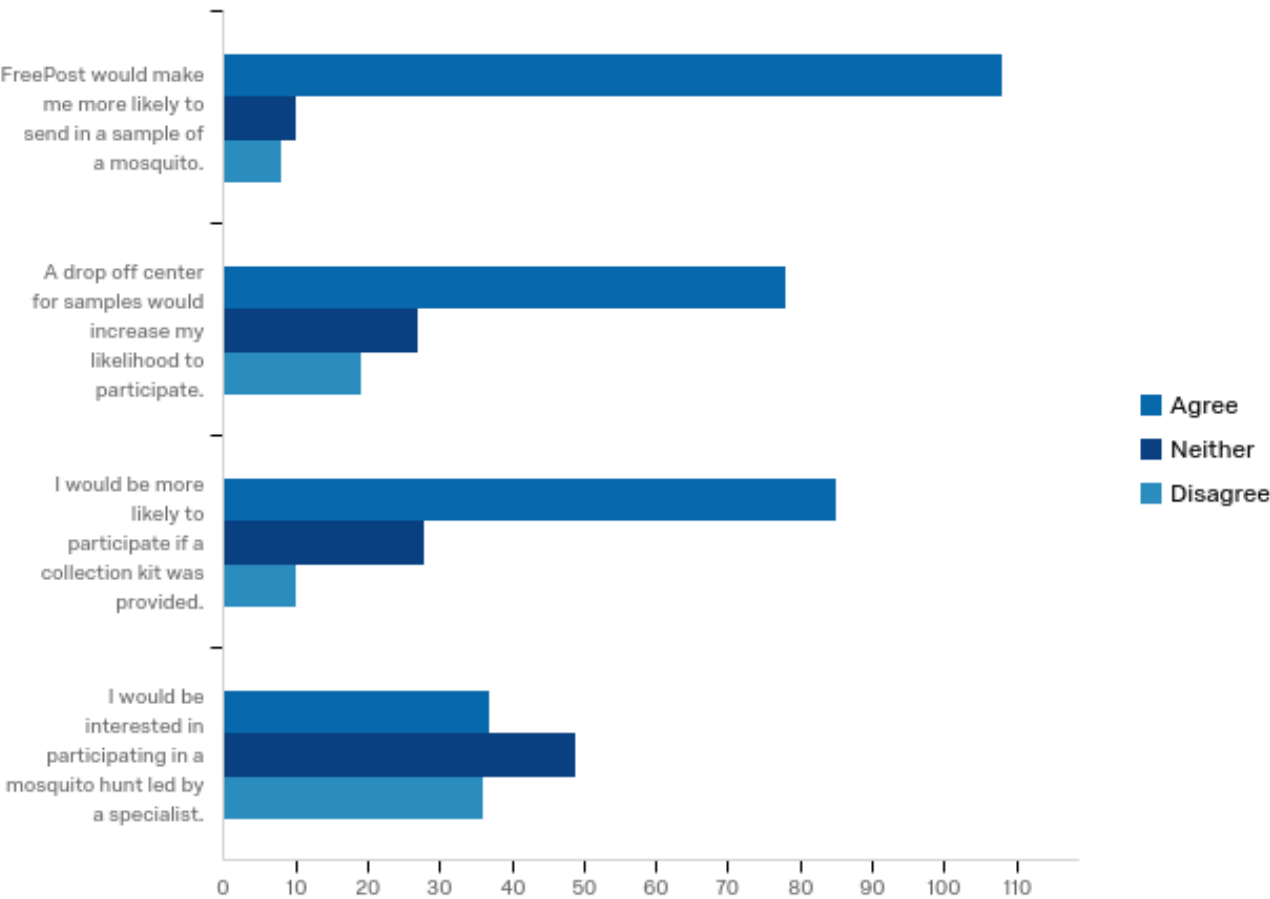
Q8 - How often do you notice mosquitoes in your daily life?



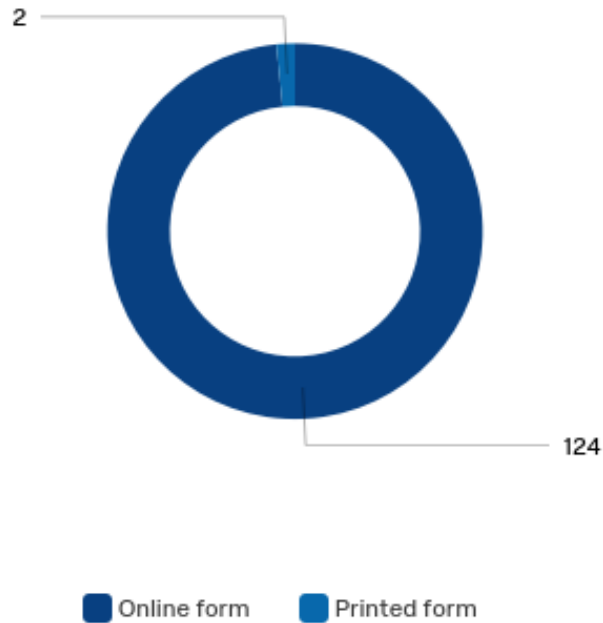
Q9 - How likely would you be to participate in the Mosquito Census by sending in a sample?



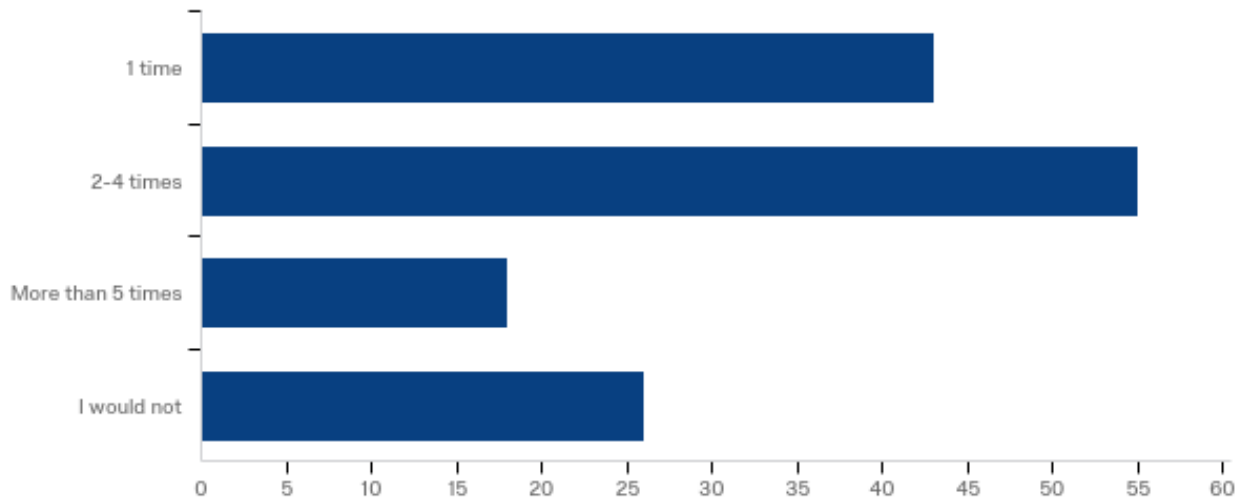
Q10 - For each of the following statements about the Mosquito Census please rate whether you agree or disagree.



Q11 - Would you be more likely to submit an online form or a printed version of the form?



Q12 - If at all, how many times do you see yourself contributing to the Mosquito Census?



Q13 - Why or why not?

Why or why not?

help nz biosecurity

I know the importance of mosquito surveillance and the potential uses in future research that require a large sample population

Too much effort

We would want to get rid of them, disease

Around mosquitoes a lot

Never thought about it

Reason: just visiting

I imagine they would be hard to catch

Topic fairly interested in, important, seen other things like spiders and birds and seen things in other countries. Would be honored to participate

I think it seems like a cool project but seems time consuming

I'd be keen if it was easy :) I've been seeing mozzies daily recently and they are very much irritating me!

I don't have the time.

Because I don't come into contact with Mosquitoes often

time

so many other things to contribute in

It is fun and I get to contribute to science.

I'm likely to be seeing the same species over and over so it may not be useful to keep collecting more except to show presence over time.

My kids enjoy engaging with insects and very much dislike being bitten by mozzies so I would likely include them in the activity and it would feel good to be helping.

we get the occasional at home. concerned about the spread of viruses through mosquitos

Because I do not see them very often

I feel like I'd do it once or twice but lose interest.

If it helps the eco balance of our country, then I want to help

It sounds an interesting project.

Seems like a cool experience

Short on time lately

I don't often see them

I dont know enough about the importance of this and what it impacts to know why i should do this

It would be annoying to catch or collect the mosquitoes. Requires sending away the sample which is time consuming.

It's an interesting project

Amount of effort and time required

Hopefully better data means fewer mozzies

It's not an interest in the mine

Depends if the opportunity is there

I would probably forget and squish the mosquito

Can't be bothered

Busy as hell! :(

Seems like a bit of an effort. Bit harder to catch a mozzie than to just spray it

It seems like work. Post is hard to access. I don't fully understand the need for it so don't feel as obligated

If I was around mozzies and able to catch them, I'd love to help!

Science and research are awesoooooome

Lazy

It sounds way too hard to catch the mosquitos - it's hard enough to kill them!

I'll probably forget about it

only find mosquitos when I am trying to sleep

Sounds like it could be fun but I'm pretty lazy

Sounds fun! But I think the novelty would wear off.

Im a science student, in the environment field. so i would be interested in the results

It sounds interesting

Not too sure

I don't see many where I live, but happy to contribute.

Why

Only a little bit interested.

We have a mozzie problem

I don't really see them that much, and I'd probably kill one before remembering about this

I do not see mosquitos very commonly

If I figure out how to, including spotting mosquitoes as opposed to other bugs, then I'll probably do it a few times

Time and work commitments. I am often away from New Zealand

Don't see a lot of mosquitos

I only notice them if they are in a room when I'm trying to sleep

Depends on a lot of things

I adopt a "take no prisoners" approach. See a mosquito, it dies a sudden and violent death. None of this capture, kill business for me.

I never catch them alive. I also don't have time for that.

Mosquitoes are had enough to kill, let alone catch.

We have quite a few here because of a creek that runs in front of us.

I get a lot of mozzies around my house. I hate them. Anything to help move the needle on mozzie research gets the thumbs up from me.

I get bitten a lot so if there are mosquitos about I'll likely be killing them instead of trying to catch them

We are absolutely over run with mosquitos where we live, we have never experienced anything like it.

Timing

There really aren't that many mosquitos where I am currently living

Can't be bothered

Going overseas

I feel as though there's likely only one variety in my area

Would probably only do it if it was easy and didn't require me to go too far out of my way

i am a busy university student

Because I am bitten daily by them and I hate them!

I am interested in citizen science

Squashing mosquitos is hard enough, catching them unsquashed seems impossible.

Locations I can do are limited to current city.

Mosquitos love me but I do not like being bitten so a walk around the garden and I will easily have some samples

The bastards eat me alive so I'm a "kill on sight" type of gentleman

There are few mosquitos near my home to participate with.

They ones here are all the same

I'm quite busy, just not that important to me however I could see myself doing it once or twice.

Busy life, understanding impact

I would like to see all mosquitoes eradicated

Time restraints with work

Because I hate being bitten and have massive welts on me at the moment.

I don't get many mozzies around my home, so I would need to go looking for one, and if I was somewhere that had mozzies, chances are I wouldn't have anything to catch it in

Seems fun

I'd probably get bored

Because once feels like enough

Would continue once we get into it

I would like to see mosquitos get a bit more under control

It could be a fun activity to do with my children

Interest in protecting health

We're not inundated with them. To me it doesn't matter

If I found one I would

Very few in local district

I can't freeze anything, in hotel

I think this is a cool project but might be time consuming
