Exploring the actions of citizens as scientists through experimentation with aquaponics

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Abstract

Scientists are increasingly collaborating with citizens to engage in science where, on their own, they lack the resources to collect or analyse the data. In most of these collaborative projects, citizens can be classified as science assistants, helping scientists in their endeavours. While this can produce significant benefits for both the citizen and the scientist, the question arises as to the extent that citizens can contribute to all aspects of the scientific process.

This thesis explores how citizens contribute to scientific discovery by experimenting at home in aquaponics systems. Aquaponics allows fish and plants to be grown together providing fresh, locally grown vegetables and fish to homes and communities. Despite the core principles being well known, most systems are independently designed by individuals and show high levels of innovation. There is significant scope for learning how system design, location and other factors affect the success of these systems. The question arises as to whether these innovators are able to join together to research this area by providing detailed on-line data that tracks their system progress as well as analysing the collected dataset, proposing hypotheses, and resolving them based on the available data.

From an aquaponics point of view, this was the first systematic study of how home based systems, which comprise of 86% of all aquaponics systems, performed, informs the home aquaponics industry and provides data for future analysis.

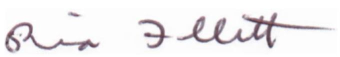
From a citizen science point of view, this study investigates the key question as to how citizens contributed to science. The ways the citizens research was compared and contrasted with the way scientists researched in the field of aquaponics, providing insights into areas that need further consideration when endeavouring to involve citizens in all aspects of scientific research.

Certificate of candidate

I certify that the work in this thesis 'Exploring the actions of citizens as scientists through their interest in experimentation with Aquaponics' has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and has been written by myself. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

The research was conducted under Ethics Committee approval (Ref number: 5201300594 dated effective from 19th August 2013).



Ria Follett

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I would like to thank Prof Vladimir Strezov for the opportunity to undertake this interesting research at Macquarie University and for supporting a project that is very different than other projects conducted in his department. I appreciate his insightful guidance into this research and his ability to draw out what I am thinking in a way that can be expressed in a coherent way that can be understood both by scientists and by the community.

I would also like thank the Murray Hallam from Practical Aquaponics, John Burgess from Fresh by Nature and Lance Gerber from the Bondi Community Gardens for their critique and input into the aquaponic survey and diary prior to conducting the experiment.

The most important contributors to this research were the participants in this research, the aquaponic users who experimented with their systems and contributed to the survey and diary. They provided the data, insight and research upon which this thesis is based. Although they cannot be named for privacy reasons, I acknowledge and thank them. The nicknames of the citizen researchers quoted in this thesis, and from whom images are sourced, are listed in the Appendix A.

None of this would have been possible without the support of my family, especially my husband Doug, who not only encouraged and supported me, but enabled me to take the time pursue my interests.

Publications

This thesis is based on two journal and one conference publications and published conference extract with abstracts shown in Appendix B

Peer-reviewed journals

Article 1

R. Follett and V. Strezov, Application and Publication Patterns of Citizen Science in Scientific Research. *PLOS One* (Submitted 5th March 2015)

Article 2

R. Follett and V. Strezov, Exploring the participation by novices and experts in a citizen science project in aquaponics. *Public Understanding of Science* (Submitted 8th April 2015).

Published conference proceedings

R. Follett and V. Strezov, Exploring Experimentation in an Innovative Citizen Science Project, *Citizen Science Conference*, San Jose, California, USA, 11-12 February 2015.

Published extracts (abstracts) of conference papers

R. Follett and V. Strezov, Citizen Science Partnerships between Universities and the Community, *2014 Engagement Australia Conference*, Wagga Wagga, Australia, July 21 - 23, 2014.

Chapter 1: Introduction

1.1. Background

Citizen science is increasingly seen as a way to engage the public in science, to interest them in science and to improve their scientific literacy. Citizen science is also increasingly utilized to contribute to new scientific discovery in projects that are difficult to achieve with existing science resources. This approach has been applied in wide range of areas from monitoring the environment to exploring the universe.

The role of the volunteer citizen varies considerably. The volunteer may collect data, analyse data collected by citizens or even play games that lead to the mapping of the brain, or genetic discovery. In most of these studies the citizen takes the place of a research assistant, assisting the research by collecting or analysing of data.

The research presented here investigates how citizens involved in a citizen science project conducted their own research, with the longer term aim of empowering them to be more than research assistance, and contributing to all aspects of scientific research (Lakshminarayanan, 2007). A new citizen science project where the citizen is involved in all aspects of the research is the basis for this research which is divided into two distinct sections:

- A citizen science projects on home based aquaponics, providing results of value to the aquaponics community;
- An analysis project that explores the actions of the citizens in the citizen science project, providing results of value to the citizen science community.

Aquaponics, the raising of plants and fish together in a mutually beneficial relationship, was chosen as the topic for the citizen science project as citizens are already experimenting with their own systems at home, and sharing their experiences in an ad-hoc manner on aquaponics forums and in blogs. There are also a number of research studies available from the university and community sectors that can be used to compare with the research done on these home based systems. Home based experimentation is a new untested area of conducting citizen science, and provides the opportunity to explore citizens involved in the whole research cycle, from the design of the experiment (their own system), to the collecting of structured data and the analysis of this data. In addition this provides an opportunity for citizens to postulate new hypotheses and test these hypothesis against the data collected by the whole group.

The observation of citizens conducting science provides insights into the way they experiment, allowing comparison with scientific studies. This insight is a starting point for the development of new ways of overcoming those limitations.

1.2. Specific Research Aims and Questions

The scientific method consists of “observation, hypothesis, prediction and testing” (Trefil & Hazen, 2007). The primary objective of this study is to explore whether citizens can be more than science assistants and apply aquaponics as a case study to determine whether citizens will:

1. “recognize and formulate” a question or problem to be answered (hypothesis and prediction),
2. “collect data” by observation and experiment (observation),
3. systematically analyse the data to test the question or problem to be answered (testing),
4. share the data as a group to allow research across data with different input parameters,
5. learn from the shared data and
6. use this data to come up with new knowledge.

The secondary objective of this research is specific for the area of aquaponics, discovering what works and what does not work in home based aquaponics. Although there is a body of work looking at elements of aquaponics systems in controlled situations, there is a lack of data that tracks the success of these systems over a wide range of conditions. Specific questions addressed in this area are:

1. What plants grow well in aquaponics systems and how are they influenced by location, climate and system design?
2. What fish are grown in aquaponics, how long does it take to grow these to “plate” size and how is this influenced by location, climate and system design?
3. How water efficient is aquaponics compared to conventional agriculture?
4. Will the citizens who have built and run their own system disclose the design and operating parameters for the purpose of science development?

1.3. Thesis Structure

This thesis is constructed to reflect of the dual aspects of this research, where a citizen science project on home based aquaponics provides data not just in the field of aquaponics, but also for research into how the participants in the project conducted the research, comparing their actions to the scientific method. This dual nature requires discussions not only on background and experiments on aquaponics but also the background on citizen science.

Chapter 2 reviews research into areas where citizen science is conducted, the acceptance of this method by scientists and the involvement of volunteers. This review highlights the extent that research into the process of conducting citizen science projects has resulted in providing high quality data for scientists. Research into the motivation and benefits to citizens provides insight into how studies can be designed for their benefit as well as scientific discovery.

Chapter 3 reviews the publication patterns of citizen science in peer-reviewed scientific research to comprehend the acceptance and influence of citizen science in peer reviewed literature. This analysis is the basis of an article submitted to PLOS one (Appendix B)

Chapter 4 provides the background and literature review on aquaponics, including not only on home and community based research but also on university based research. Aquaponics provides the basis of the research of citizen scientist is compared with how the scientists researched.

Chapter 5 provides details of the aquaponics experiment and the results obtained as it pertains to the aquaponics community.

Chapter 6 compares how citizens conducted the research described in chapter 5 and compares their actions with those described in the scientific studies on aquaponics.

Chapter 7 concludes the thesis and addresses how well the research answered the initial research questions and recommendations on ways to support citizens to increase their ability to research at scientific levels.

Chapter 2: Background of Citizen Science

2.1. Introduction

The Citizen Science research methodology is defined as “general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort, or surrounding knowledge or their tools and resources” (European Commission, 2013). Citizen science engages the public in scientific projects that are difficult to conduct solely by scientists who lack the resources to gather or analyse data on a large scale (Hochachka et al., 2012), such as monitoring wildlife (Wiersma, 2010), classifying images (Smith et al., 2011) and transcribing old records (Hill et al., 2012). Project objectives range from supporting scientific investigations within academic institutions (Antelio et al., 2012) to increasing the interest and knowledge of the general population on science and ecology (Toomey & Domroese, 2013).

The development of appropriate methodology and processes underpin the growth and acceptance of citizen science. Although some projects provide fun ways of engaging the pubic in science, other projects are aimed at scientific discovery (Pattengill-Semmens & Semmens, 2003). An overview of citizen science research shows maturing of this approach and suggests new ways of harnessing this potential.

2.2. History of Citizen Science

Citizen science is often seen as a new movement, however, members of the public have contributed data for scientific enquiry since the beginning of recorded history. Farmers, hunters and amateur naturalists have all been involved in collecting data for scientific discovery. Records of over 1,900 years of locust harvests in China form the basis of research into long term climate change (Tian et al., 2011). Other historical datasets kept by non-scientists include over 640 years of grape harvests in France and 1,200 years of dates for the cherry blossoming (Miller-Rushing et al., 2012). This long tradition of public participation in data collection provides valuable data for scientists that is still being used for new discoveries.

In the mid-18th century the Norwegian bishop Gunnerus created a network of clergymen and asked them to contribute observations and collections of natural objects throughout Norway to assist him with his research (Bakken et al., 2012). This appears to be the recorded project whose format closely models a modern view of collaboration between "professionals" and amateur collectors (Brenna, 2011).

In Australia, the first weather observations were made by a Royal Marine, Lieutenant William Dawes, within days of European settlement in 1788 and are still being used as the basis of past climate reconstruction (Gergis et al., 2009). The practise of the collection of weather data by volunteers continues with over 6000 Australians contributing to rainfall data (BOM, 2014).

Prior to the professionalization of science in the 19th century, almost all scientific research was conducted by amateurs, in other words by people who were not specifically trained as scientists or paid for to do science (Miller-Rushing et al., 2012). These amateurs would now be known as citizen scientists.

Early recognized scientists made their living in other professions. For example Benjamin Franklin (1706-1790) was a printer, diplomat and politician and made important discoveries in many areas including electricity (Guarnieri, 2014) and Charles Darwin (1809-1888) sailed on the Beagle as an unpaid companion to Captain Robert Fitzroy, not as a professional naturalist (Silvertown, 2009).

It has been argued that the professionalization of science has caused a decline in skilled amateurs (Bowen & Bass, 1996). However since the 1970s the number of volunteers and volunteer projects in environmental monitoring have again been growing (Swengel, 1990) with data collection being facilitated by curiosity about nature and the use of leisure time to collect and describe it (Jardine et al., 1996). This rise in interest has been facilitated by the easy access to technical tools for disseminating information and gathering data (Silvertown, 2009). The internet, smart phones and various applications and software programs make it easy to contribute in meaningful ways supported by advances in communication, education and transportation. These advances have also made it easier for the scientists and volunteers to manage and analyse the collected data.

The rise is also driven by the increasing realisation among professional scientists that the public represents a free source of labour, skills, computation power and even finance. This contribution has extended to projects, such as Earthwatch, where thousands of members of public pay for the privilege of spending weeks of their vacation time in field research (Brightsmith et al., 2008).

The increasing number of citizen science articles published in peer-reviewed literature is discussed in Chapter 3. As peer-reviewed publications are not generally accessible to the community, and even when accessible not easy for them to comprehend, many articles and their outcomes are published in societal publications, such as newspaper articles, television, presentation, websites and social media either in addition or instead of peer reviewed articles (van Vliet et al., 2014).

The rise of community based science projects is also driven by the desire to decrease the gap between scientists and the general public. A survey of researchers in Forestry Management shows that, while 43% of the scientists considered peer reviewed papers as their most important factor in performance assessments, only 15% considered peer-reviewed journals as effective in promoting conservation and/or development (Shanley & Lopez, 2009). The survey also showed that few scientists were engaged in activities that they perceived as necessary for the success in conservation and development. Citizen science projects are seen as means of augmenting this research and promoting conservation either by scientists themselves (McKinley et al., 2013), or as direct response to community concern on environmental issues (Karney, 2009).

2.3. Classification of Citizen Science Projects

Citizen science projects range from fun projects aimed at encouraging interest in science, through projects aimed at conservation and community action, to projects aimed at rigorous scientific discovery. A history of the classification of citizen science projects shows the maturing of the citizen science concepts and enables learnings from similar types of projects to be more easily applied to new projects.

An early definition (Wilderman, 2007) breaks community science projects into either Community Consulting projects, where community groups consulted with the scientists to investigate a problem they identified and requesting a scientific response, and Community Workers projects where the community assisted the scientist in data collection and analysis phases of the scientist's project. The first category would not be classified as "citizen science" today, whereas the second project describes a category of citizen science. This model was refined (Cooper et al., 2007), into 5 categories, and the term "citizen science" was reserved for the one category where scientists ran the study, and the participants collected the data (corresponding to the community workers category above). The community consulting category was reclassified as "scientific consulting", and three new categories added in additional to the "citizen science" category. Adaptive citizen science included citizens in analysing and interpreting the data, adaptive co-management, where the citizen were also involved in management at each stage.

An alternative classification view was proposed (Bonney et al., 2009a) based on the role of the participant, being contributory, collaborative or co-created. Table 1 compares these three classification schemes based on which tasks are performed by the professionals (🯅), or by the community (Community). These early analyses all assumed that the volunteers collected data. None of the studies include virtual projects where the volunteers analysed data provided to them by scientists. Virtual studies first appeared in scientific literature in 2009 (Shkolyar, 2009).

Table 1. Alternative Citizen Science Classification of Projects

Task	Wilderman		Cooper					Bonney		
Legend: Scientist = Scientist or Professional; Community = Community	Community consulting	Community Workers	Scientific consulting	Citizen science	Adaptive citizen science	Adaptive co-management	Participatory action	Contributory	collaborative	co-created
Management	Community	Scientist	Community	Scientist	Scientist	Scientist Community	Community	Scientist	Scientist	Community Scientist
Define the problem	Community	Scientist	Community	Scientist	Scientist	Scientist	Scientist	Scientist	Scientist	Community Scientist
Gather resources								Scientist	Scientist	Community Scientist
Develop Hypothesis								Scientist	Scientist	Community Scientist
Designing the study	Scientist	Scientist	Scientist	Scientist	Scientist	Scientist	Community Scientist	Scientist	(Community) Scientist	Community Scientist
Collect samples	Scientist	Community	Scientist	Community	Community	Community	Community	Community Scientist	Community Scientist	Community Scientist
Analyse data/samples	Scientist	Community	Scientist	Scientist	Scientist Community	Scientist Community	Community Scientist	(Community) Scientist	Community Scientist	Community Scientist
Interpret the data	Scientist	Scientist	Scientist	Scientist	Scientist Community	Scientist Community	Scientist Community	Community Scientist	(Community) Scientist	Community Scientist
Disseminate conclusions			Community	Scientist	Scientist	Scientist Community	Community	(Community) Scientist	(Community) Scientist	Community Scientist
Discuss ask new questions								Scientist	Scientist	Community Scientist

Later research, based on an empirically grounded study, surveyed citizen science projects and their characteristics (Wiggins & Crowston, 2012) utilized a hierarchical clustering algorithm to cluster projects by participation tasks and by goals. Five different clusters were identified for participation and another 5 for goals. They discovered that clustering on participation, as done by preceding work, were straightforward, providing little room for conceptual development. However the clustering by goals provided more interesting patterns, thus providing a richer conceptual basis for understanding projects. The clustering by goals identified five mutually exclusive and exhaustive types of projects (Wiggins & Crowston, 2011) which were:

- Action projects where volunteer initiated research to encourage intervention in local concerns
- Conservation projects address natural resource management goals (not focusing purely on immediate local issues).
- Investigation projects focus on scientific research goal in a physical setting

- Virtual projects also focus on scientific research goals but are entirely based on information technology
- Education Projects make education and outreach primary goals.

Yet another potential type of project is when citizens are designing and running their own scientific experiments at home, and collaborating with citizens and professionals to deliver scientific outcome. An early example of this is the PatientsLikeMe project (Swan, 2012), where patients with rare diseases share detailed medical records with other patients, and run experiments on themselves to discover the effect of potential treatments. This area is yet to be explored in more detail.

A further classification of projects can be on the basis of the topic of projects studied which varies from astronomy, archaeology, plants and animal surveys.

2.4. Design Considerations

2.4.1 Methodology

The appropriate methodology for high quality research is dependent on the objective of the study. However, there are critical aspects that apply to almost all citizen science projects (Worthington et al., 2012). Even when the focus of studies is data collection and analysis, the key areas that determine the success of projects are:

1) Design of appropriate project,
2) Recruitment, motivation and training of volunteers and
3) Ensuring data quality.

The project design is seen as vital to the success of the project, especially for those that monitor the physical world including both short term (Pocock & Evans, 2014) and long term projects (Miller et al., 2013) and this design is heavily influenced by project objectives, such as whether they are aimed at influencing decision makers or scientific discovery. A comprehensive framework was developed as a result of years of experience and noting that many projects were ‘poorly designed’ or ‘poorly planned’ (Vos et al., 2000).

The first step concentrates on identifying relevant stakeholders and developing a relationship with them. Stakeholders may include “Key Players” (high interest, high influence), “Context Setters” (high influence, little interest), “Subjects” (high interest, low influence) and “Crowd” (little interest or influence). Identifying the conflicts and interdependence between these groups allows the expectations of these stakeholders to be managed (Romanelli et al., 2011).

The second step is to identify skills and resources, and comprises of champion identification, member assessment and resource identification. The champion is a person that leads and promotes the activity, and is shown to be critical in the success of longer term projects (Pollock & Whitelaw, 2005). Member assessment determines the level of skill of potential participants and is essential to determine whether the goals can be achieved, or whether changes to project design, or training are required. Appropriate changes in project design may include changing from chemical markers of water quality to biological markers (Savan et al., 2003), use of a mobile sensing monitor for monitoring air quality (Willett et al., 2010) and using smartphone applications for easier collection of GPS location, date and photographic images (Sequeira et al., 2014).

The next step is to implement the monitoring and communication plans (Conrad & Daoust, 2008). The plan identifies the data that is relevant to the stakeholders, and identifies the methods and protocols to be used. The communication plan needs to identify the audience the group needs to communicate with, such as the stakeholders, participants, scientific community and general public depending on the goals and objectives and in a way that they understand (Jansujwicz et al., 2013). The plan also needs to include how and in what media the communication should occur. This may involve a significant investment into software design to visually present the results to the volunteers for continual engagement and utilize their local knowledge (Willett et al., 2010). A website that can act as an avenue of data input as well as for viewing project results needs to be intuitive to use. Many monitoring websites include Geographical Information Systems (GIS) and users not familiar with this technology have been shown to have difficulty utilizing these web sites, and better ways need to be discovered (Newman et al., 2010). Appropriate communication is vital to the project's success and may have additional potential benefits, such as increased stakeholder involvement and well as possibly increased funding.

The last step is to implement the project, which brings together the monitoring and communication plans. The implementation step includes implementing the monitoring plan, analysing the results, and communicating them as defined in the communication plan. Evaluation and feedback must occur to ensure that the goals are met.

2.4.2 Technological Advances

Although volunteers are the core of citizen science projects, many projects benefit from recent technological advances, and some are only possible due to these advances. The increasing use of mobile technologies, such as the smartphone, allows information to be automatically tagged by the GPS coordinates, date and time making it easier for volunteers to enter the data. In addition submission of photographs as either part of the project or as validation method is also common (Wiggins et al., 2011).

Other innovative projects utilize additional smartphone features with specially designed applications, such as NoiseTube that turns the smart phone into a noise sensor for a noise monitoring project (Maisonneuve et al., 2010), and includes an analysis of smartphones' noise level accuracy to ensure they are suitable for the task (Kardous & Shaw, 2014). In a study on forest fuel loading, not only were the images and GPS coordinates recorded but the slope and aspects were calculated using the inbuilt magnetometer and automatically recorded (Ferster & Coops, 2014). Another study used a smartphone application to detect and classify cicada's calls (Pantidi et al., 2014).

Volunteered Geographical Information (VGI) is used not only to collect data but to disseminate data in a meaningful way. Amalgamated geo-tagged information is commonly used to map the results of the citizen science on the web both as a way of disseminating the results as well as motivating volunteers as in Figure 1 (Connors et al., 2012).

Figure 1. Map of Oak Trees from Volunteers and Professionals (Connors et al., 2012)

Another method being increasingly popular is to use publically available information as a source for research, for example Google Earth imagery is being used in a project for early detection of invasive alien species (Visser et al., 2014) and for finding potential archaeological dig sites (Lin, 2010). Publically sourced data from sites, such as Flickr, are used in projects aimed at tracking humpback whale movements (Yeimaya, 2008) and whale-shark aggregations (Davies et al., 2012).

Another new technique being explored is combining data from multiple sources in a process called data mashups. For example, a case study in disaster management combines the marine traffic map, with crowd-sourced data from ships personnel to provide a rich combined view, as shown in Figure 2 (Sotiriadis et al., 2010).

Figure 2. Data Mashups in Disaster Management (Sotiriadis et al., 2010).

2.5. Data Validation

A common criticism of citizen science is that the use of volunteers poses the risk that the quality of data is poor leading to questionable project outcomes. Studies on data validation from various citizen science projects highlight areas where volunteers collect data comparable with professionals, and areas where significant differences in data quality arise, as well as discovering mechanisms that can be employed to mitigate against poor quality data.

2.5.1 Factors affecting Volunteer Accuracy

A comparison of the results of a survey on oak stands between trained students with professionals found that on some aspects, such as the number of oaks in the designated area, their diameter and crown classification, and the students performed at a comparable level to the professionals. However, as students selected the areas to sample, they tended to select areas that included larger and rarer trees, thus creating a significant bias in the data. The study recommended that the researchers present research implications resulting from data collected to ensure they understand the importance of accurate data and random sampling (Galloway et al., 2006).

A large scale ladybird survey (Gardiner et al., 2012) found that the volunteers identified most species with high levels of accuracy. However, they had issues with 10% of the species. The most common ladybird species *H Axyridis* was misidentified as another species resulting in significant underreporting. This species alone accounted for up to 70% of all errors. A probably reason was its phenotypic variation where species may be black with red spots, or yellow to red with or without black spots. The majority of errors identified this species as the pine ladybird or kidney-spot ladybird. The key to reducing errors in this study lies in the ability to understand species that citizens would find hard to identify accurately and devising a way of overcoming this. Relying on citizen science data without checking for validation issues can be misleading.

An analysis of accuracy of results from a study that maps the distribution and abundance of common marine organisms within Scotland (Foster-Smith & Evans, 2003) showed volunteers could identify the organisms and count their occurrence on specific parts of the shore, and also measure their lengths at an accuracy comparable with professionals. However the volunteers could not fulfil the “assessment of abundance” task with a high level of accuracy. This was attributed to a lack of field experience, inadequate guidelines and the complexity of this task.

Observer variability was investigated in the American pika monitoring survey (Moyer-Horner et al., 2012) looking at variability among professional observers, volunteer observers and mixed teams. The study found that estimates of pika occupancy were consistent with each team conducting sitting surveys. However, the collected data on population dynamics varied between the teams, with the professionals consistently finding more signs per unit of survey effort. The study highlights the importance of identifying observer variability between various tasks to determine the tasks where citizen science can be used with confidence.

In yet another study on citizen-driven intertidal monitoring programs, the quality of data conducted by secondary school students were compared to researchers conducting the same monitoring exercise. The study found that the secondary students accurately collected data within the range of variations occurring between the researchers. However, they were more likely to misidentify cryptic and rare species (Cox et al., 2012).

Factors affecting data accuracy was studied in a crab survey which compared the volunteer’s age (ranging from 3 to 78), education level (ranging from pre-kindergarten to PhD) and group size (1-10 people) with their ability to survey a site, collect crabs, divide them into species and gender. The study found that education was a highly significant predictor to their ability to correctly identify both the species and gender of a crab. Third grade students were at least 80% accurate, while seventh grade students were at least 95% accurate in differentiating native and invasive crabs. However, the 95% level for identifying the sex of the crab was only obtained with volunteers with at least 2 years of university education (Delaney et al., 2008). This highlights the need to identify the difficulty of the task, and ensure that the citizen scientists have the necessary skills to match the difficulty.

The Galaxy Zoo Project has shown that the use of multiple independent volunteer classifications is a robust method for ensuring the accuracy of results when analysing large datasets of galaxy images (Willett et al., 2013). Whereas this approach can be utilized in many virtual projects to measure data accuracy, it is not applicable to most monitoring programs.

Citizen science projects of transient phenomena are especially hard to validate. Contrails are anthropogenic cirrus clouds formed under certain atmospheric conditions when heat and water vapour emitted from aircraft exhausts mix with cool ambient air and can disperse instantly or last many hours. The presence of contrail is important for regional and global climate change implications. Data collected by citizens were validated by comparing their results to four supporting datasets. Photos taken by the citizens were the only direct evidence being the first dataset, although few photos were actually received. Another dataset used was the national contrail observer network, run by professional meteorological observers, who make regular observations. In addition, two other datasets, a network of real-time aircraft locations and a relative humidity with respect to ice dataset were used to validate the correlation between the likelihood of a contrail in a location and time with the volunteer observations. Comparing citizen science data to these datasets showed that the citizens were able to correctly identify the sky state (Fowler et al., 2013).

The examples presented above highlight the following areas that should be considered in the study design in order to ensure that the data received is of high quality:

- Provide appropriate training to citizens, ensuring they understand the aims of the study and the importance in providing accurate data.
- Identify areas where the public may struggle (e.g. following a trial study) and modify the study, or add additional training to overcome these issues.
- Ensure that volunteers have an appropriate background (e.g. education or experience) in order to perform, or provide additional data verification for novices.
- Where possible, validate using multiple analysis of the same data.
- Where possible, provide hard evidence, such as photo, GPS and time coordinates from mobile devices.

This study of aquaponics limited participants to those who had already designed and were running their own system, and as such had a level of understanding of the subject matter and the appropriate background. However, since the aim was to observe how the participants experimented, providing training on how to participate would have invalidated a key objective. Instead, three recognised experts were consulted to identify areas where the participants may struggle, where accurate data cannot be obtained and to ensure that the collected data is useful to the participants. Changes were made to modify the study design to overcome these issues, such as changing terminology from “log” to “diary”. In addition, by building a system and using the software as a “participant” over several months a realistic test of the software and results was conducted. A photo diary was added to allow for the collection of photos. However the key validation point was that the data collected was visible to other participants and issues could be raised by other participants if they identified issues.

2.5.2 An in-depth example from eBird project

Maximising information from broad scale projects that gather species occurrence data relies on finding the proper balance between data quantity and quality. Quantity is important, because a sufficiently large volume of data with relatively lower per-datum information content can contain more information for broad-scale species distribution estimates than a smaller amount of higher quality data (Munson et al., 2010). To increase quantity, the number and spread of volunteers also need to increase. Given the broad spread of volunteers, ranging from expert birdwatchers, to less experienced observers, data collection protocols need to be simple and designed to minimise errors (Bonney et al., 2009b). The eBird project team has conducted extensive investigation in observation and recording errors and based on these findings have implemented a range of measures at each stage of the project.

2.5.2.1 Data Entry

The recording of incorrect data is the greatest source of errors so the user interfaces need careful design. The interfaces need to be easy to use and informative to assist in correct species identification and utilize electronic field guides (Stevenson et al., 2003). The interfaces should strive to limit incorrect data entry (e.g. spurious species identification). Once data is entered, quality filters can identify outliers and challenge the volunteer to verify the data. Quality filters can be based on the experience of the volunteers to avoid unnecessary annoying verification steps. This is the first level of validation and requires customised forms for specific regions, quantifying the expertise of contributors, as well as statistical analysis on received data (Hochachka et al., 2012). The design of the software, database and hardware infrastructure to support the tens of thousands of contributors is key to reducing errors at the data entry stage (Kelling et al., 2013).

2.5.2.2 Post-entry Validation

Initially a second level of validation of data was applied on all received data where experienced volunteers check the entries of unusual species for that location and time of year (Hochachka et al., 2012). As the volume of collected data has become too large for manual screening of outliers, a machine learning algorithm was developed to estimate observer expertise to determine whether unusual observations should be flagged for review (Yu et al., 2012). The emergent filters, based on aggregated historical data and observers experience, not only improved the quality of data, but allowed the filters to be included in the user interface, guiding the observers with immediate feedback on observation accuracy (Kelling et al., 2013).

2.5.2.3 Limitations of Filters

This approach was extended and trialled in the project FeederWatch, which tracked changes in distribution and abundance of birds in winter (Bonter & Cooper, 2012). The filters using historical data and "allowable" species was extended by flagging a species that had not been reported by at least 4% of participants in the state prior to the current season. Maximum counts for each species were calculated based on historical reports. Results over 3 years showed that the smart filter is effective in identifying potentially erroneous observations, but ineffective at identifying incorrect report of sightings that are plausible for the location and date.

2.5.2.4 Benchmarking eBird Data Quality

To ascertain the level of data quality, the eBird data has been validated against a second benchmark data source (Munson et al., 2010). A study comparing the highly standardised North American Breeding Bird Survey (BBS) with the eBird shows that the eBird data contains information similar in quality to that in BBS, but the information per BBS data element is higher. In addition, the eBird data was noisier due to non-uniform spatial sampling, lower detection probabilities or varying survey lengths and durations. The discrepancies with most species between the databases are shrinking as the volume of data increases, and it is expected that eBird will soon equal the information within BBS. For some species eBird is already more accurate, whereas for other species, such as nocturnal birds, are rarely counted within eBird. These types of comparisons show both the strengths and weaknesses of citizen science projects which suffer from an uneven distribution of the areas being studied, usually dependent on the ease with which the volunteers can access the areas.

2.5.2.5 Data Bias

Data quality suffers from biases based on:

- **Location** – most data was collected in areas easily accessible to birdwatchers.
- **Time** - most data was collected at times suitable to birdwatchers. For example, nocturnal birds are rarely counted.
- **Weekend bias** – Through a study of the "first" migration arrivals of birds it was found that a greater percentage of first arrivals were reported on the weekends (Courter et al., 2013). The effect of weekend bias has decreased during the study period from 1997 to 2010 from 33.7% to 32%. The bias reported in the US study was low compared to a

similar study in Europe (Sparks et al., 2008) where 43% of "first" arrivals were reported over the weekend.

Understanding bias and its correction reduces the barriers of incorporating citizen science into projects collecting data for scientific research.

2.5.2.6 Other Methods for improving quality

Other alternative methods for improving quality included:

- creating online games or quizzes that quantify the bird identification skill of each participant, and use this within the smart filter,
- submission of photographs to validate the finding (Hochachka et al., 2012).

Another technique for improving data quality concentrates on finding out the percentage of false positives in the data using key informant interviews, prior data, pilot studies or existing literature. Applying corrections for both false negatives as well as false positives allows a better understanding of the resulting datasets (Pillay et al., 2014).

2.5.2.7 Learning from e-Bird

The e-Bird project demonstrates the depth of research that informs methods that can be used to ensure data quality in projects where the data provided by the participants cannot be independently verified. Ideas from e-Bird are reflected in the study design, such as specific forms to adding different types of data to check answers and avoid errors. The use of drop down lists for species, and numeric data allow for some level of data verification. Secondly, the participants can enter the data in units of measure with which they are familiar, including weight, length and temperature measurements as well as display data in their units of measure. The appropriate conversion required to compare data are hidden within the software. All the dates they view are also local to their time zone. These measures limit data entry issues. In addition their raw data accessible for other users to view and comment on allowing data validity questions to be raised. The submission of photos were also included as a further validation and communication method.

2.6. Volunteer Motivation

As citizen science projects rely on attracting interested volunteers, the question arises as to what motivates people to volunteer. Volunteering in environmental and wildlife monitoring has a long history, and studies on the volunteers' motivation have identified reasons as (Measham & Barnett, 2008):

- contributing to community;
- social interaction;
- personal development;
- learning about the environment;
- an ethic of care for the environment;
- an attachment to a particular place.

The two main themes of helping the environment and learning appear in almost all the motivational studies on environmental and wildlife monitoring, although expressed in different terms such as "seeing improvements in the environment" or "protecting natural areas" (Schuett et al., 2014). This is also expressed as "giving something back" (Hibbert et al., 2003). In addition, project organisation significantly affected volunteer commitment (Ryan et al., 2001). Projects with high levels of motivation were those that were well organised with a good leader and where the project clearly defined what was expected by the volunteers.

Although most studies show that learning is a major motivation, some other studies show a negative relationship. Studies attracting highly experienced volunteers appear to be more prominent where learning did not appear to be a major motivation (Ryan et al., 2001).

Additional motivations found in other wildlife monitoring studies included seeing wildlife (Hobbs & White, 2012), being able to contribute while doing an activity in which they were already participating (Schuett et al., 2014) and prior interest in the field (Raddick et al., 2013).

Personal factors, such as improving health and wellbeing, were also reported (Hobbs & White, 2012), as well as wanting to assist with scientific research (Koss et al., 2009) and the feeling of being needed (Ryan et al., 2001).

Another study found that motivation changed as the project progressed. Egotism was a major factor in the initial phases, where participants wanted something that satisfied their needs, interested them and educated them. This need was satisfied by attaining attribution and recognition, particularly by the scientists. Following active collaboration, collectivism and altruism became significant, with participants wanting to do something for the larger community and advocacy (Rotman et al., 2012).

Long term participation requires broader motivations than self-directed motivations, such as personal interest and is hampered by poor communication and poor infrastructure. The key motivator for long term participation is the relationship between volunteers and scientists, and between volunteers and their communities. Projects that enabled volunteers to easily contribute data, retrieve it, see its broader impact on scientific advancement and their own community were those motivated to deeper engagement for longer periods of time (Rotman et al., 2014).

Most citizen science projects do not include any monetary payment so the question arises as to whether this would affect the motivation and project outcomes. In an experimental study to access how volunteer performance was affected by paying them it was found that increasing the level of payment attracted more workers as well as increasing the number of tasks the workers completed. However they found that payment did not significantly improve accuracy of their results. In fact those that worked for no payment achieved higher accuracy rates not only for simple tasks, but also for more complex tasks. The same study found that simplifying the tasks also lead to quicker results (Rogstadius et al., 2011).

However specific non-monetary benefits have been shown to be significant in attracting and retaining volunteers, such as keeping personal lists of observations, displaying their observations on maps and graphs and providing “awards or badges” to reward contributors (Bonney et al., 2009b). The eBird project is an interesting example. The original expectation of the investigators was that the main motivation for participation in the eBird project would be to provide data for scientific research, but few participants volunteered. By improving the web site and providing direct, non-monetary rewards to participants resulted in rapid growth in the number of citizen science participants. These included features that allowed them to keep track of their own bird sightings, sort their personal bird lists by date and region, share their lists with others and visualise their observations on maps and graphs (Hochachka et al., 2012).

The motivations are reported in virtual citizen science, where participants contribute purely on-line, are quite different from participants contributing to monitoring studies. Key motivations for these projects are:

- social engagement with the project,
- interaction with the website including the enjoyment using the various features, and
- helping the scientists (Reed et al., 2013).

In astronomy (Raddick et al., 2013) motives for citizens participation also included:

- the ability to see galaxies that few people have seen before,
- enjoying looking at beautiful galaxy images,
- amazement at the vast scale of the universe and
- being able to contribute to original research.

Given the above findings, the question is how these ideas can be utilized in the design of new citizen science projects. Firstly, areas of study likely to result in successful citizen science projects are those where there are significant groups of citizens with prior interest with willingness to improve knowledge in the field, and a desire to connect with others of similar interest. With longer term projects, in order to keep the citizens motivated, it is important to ensure that citizens benefit from the project through learning new skills, sharing knowledge, creating partnerships with researchers, enhancing the social relationships and increasing their knowledge of the topics being researched (Koss et al., 2009).

2.7. Additional Benefits and Outcomes

2.7.1 Volunteers

In addition to utilizing citizen science for scientific research purposes, the objective of many citizen science projects is to enrich volunteers, reunite them with the environment, increase their scientific literacy or as a fun way of teaching science in schools. Even projects with a clear research focus often result in beneficial outcome for the volunteers (Phillips et al., 2012).

Many volunteers found that the perceived rigidity of the scientific process gave participants the excuse of doing an activity that they already enjoyed with like-minded people (Lawrence, 2006). Some of these direct benefits are postulated to be (Haywood, 2014):

- Enhancing scientific knowledge and literacy
- Enhancing understanding of the scientific process and method
- Improving access to science information
- Increases in scientific thinking
- Improved ability to interpret scientific information
- Strengthen connections between people, nature and place
- Demystifying science
- Empowering participants and increasing self-efficacy
- Increasing community building, social capital, social learning and trust
- Changing attitudes, norms and values.

The improvement in scientific information, literacy and thinking is often perceived as a beneficial outcome but closer scrutiny shows this is more complex than initially appears. Many studies, such as a study of invasive plants, tested the participant's knowledge of invasive plants before and after their involvement and found that their knowledge increased on an average 24%

but this study raised doubts as to whether there was an increased understanding how scientific research is conducted (Jordan et al., 2011). Another study performed in conjunction with a bird box nesting project showed that the project increased participant's knowledge of bird biology, but there was no statistically significant change in the participants' understanding of the scientific process, attitudes toward science and attitudes towards the environment (Brossard et al., 2005). However in another study there was evidence of an increased appreciation of complex issues, for example understanding "biodiversity", how science works and how scientific research is published. This group were given the opportunity to suggest hypothesis that could be the basis of future studies (Foster-Smith & Evans, 2003).

Further work on how citizen scientists formulate new insights as they contribute to research would inform project design that further benefits the participants as well as the project. Other personal benefits were found to be improved fitness, keeping alert, meeting others and reducing stress levels (O'Brien et al., 2010). The benefits can also be seen in a change in the behaviour of volunteers, for example creating native landscapes in their own garden (Ryan et al., 2001) as well as forming an increased appreciation of natural areas, attachment to volunteer site and environmental activism (Ryan et al., 2001).

This transformational experience when participating in citizen science is well illustrated in a project where volunteers included members of a disadvantaged group from drug rehabilitation programs as well as more privileged participants. In an arduous and repetitive study involving trapping and measuring mice and observing badger and deer presence, the effect on the volunteers could be seen in that 7 of the 155 volunteers subsequently started careers in biology and at least 50 joined conservation organisations. Over a third found participation in science a transformational process (Lawrence, 2006) (Newman et al., 2003).

2.7.2 Community

Well conducted and validated projects contribute not only to the scientific knowledge and environmental outcomes, they also influence community attitudes and decision making. A study into the effectiveness of citizen science projects in environmental decision making as compared to professional studies (Danielsen et al., 2010), shows that local monitoring projects were more effective at influencing local decision, with changes appearing within 0-1 years, while studies executed by scientist informed decision within regions, nations and international conventions, take between 3-9 years to be implemented and often have little impact at the village scale. An example of a very effective citizen science project is the Martha's Vineyard project (Karney, 2009) where water quality studies by residents allowed them to pressure the various local authorities and businesses to act, for example, in inspection and replacement of failed septic systems, removal of an underground oil tank, the addition of free pump out of boat septage at Edgartown, the redirection of road effluent into adjacent wetlands for filtration and changed methods of livestock farming.

2.7.3 Changing Attitudes

Public engagement in science has been demonstrated as an effective strategy in changing individual perspectives, attitudes about the environmental and the personal relevance of science. This movement has significant implications to both science and the community because there can be little doubt that the lay public's failure to comprehend scientific issues is a root cause of the under-funding of science (House of Lords, 2000) as well as affect the debate on specific issues such as climate change.

2.8. Conclusions

The recent rise in citizen science projects follows a long history of public involvement. This rise is underpinned by the development of methods that address issues that arise when inviting a wide variety of people, who often lack scientific training, to contribute, Significant research into methods of validating data has resulted in improving data quality.

The range of projects have also grown, and now includes, as well as monitoring projects, virtual projects that are done purely online.

Research into the motivations of volunteers led to understanding the benefits that citizens obtain in being involved, allowing projects to be designed that, as well as contributing to science, also benefit the citizens.

Chapter 3: Scientific Publication Patterns

3.1. Introduction

With the increase of research based on citizen science, the question arises as whether this methodology is accepted by the scientific community (Bonney et al., 2014). An analysis of peer reviewed papers provides an indication of scientific research effort, its growth and areas to which this is applied. This analysis provides a useful baseline, although the real extent of scientific research will be significantly higher as not all research that utilizes citizen science reach peer-reviewed scientific research (Theobald et al., 2015).

The peer reviewed literature not only describe projects using citizen science but also the methods that are applicable. The articles on methodology investigated project design, applicable methods and models, and tools required to ensure that the projects satisfy both scientific and educational outcomes (Bonney et al., 2009b).

3.2. Methods

This research is based on a review of peer-reviewed articles collected from the Web of Science (Hladka et al., 2012) and Scopus. All articles with “citizen science” in the topic were extracted for all its databases and years up to and including 2014. The 772 articles extracted from the Web of Science and the 803 articles extracted from Scopus provide the basis for this analysis. As 481 articles were in both Web of Science and Scopus, and 23 articles duplicated in the extracted list, 1071 unique articles were identified. It should be noted that this list could have been substantial larger if the search was extended to include other terms such as “Volunteer Monitoring” or “Volunteered Geographic Information” or extended to further collections of scholarly articles. Google scholar contained 14,680 articles for “citizen science” over this period, but was not utilized in this analysis as articles on Google Scholar includes both peer-reviewed and unreviewed articles such as technical reports, and drafts (Google, 2015). Even with these caveats, the extracted list of articles provides interesting and useful insights.

The information included the extracted list consisted of the name of authors, title of the article, the source title, the abstract, and the year of publication.

The first step was to ensure that the extracted references were on the subject of citizen science as defined by the European Commission Green Paper (European Commission, 2013). The title and abstracts of these articles were examined, and articles not satisfying this definition, such as crowdsourced funding, surveying citizens to provide input for research, science education to citizens, political science and government, citizens jury, science tools useful for citizens and tweeting science information to citizens were excluded from further analysis, reducing the number of articles to 871.

The second step was to tag each remaining article on the multiple dimensions of focus, and for articles describing case studies or projects, the goal of study and the topic studied. Articles using data from past citizen science projects for further research were also tagged and analysed.

The focus of the article was determined by careful examination of the text of the title and the abstract, which should reflect the key message of the article. Using an inductive approach, the titles and abstracts were examined to determine suitable categories, and the following six categories were selected: (i) general articles on citizen science, (ii) articles investigating and proposing citizen science methodology, (iii) articles investigating and proposing validation techniques, (iv) articles exploring the motivation of participants, (v) articles exploring the effect of participation on the participants and (vi) articles describing and reporting the results of a case study which are specific projects where the main objective was to obtain the results of the study for scientific or educational purposes. It is noted that these categories are not mutually exclusive, for example many case studies also discussed how the collected data was validated, either to justify the case study results, for example a study of global night sky lumination (Kyba et al., 2013), or to evaluate various validation methods, for example a study of invasive and native crabs in the US which not only identified the distribution and abundance of the species but also identified predictors of volunteers' ability to correctly identify the species and gender of the crabs (Delaney et al., 2008). The former example was included only in the case study category, whereas the latter was included in both the case study category and the validation category.

The case studies were classified based on their goals, using the five types defined by Wiggins and Crowston (Wiggins & Crowston, 2011), being action, conservation, investigation, virtual or education.

In addition, the case studies classified based on the following topics astronomy, environment, biology and other topics. As the biology component was significant, this category was further broken using an inductive approach into the popular categories of birds, insects, marine biology, plants and others.

The case studies that re-used data from past case studies for research purposes were also identified.

The third step was to analyse the tagged data. The number of articles available in the Web of Science, Scopus and both were plotted against the year of publication.

For each of the above dimensions, the percentage in each of the categories were calculated and values plotted against the year of publication to explore changes that occurred over time.

The fourth step analysed the journals where the articles were published, to determine the most popular journals for the citizen science publications and also the spread of articles over the journals identified.

3.3. Results and Discussions

The analysis of published dates shows that though the first publication was in 1997, few publications followed during the next 10 years. In 2007, 6 papers were presented at an Ecological Society of America Meeting, which included general articles and case studies on hummingbirds and butterflies and this exposure may have contributed to a substantial increase in publications from that date as seen in Figure 3. The coverage of publications in this area is even between the two databases, Web of Science and Scopus, with each covering 73% of the extracted publications. Only 46% of the publications appear in both databases, indicating that to rely on one source is not sufficient.

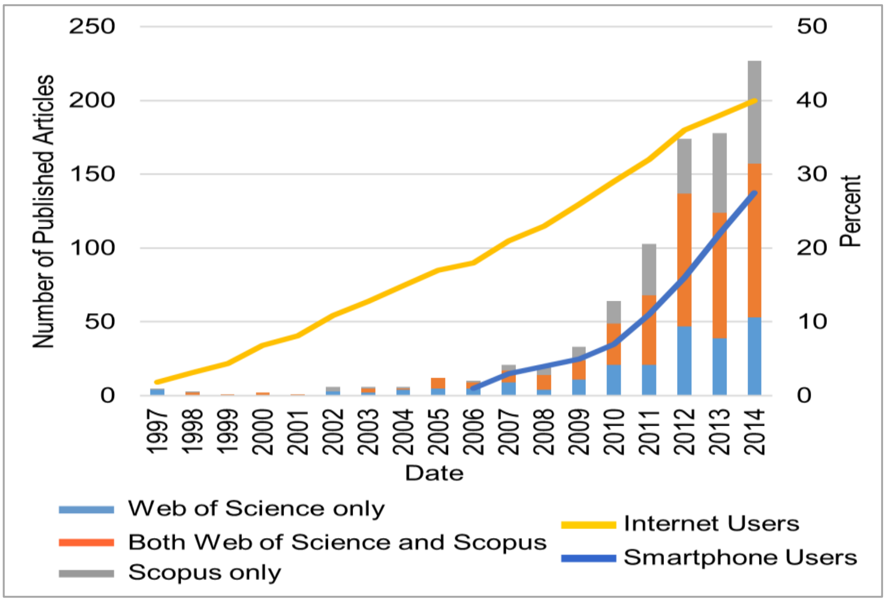


Figure 3. Increase in Number of Articles Published

Although it may be considered that the growth in the application of citizen science method for research is driven by the growth in internet use (Bonney et al., 2014), it is interesting to note that the average annual growth of citizen science publication output lags internet use until 2009 (Sanou, 2014), while in the following years the growth of citizen science publications averages 51% outstripping the internet growth of 9%. Although the internet is critical to many citizen science projects, and is an enabler of projects, it is not the only reason for its increase. It is interesting to note that the growth in smartphones of 41% is a close match to citizen science articles. As many new citizen science projects utilize smartphone apps it is possible that smartphones are a significant driver in the recent update of citizen science (Starr et al., 2014).

The most popular focus of the citizen science publications was case studies (51%), where the main objective was conservation, scientific research or education. General articles that discussed citizen science in broader terms were also popular (30%). The focus of articles has changed over time, with initial interest being in general articles and case studies as shown in Figure 4. These two areas of focus have continued to grow in importance, but after 2009 papers have shown an increased interest in methodology and validation issues. This increased interest is key to ensure high quality data suitable for scientific study. Many of the studies show that by applying those techniques the data collected by citizens can be comparable to those collected by scientists (Danielsen et al., 2014). Studies on motivation of citizens, and the effect on the citizens are more recent and still lag. These studies will be key in increasing volunteer numbers and retention.

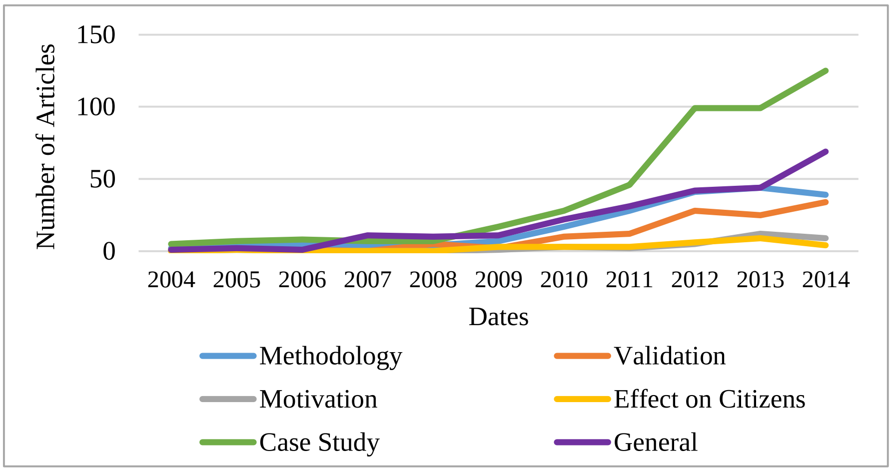


Figure 4. Focus of Articles over Time

The case studies were divided into their topology based on their goals, which are defined as action, conservation, investigation, virtual and education (Wiggins & Crowston, 2011). Only three articles were found to fit into the action category, where the projects are initiated and driven by the public, and as such did not generally result in scientific publications. The investigation category accounted for over half (57%) of the articles, as shown in Figure 5

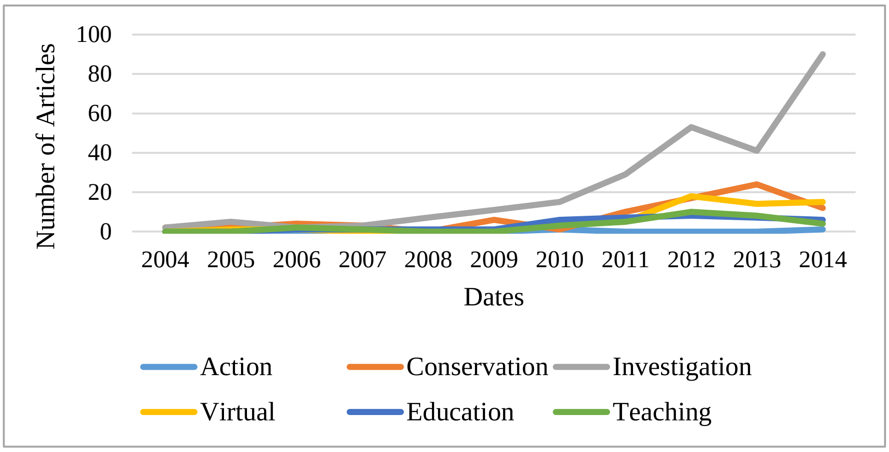


Figure 5. Typology of Case Study over Time

covering articles focused on scientific discovery in a physical setting, for example a detailed study of otter demographics in California (Brzeski et al., 2013). The conservation category was also popular with 19% concentrating on physical studies with a resource management, rather than scientific focus. This includes, for instance, road watch study, which recorded road kills in Canada, addressing concerns from both human safety and wildlife conservation perspectives with the aim of mitigating the effects of highway expansion (Lee et al., 2006). It should be noted that it many of the articles in the investigation category are also focused on conservation, the main difference being that these are normally scientist initiated and run and focused on obtaining scientifically valid data for research. With the popularity of Galaxy Zoo, resulting in numerous publications, it is surprising that that virtual projects only comprise of 13% of the case studies. This low number may be due to many publications based on data provided by citizen science projects do not refer to the origins of their data. For example Galaxy Zoo publishes a list of 48 publications (up to the end of 2014) on based on data obtained by their citizen scientists (2015). Only 4 are contained within the analysed list where the topic is restricted to those referring to “citizen science”. This indicates that the contribution of citizen science to science is significantly greater than apparent from literature on citizen science. Virtual projects are likely to grow with recent projects based on using publically available data sources, such as Google earth and picture archives, and used for projects such as the discovery of new archaeological sites (Lin et al., 2013). The education category was not significantly represented (9%) and consisted mainly of projects that could be performed in the classroom or school grounds often as part of a science curriculum, such as the butterflies and ground squirrel monitoring projects (Kelemen-Finan et al., 2013). Where published, these studies are more likely to be published in popular media than scientific journals.

Biology dominates the topics, with 76% of the case studies in this category (Figure 6). As well as being the most dominant topic, it has been the area with the most rapid recent growth with the most common objective being to determine diversity and distribution of species (Donnelly et al., 2014). The other case studies are evenly spread between Astronomy, the Environment and the other category. The other category illustrates the diversity of citizen science topics and methods with topics transcribing historical weather records from shipping logs for climate change research (Brohan et al., 2009) and citizens playing games to align multiple sequences of DNA (Kawrykow et al., 2012) for medical research. The latter study provides input to studies in evolution, annotating genomes and understanding the causes of various genetic disorders (Kawrykow et al., 2012).

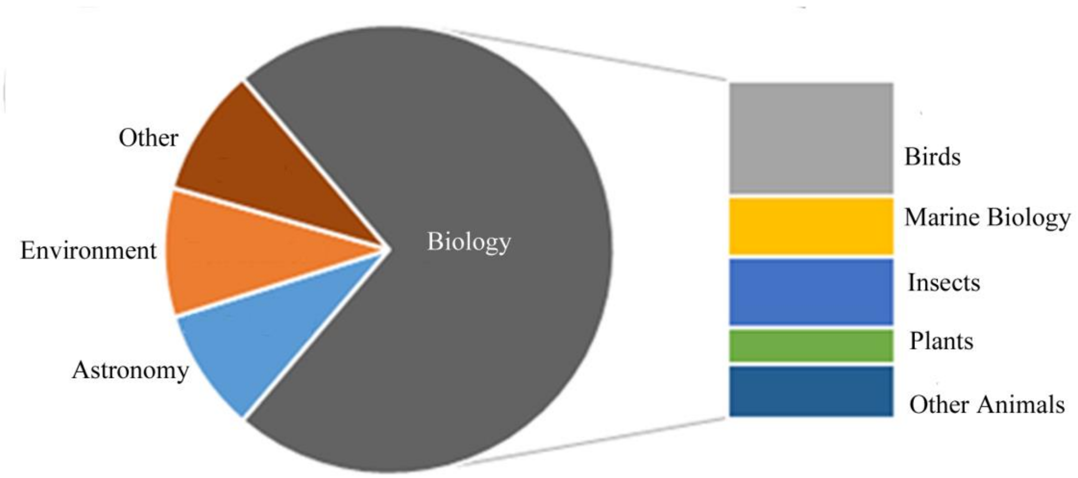


Figure 6. Target of Case Study

Dividing the large biology category into distinct areas show that birds dominate this research with 35% of the projects followed by insects at 21%. The Other Species category illustrates the variety of subject topics with studies focusing on monitoring of bats (Fahr, 2013), river otters (Brzeski et al., 2013), coyotes (Weckel et al., 2010), and reptiles (Sewell et al., 2012).

An increasing number of articles reused data from previous citizen science studies (Bonney et al., 2014), with the most prolific being bird data (38%) as seen in Figure 7 driven by the eBird project which is a collection of bird projects with a combined list of over half a billion records and is available for free download to researchers (Sullivan et al., 2014). The eBird web site (eBird, 2014) claims that over 120 peer-reviewed publications have used their data, and there have been over 6,500 requests for download in an 18 month period, although only 29 appear in this research dataset. The analysis of the extent of reusing of citizen science data is very challenging and needs a more detailed elaboration through tracking of the citations to the original articles (Cooper et al., 2014).

The most common reason for re-using data is for climate change research (Hurlbert & Liang, 2012) which combines data from many different datasets, for example transcribed old weather records, plant flowing and bird migration (Havens & Henderson, 2013). 29% of studies re-using citizen science data specifically mentioned climate change.

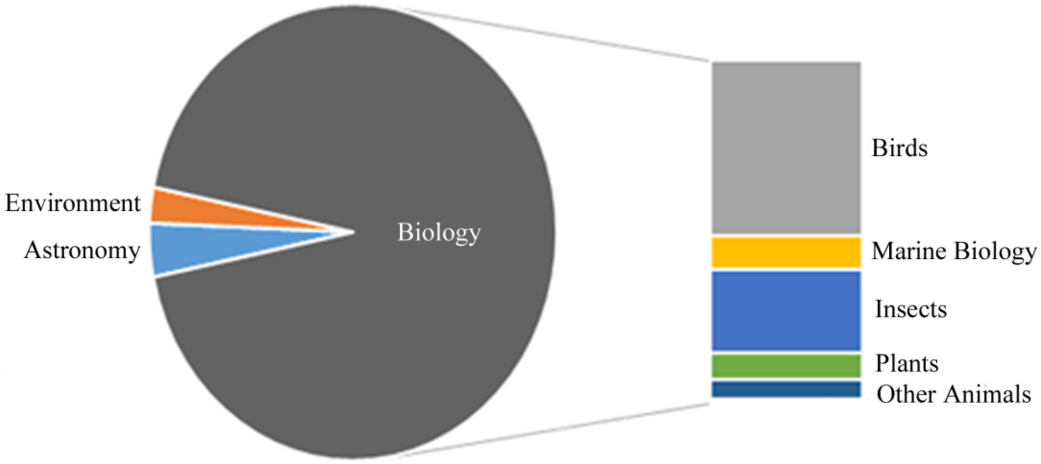


Figure 7. Topic of Articles Re-Using Data

The citizen science articles are scattered over many different publications with the 886 articles analysed here appearing in 619 different publication sources as see in Figure 8. 83% of these articles appeared in publication sources that have only ever published one or two articles on citizen science. PLOS One (26 articles), Frontiers in Ecology and the Environment (19 articles) and Biological Conservation (19 articles) are the most prolific sources of citizen science articles. The spread of articles hinders the accessibility to researchers wishing to understand how to apply citizen science to their studies and the cross-fertilisation of ideas. The imminent Citizen Science Journal (Citizen Science Association, 2015) will also provide a focus on citizen science articles.

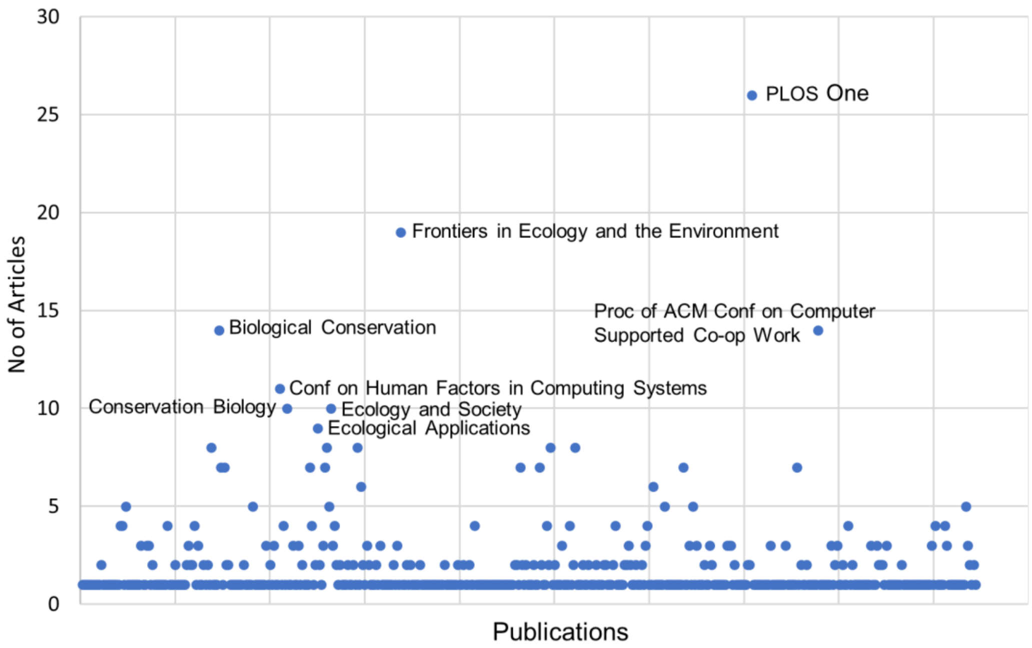


Figure 8. Sources of Articles on Citizen Science

3.4. Conclusions

The study of scientific publication patterns indicate increasing acceptance by scientists that citizen science and projects based on citizen science can produce scientific outcomes. Although most of these published studies are primarily for the benefit of the science community, significant benefits can flow to the participants.

In the majority of these studies citizens gather data for use by the scientists, or analyse data provided by the scientists, giving rise to the question as to whether citizens can be involved in all areas of the scientific process. This thesis examines how participants in the aquaponics citizen science project contributed to all stages of the scientific method and attempts to shed some light onto this question.

Chapter 4: Aquaponics

4.1. Introduction

In order to study how citizens researched, a new citizen science project in aquaponics was conducted. The results of this project provides insights into the field of aquaponics, as well providing the data for the core research on how the citizens experiemented. This chapter provides an overview of aquaponics and current aquaponics research. Aquaponics is “the integration of aquaculture and hydroponics” (Love et al., 2014)**.**

4.2. Aquaculture

The increasing demand for fish as part of our diet, resulting from population growth, has led to the exploitation and degradation of natural fishing stocks (Levin et al., 2006). In response, fish farming (aquaculture) forms a significant global food source. The growth rate of aquaculture (7.8%) is substantially higher than poultry (4.6%) pork (2.2%) dairy (1.4%), beef (1.0%) and grains (1.4%) between 1990 and 2010 (Troell et al., 2014).

Aquaculture currently sources around half of the fish consumed worldwide (Food and Agriculture Organisation of the United Nations, 2013) and its share is expected to increase. However, aquaculture itself brings significant challenges requiring not only fish food and clean water, but producing large amounts of wastewater containing compounds, such as suspended solids, total nitrogen and total phosphorus (Turcios & Papenbrock, 2014). Constructed wetlands is becoming more important in recirculating aquaculture systems as a cost effective way of treating wastewater as these can filter the solid and soak up the nutrient content in plant growth. As the wastewater is rich in fish waste that could be transformed into the plant nutrients required for plant growth, the question arises as to whether the wastewater can be used to raise food crops.

4.3. Hydroponics

The early research into the essential nutrients needed for plant growth and development can be traced to the period between the 1700s and 1800s. To isolate the essential nutrients for plant growth, plants were grown in soilless culture trialling various nutrient solutions. By mid 1900s all the currently recognised essential elements required for green plants growth were discovered (Jones Jr, 1982). This research is the basis for hydroponics, a new term coined in 1930 by Dr W.

F. Gericke (Paterson & Hall, 1981). Hydroponics has recently seen renewed interest, possibly due to the depletion of land and societal interest in urban farming (Buwalda et al., 2013).

Hydroponics rely on the availability of suitable nutrient solutions, and require considerable ongoing effort in ensuring that the solutions are correctly balanced (Checkai et al., 1987). In addition, to avoid the build-up of toxins, such as sulphates, chlorides and bicarbonates, hydroponics require that the solution is periodically disposed of, leading to research as to how and when this solution can be recycled (Zekki et al., 1996). Agricultural waste, in general, is a significant source of excess nutrients which has significant impacts on freshwater, marine and terrestrial ecosystems (Smith et al., 1999).

4.4. How Aquaponics Work

The issues associated with aquaculture and hydroponics suggest that together, a more sustainable solution can be developed, known as the aquaponics cycle. Aquaponics uses fish waste as the source of nutrients for plants. Fish produce waste with ammonia being a dominant waste product. Aerobic bacteria from the genera *Nitrosomonas* converts ammonia to nitrites which is further converted to nitrates by the bacteria *Nitrobacter* through a natural process called nitrification (Nichols & Savidov, 2012). The nitrification process occurs in a water filtration system, such as a gravel media bed or a biofilter. The nitrates, together with other fish waste, are used to grow plants (Figure 9).

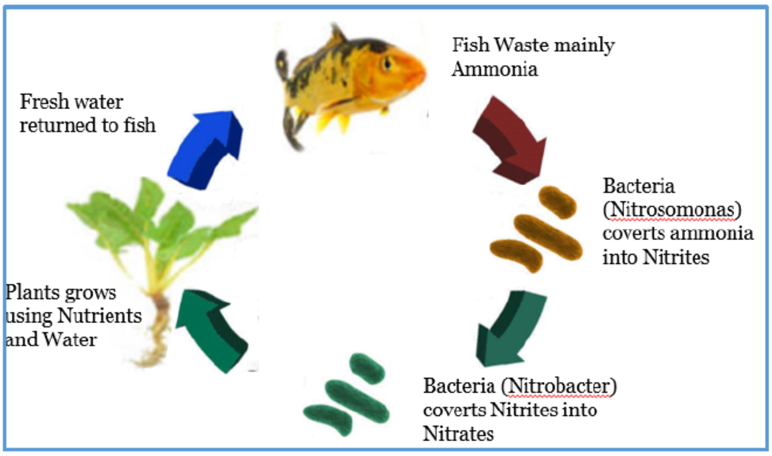


Figure 9. The Aquaponics Cycle

In addition the filtered clean water is returned to the fish, avoiding the need to release of waste water into the environment (Bernstein, 2011). As the water is recycled, the water loss is reduced to evaporation and plant transpiration resulting in a very water efficient system where the main inputs are fish food and electricity for pumping the water through the system.

4.5. Aquaponic Designs

The aquaponics cycle is the basis of all aquaponic systems, and has been implemented in many variations, ranging from small scale home systems to large commercial systems. The designs are classified based on how the plants are grown, which can be divided into three main classes, media bed, nutrient film technique (NFT) and floating raft systems.

4.5.1 Media Beds

Media Beds are used as both biofilters and as the medium for growing plants as seen in Figure 10. A survey of aquaponic systems (Love et al., 2014) showed that 86% of responders used media beds. This design is particularly common in small scale home and community systems due to the simplicity of use. The most popular media used is expanded clay balls and gravel.

Figure 10. Media Bed

4.5.2 Floating Raft Systems

In floating raft systems, plants are gown in rafts that float above the water as seen in Figure 11. In this instance either a separate biofilter is used, or this system is used in conjunction with a media bed which acts as the biofilter. Systems using both a media bed and a raft are known as hybrid systems. The aquaponics survey (Love et al., 2014) showed that 46% of their recipients used floating rafts systems either in addition to or instead of the media system.

Figure 11. Floating Raft System (en.wikipedia.org)

4.5.3 Nutrient Film Technique (NFT)

The nutrient film technique is common in hydroponic systems, and is often used in commercial hydroponic or aquaponic systems. Plants are grown in holes within pipes through which nutrient rich water flows (Figure 12). This technique also needs either a biofilter, or a media bed to convert the ammonia to nitrates. This was used in 19% of the systems in the survey (Love et al., 2014).

Figure 12. Nutrient Film Technique (de.wikipedia.org)

4.5.4 Other Variations

Other methods used are vertical towers where plants are grown in vertical pipes and wicking systems where nutrient rich water is provided to the plants from a reservoir under the soil in a similar way to "self-watering" pots.

4.6. The Genesis of Aquaponics

The aquaponics principles can be traced back to ancient cultures. The Aztecs cultivated plants in artificial agricultural islands known as chinampas as early as 1150-1350 BC, allowing the postclassic Aztec civilization to flourish (Turcios & Papenbrock, 2014). The chinampas were created by staking out a section of the shallow lake bed, fencing it with wattle and then layering it with mud, lake sediment and decaying vegetation until these artificial islands are above the level of the lake. Fish waste was collected from the bottom of the canals separating the islands and used to fertilize the plants. This process resulted in very high crop yields with between 4 and 7 harvests a year (Van Tuerenhout, 2005).

A similar process is still in use in Bangladesh where plants are grown in floating rafts called dhaps. Dhaps are closer to the modern aquaponics systems in that they are soilless. The rafts are built using water hyacinth, local grasses, husk and coconut fibres and obtain nutrients directly from the water within which they float (Islam & Atkins, 2007).

The modern revival of aquaponics grew from four intersecting areas of experimentation conducted between 1970 and 1990:

1) The interest in intensive fish production prompted a group of researchers (Naegel, 1977) to consider alternate ways of removing waste from intensive fish production. After noting that nitrifying bacteria in an extended aeration process was insufficient to reduce the nitrate concentration in the water, Naegel attempted to grow ice-lettuce and tomatoes in the recirculating water. Not only did this result in successful plant growth, but the weight of the fish increased and nitrate levels were reduced.
2) The increased popularity of hydroponically growing plants prompted the search for an organismic fertilizer to replace the chemicals used in these systems resulting in hydroponic growers experimenting with integrating fish within their systems (Nelson, 2014).
3) The codification of the permaculture in the mid-1970s, which has been practiced for thousands of years (Vandermeer, 1995), led to an interest in more natural farming

systems. Aquaponics was considered as "mimicking nature" (Adams & Ghaly, 2007) .

4) The increased interest in sourcing food closer to where it is consumed led to urban agriculture (Laidlaw & Magee, 2014).

These four areas of research sparked the interest of community based aquaponics, supported by the Aquaponics Journal first published in 1997 (Nelson, 1997) and the formation of community information sites and forums. Despite a number of large scale commercial systems (Love et al., 2015) aquaponics do not yet have a significant impact on the current aquaculture industry as well not being applicable for salt water fish species. Current research is looking at new food sources that can be grown in salt water wetlands, such as *Salicornia* (Shpigel et al., 2013).

4.7. Current Aquaponics Research

Aquaponics research can be divided into university based, community based and individual based research.

4.7.1 University Based Aquaponics Research

Early university based research into aquaponics investigated the water usage and plant growth efficiency of the system (McMurtry et al., 1997) and was followed by investigations into the role of aquatic macrophytes for wastewater removal from recirculating systems and in particular their effect on nitrogen removal (Rakocy, 1980).

A number of university researchers investigated how aquaponics can be established as a viable agricultural enterprise, including topics such as the suitability for raising tilapia (Rakocy, 1980), balancing fish production and plant nutrient assimilation (Lennard, 2005) and comparing the different hydroponic systems used in conjunction with aquaponics (Lennard & Leonard, 2006).

The University of the Virgin Islands has an agricultural experimental station where significant early research was performed into aquaponics production of tilapia and basil (Rakocy et al., 2003; Rakocy et al., 2004) leading to a commercial aquaponics facility (Bailey et al., 1997).

West Virginia University conducts aquaculture and aquaponics research in their Reymann Memorial Farm (Buzby, 2010), which has resulted in a number of papers and posters on the use of plants as effluent removal (Miller et al., 2007) and the effective uptake of nutrients for plants (Buzby & Lin, 2014). West Virginia University also runs a very successful aquaponics course.

Despite the prevalence of these two research groups, university based research has spread over many other universities as seen in Table 2. Most of this research is focused on methods for future use in large scale aquaponics, either for community and commercial benefits, and many of the early researchers are now engaged in aquaponics development and consulting. This method is seen to be ideal for food production in arid regions (Pfeiffer et al., 2014) and commercial facilities have been built in these areas (Al-Hafedh et al., 2008), as well as in disadvantaged areas where there is a lack of fresh high quality food, such as in Palestine (Viladomat & Jones, 2011).

As well as utilising aquaponics for the purposes of food security, another area of research is the use of aquaponics for effluent treatment purposes, and in particular from the effluent produced by the existing aquaculture facilities (Miller et al., 2007). In addition, research is focused on using aquaponics as alternative strategies for improving aquaculture in developing countries (Pantanella, 2008).

4.7.2 Community Based Research

Community pilot projects evaluate the suitability of aquaponics to solve local issues, such as the lack of an affordable source of local high quality fruit and vegetables within the community in a very practical way.

The Occupied Palestinian Territories suffer from high unemployment, poverty and lack of fresh high quality vegetables and protein. Aquaponics appears attractive for domestic use, or for food security and income generation. A pilot project constructed a domestic scaled system, and evacuated its effectiveness in terms of water and cost efficiency in producing vegetables and fish harvests, and compared this to growing crops in the soil. In addition, they assessed the effectiveness of knowledge transfer and training to set up and maintain these in the future (Viladomat & Jones, 2011). This study found that aquaponics uses less than half the water than conventional agriculture, and showed more harvest and growth. Daily growth rates of vegetables ranged from 4.2 times the growth for tomatoes to 12.5 times for okra. Economically, they showed that aquaponics system could contribute upwards of 30% of the average daily salary, or provide high quality food for the family. They also found that the participants easily understood how to build and operate this type of system.

Table 2. Summary of University and Community Based Aquaponics Research

Researchers	Title	Core Research Question and Findings	Variables and Tests Performed
North Carolina State University, USA. (McMurtry et al., 1997)	Efficacy of Water Use of an Integrated Fish/Vegetable Co-Culture System	Compared effect of bio filter to fish tank volume ratios on water efficacy, and production of fish and vegetables.	2 trials of 4 replicate systems with sand media beds for 4 months. Plants: tomatoes Fish: Tilapia
University of the Virgin Islands, USA. (Rakocy et al., 2003)	Aquaponic Production of Tilapi and Basil: Comparing a Batch and Staggered Cropping System	Compared staggered cropping to batch cropping and found increased basil production. Nutrient deficiency appeared only in batch cultivated basil	2 trials of 28 days, one trial with batch cropping, the other staggerec 4 fish tanks with filters, 6 raft tanks, Tests: pH, DO, water temperature, total NH3-N (TAN), NO2-N, NO3-N, TDS, EC, Ca, Mg, K, P, Fe, Mn, Cu, Zn, B and Mo
Crop Diversification Center, South Alberta, Canada .(Savidov, 2005	Evaluation of Aquaponics Technology in Alberta, Canada	Evaluation of stand-alone systems for sustainable balance between fish and plants, and optimizing plant crop yields. Plants growth exceeded soil growth by 10-15%. All nutrients from fish other than supplementing potassium and iron.	4 fish tanks, 4 raft troughs for 10 months Fish: Tilapia Plants: 60 different plant species but concentrating on tomato, basil and cucumber Tested: Ammonia, pH and nitrate (N-NO3-)
RMIT Australia. (Lennard & Leonard, 2006)	A comparison of three different hydroponic sub-systems (gravel bed, floating and nutrien film technique)in an Aquaponic test system	Compared media bed, rafts and NFT designs. Found biomass gain and yield were best in Grave bed, followed by raft then NFT. Daily water use was also least in gravel.	4 systems – one for each option and another control (no plants) for 21 days Fish: Murray cod Plants Lettuce Tested: DO, Ammonia, nitrate, nitrate, phosphate.
Byspokes Organisation. (Viladomat & Jones, 2011)	Development of aquaponic system for space and water efficient food production	Compared aquaponics with soil based. Aquaponics more efficiently than conventional growth in water use and growth rates. Would contribute 30% of average daily salary if used as home based systems.	One aquaponics system and one soil based for a period of 5 months Fish: Tilapia Plants Basil, Swiss Chard, tomato, squash, Melon, Okra, sweet pepper, chilli pepper Tested Am, pH, Ni, Na, EC, hardness
University of Wisconsir USA. (Hanson et al., 2008)	Cultivation of Lemon Basil, Ocimum americanum, in two different hydroponic configurations supplemented with various concentrations of Tilapia aquaculture green water	Combined different concentrations of Tilapia Fish water to hydroponic solutions to compare plant growth.	3 floating raft systems with different concentrations of Tilapia water – 9 weeks duration Plants: Lemon basil Tested: tissue analysis - N, P, K, Ca, Mg, Mn, Fe, Zn, Cu. Water Ph, EC, No2-N

Summary of University and Community Based Aquaponics Research (continued)

Researchers	Title	Core Research Question and Findings	Variables and Tests Performed
University of Florida,, USA (Tyson et al., 2008)	Effect of Water pH on Yield and Nutritional Status of Greenhouse Cucumber Grown in Recirculating Hydroponics	Optimum yield found at pH of 7.5-8.0 except during early season, where yield was higher at pH 5.0	6 treatments with 3 replications, media beds with perlite – one for each of pH 5, 6, 7, 8 and one each for pH 7, 8 with an additional foliar nutrients for a period of 24 days Plants: Cucumber. Hydroponic solutions (no fish) Tested: Ni, Na, pH, EC in water, Nitrate-nitrogen in sap
McGill University, Barbados. (Bishop et al., 2009)	Bairds Village Aquaponics Project	Developed alternate agriculture method in Barbados that is easily implemented and sustainable for the average Barbadian home. Cost benefit analysis and results of tests showed feasibility.	Single fish tank and media bed using coconut husks for a period of 6 weeks Fish: Tilapia Plants: Okra, Basil Tested: temperature, pH, salinity, phosphate, Ni, ammonia and DO).
University of Rafsanjan, Iran. (Roosta & Afsharipoor, 2012)	Effects Of Different Cultivation Media On Vegetative Growth, Ecophysiological Traits And Nutrients Concentration In Strawberry Under Hydroponic And Aquaponic Cultivation Systems	Compared ratios of perlite and cocopeat media and found that both yield and the concentrations of N, K, P, Fe and Mg in leaves was significantly higher in hydroponic systems than in aquaponic systems other than when perlite was used as media.	3 pots with hydroponic solution, 3 with aquaponics setups each with different rations of perlite and cocopeat. Fish: carp Plants: Strawberries Tested TAN, nitrate, nitrite, othophosphate
University of Southern California USA. (Yamamoto & Brock, 2013)	A Comparison of the Effectiveness of Aquaponic Gardening to Traditional Gardening Growth Method	Compared growth of tomatoes, beans, and pea plants in an aquaculture medium with and without fish. Found no significant differences by when growing between aquaponic vs. traditional soil. However, aquaponics growth was better than the control hydroponic growth	Traditional, hydroponic, aquaponic Media beds for 13 days Fish: Tilapia Plants: tomatoes, beans, peas Testing: Ammonia, phosphate nitrate kits, thermometer Tested: pH and salinity using verner software logger prop probes.
University Sultan Zainal Abidin, Malaysia. (Enduta et al., 2011)	Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system	Compared nitrogen removal effectiveness from aquaculture waste of spinach and mustard. Water spinach reduced nitrogen and phosphate significantly more than mustard greens	2 systems each for water spinach and mustard for a period of 4 months Fish: catfish Tested: TAN, nitrate, nitrite, othophosphate Used: spectrophotometer
University of Rostock Germany. (Palm et al., 2014)	Significant factors affecting the economic Sustainability of closed aquaponic systems. Part II: fish and plant growth	Investigated economic factors of aquaponics. Found all fish food was converted into biomass providing optimum fish productivity. Plants performed better with fish production	Conducted for a period of 3 months Fish: African catfish, Nile tilapia Plants: lettuce, tomato, cucumber, basil Tested: temperature, O2, salinity, conductivity, redox potential, TAN, NH3-N, No20N, No3-N, phosphorus, suspended particles

Other projects into the feasibility of aquaponics, and its cost benefits in their local environment was recorded in in Alberta, Canada (Savidov, 2005) and Barbados (Bishop et al., 2009), with the conclusion that aquaponics form a valuable and cost effective role in their food security. These projects are a bridge between the university based research and the individual research.

4.7.3 Individual Research

Most of the aquaponics research is conducted and funded by individuals or small community groups driven by personal interests, the prospect of commercial gain (Malcolm, 2012), or the desire to help disadvantaged communities (Hughey, 2005). The results are usually presented in personal blogs and on aquaponics forums.

It has been estimated that in 2010 there were an estimated 3,500 "backyard" systems, with over half being constructed in Australia (Armstrong, 2014). In a recent survey of 809 aquaponics practitioners (Love et al., 2014), which covered primarily USA based systems, it was found that 86% of respondents were hobbyists with their main objective being to grow their own food. It was found that aquaponics is experiencing a "period of growth where participants are innovators and early adopters of technology", with 83% of the systems designed by the users and 60% of these being on their own property. Community aquaponics users rely on workshops, on-line guides and forums to find information and get answers to their many questions.

The three most popular aquaponics forums are:

- Backyard Aquaponics (Backyard Aquaponics, 2014),
- Practical Aquaponics (Practical Aquaponics, 2014) and
- The Aquaponics Source Forum (The Aquaponics Source, 2014).

All these forums divide the discussion into topics which generally include a topic to discuss fish, plants, water and system design. Using the number of topics posted in these sections as a guide to the areas of most interest and concern to aquaponics users, Table 3 shows general system design and fish discussions are the most popular discussions on the forums.

Table 3. Topic Popularity in Aquaponics Forums (as at 12/10/2014)

	Backyard Aquaponics	Practical Aquaponics	Aquaponic Source
Fish	1418	563	495
Plants	1218	347	373
Water	(no separate category)	232	287
General System Design	5402	825	475

Forum members rely on the experience of others to come up with a solution which is a very effective way of solving issues in an environment where everyone is experimenting independently and coming up with their own solutions in an unstructured manner. Whereas this individual approach is both necessary and invaluable in allowing novices to become proficient, it is often clouded by individual prejudice rather than facts. There is a significant potential for the aquaponics community to study the process in a more structured manner and to share this research with the general public. A formal study will help separate fact from opinion, and place this methodology on a more solid foundation. A more structured study could be focused on:

- What plants grow well in aquaponic systems? Despite the forums providing discussions on plants and plant problems as well as various groups providing lists of plants (Mann, 2012) there is little research as to the condition affecting the plant growth with conflicting views being posted.
- What fish should be grown?
- How to design a system? Various sites and forums discuss system design, but there is little structured research available as to how well these designs work in different settings.

4.7.4 The Definition of Success

There is considerable debate as to what defines success in an aquaponic system. For commercial systems, the profitability of the system is a key factor, but often environmental and social concerns are also important. For the home user the most common answer is that the system provides them with fresh, organic, locally grown fruit and vegetables (Love et al., 2014) followed by environmental sustainability. Environmental sustainability includes factors such as (Backyard Aquaponics, 2014):

a) "Sustainable" (meaning the fish can/will reproduce)
b) Utilizes all fish waste efficiently by growing the largest number of vegetables possible
c) Uses the least amount of electricity (preferably solar)
d) Uses minimal water
e) Eventually pays for itself
f) Possibly "makes" money either through barter/trade or sales.

4.8. Satisfying Conflicting Water Parameters

In aquaponics, the same water flows through the fish tank, the biofilter, and the plant beds. Water parameters, such as the pH level, must support fish growth, nitrification bacteria and plant growth.

As plant pH levels affect the ability of plants to absorb nutrients, hydroponic systems recommend a pH level of between 5.5 and 6. In contrast, the conversion rate of ammonia to nitrates was significantly faster at a pH of 8.5 than at the lower values (Tyson et al., 2004).

The aquaponics forums recommended pH levels of between 6 and 7 based on the update of minerals by plants at different pH levels as seen in Figure 13 which indicates that when pH rises over 8 deficiencies in nitrogen, phosphorus, iron, manganese, boron, comer and zinc result in poor plant growth. However this does not account for the higher conversion rates of ammonia into nitrates at the higher pH levels. Further research indicated that a pH of between 6.5 and 7.0 optimizes both fish and plants (Tyson et al., 2008).

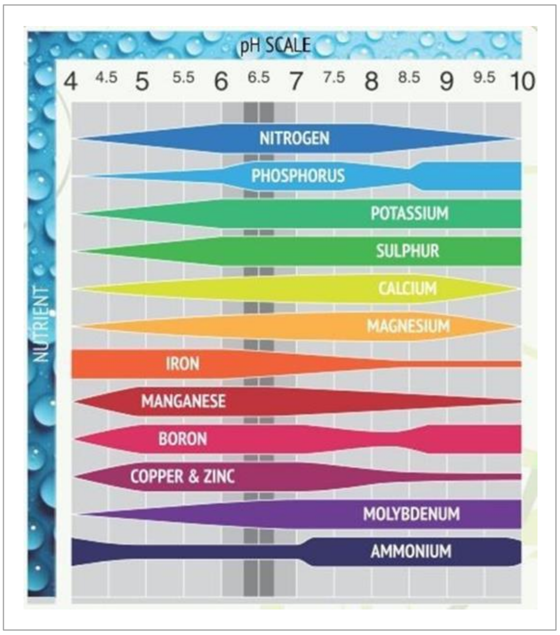


Figure 13. Uptake of Nutrients by Plants at Various pH Levels (Backyard Aquaponics, 2012)

As aquaponics users regularly test pH levels, a potential area for their research is how different pH levels affect their fish and plants, and whether other factors, such as water temperature, fish species and plant species affect the optimal levels.

4.9. Conclusions

Aquaponics is a growing area where most systems are developed by individuals at home supported by thriving on-line communities. In addition, a number of commercial operations are growing with the support of university and community level research. There is significant scope for exploring factors in a structured way that influence the success of this technology, as well as the claim that aquaponics is a sustainable alternative to fish and vegetable production, utilizing the cohort of home based aquaponics systems.

Chapter 5: Aquaponics Research Citizen Science Project

5.1. Introduction

This chapter presents and discusses the results of the citizen science project as pertains to aquaponics and seeks to answer the questions listed in section 1.2. This research was conducted as a citizen science project, where users of aquaponics systems were invited to participate by entering data about their system on a website during the period from January 2014 to November 2014.

The participants contributed by adding information to:

1) A survey that allowed participants to record the plants and fish that they have grown and/or
2) A diary that allowed them to track what happened with their system over time.

The survey would provide answers for the questions, such as how successful different plant species grow in aquaponics systems and what fish species are grown, while the diary would allow the overall success or otherwise of each systems to be tracked, and could potentially explore sustainability questions.

By recording details of the participants' location and system, factors affecting the success of these systems can be explored.

5.2. Methods

5.2.1 Recruiting Participants

An invitation to take part in this research was posted in the three major aquaponics forums in January 2014:

- Backyard Aquaponics (Backyard Aquaponics, 2014),
- Practical Aquaponics (Practical Aquaponics, 2014) and
- The Aquaponics Source Forum (The Aquaponics Source, 2014).

The website hosting this research, www.ourresearch.net was designed to be easily found in Google, and as well as appearing on the front page of a Google search for the terms "aquaponics research", "aquaponics diary" and "aquaponics citizen science".

5.2.2 The Website

This website was designed to allow the participant to enter data and analyse their own data as well as data from other participants. This site was built using a popular open source community web development tool, Joomla, which included a content management system and web tools as well as the ability to write PHP code for more complex tasks. The website was developed to suit smartphones and tablets, as well as the larger web formats, and runs on all common web browsers.

The website (Figure 14) included a public area, a member's only area and a forum. The public area allowed visitors to read blogs, understand the experiment, view survey results and read forum entries, as well as join the project as members. The members' area was restricted to those who joined the site and allowed them to enter details of their system data as well as viewing all the data contributed by other members and contribute to forum discussions.

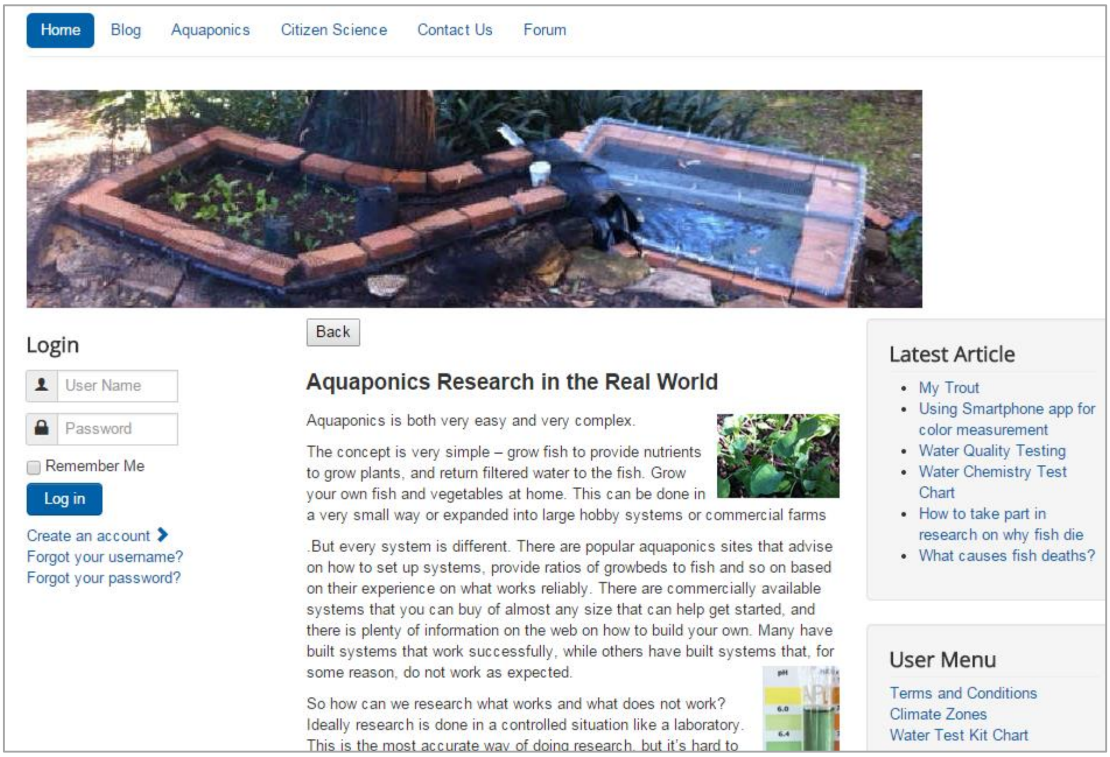


Figure 14. Homepage of the Website used as a Platform for Research

The data was entered through structured forms and stored in an SQL database to for analysis using SQL queries. The data was also exported to excel for further analysis.

5.2.3 Enrolment Process

Anyone could join the project by entering their details including email and accepting a confirmation email. When they first log in, the participants are required to accept the Macquarie University ethics statement (see Appendix D) to complete their enrolment as members. For privacy reasons, participants create a nickname, by which they are known on the site. Although all the aquaponics data is shared between the members for research purposes, personal details, such as emails, cannot be viewed or accessed by other members.

As this experiment has global reach, each member can chose their own date formats, units of measure (Fahrenheit or Celsius, gallons or litres, pounds or gram, gallons or litres) as well as currencies and time zones.

5.2.4 System Information

To take part in the survey and diary, members need to be running at least one aquaponics system and have entered the details of that system into the website. These members are referred to as participants.

The information required for each system are:

- Country
- Climate zone
- Date the system was started
- Type of system (Raft, Media Filled, NFT, hybrid, other)
- System structure (CHIST, CHOP2, neither)
- How the system was run (flood/drain, constant flow)
- Size of fish tank
- Size of grow beds for media based systems or number of holes for NFT and raft systems
- Whether grow lights are used
- How many hours of sunshine/grow lights the plants received per day in summer and winter
- Location – outside, enclosed, inside
- Whether the fish tank is heated and, if so, the temperature range.

5.2.5 Surveys

The surveys were divided into two areas:

1) fish surveys (recording the fish species, and months to harvest) and
2) plant surveys (recording the plant species, season planted and a success rating).

The surveys provided an opportunity for participants to share their experience with minimal effort. Members were able to query the system for the results of the surveys, and were able to analyse the results based on any combination of the system and location parameters described above. For example, they could find what plants grow well in the summer in tropical climates with limited direct sun.

5.2.6 Diary

The diary provided structured data for research on aquaponics and required entry of the data over a period of time. The diary records for each system were:

- Fish details - when added and harvested, as well as recording fish deaths
- Plant details – when added (as seeds or seedlings) and harvested (whole plant or part of plant)
- Water added to the system
- Fish food added to the system
- Water quality – the levels of ammonia, nitrates, nitrites, and pH as well as the water temperature. Most aquaponics users have kits to measure these regularly (Bernstein, 2011) so that these can be adjusted to be in a range suitable for the fish, the plants and the bacteria that converts the ammonia into nitrites and nitrates.

Reports were developed so that participants can view their own diary including calculations of daily plant and fish growth. Graphs were available to easily view changes in water temperature and chemical characteristics. A photo diary was also added to allow better tracking of plant growth and other data over time.

5.2.1 Researching Other Diaries

Members could select diaries from any of the participants, and view details of that system and all the reports based on data from that participant's diary.

5.2.2 Forum

A forum was added to the web site to allowed members to raise issues and participate in discussions. The forum was the area where citizens can raise hypothesis and discuss their research to address the hypothesis.

5.2.3 Analysis of site

To determine the areas of the site that visitors and members were interested in, pages accessed by the visitors and members were recorded using a component ExtraWatch, and reports based on this data were developed.

5.3. Other Aspects of the Project Design

5.3.1 Designing for Data Quality

For all citizen science projects the question arises as to whether the data was of sufficient quality for research purposes. A number of steps were taken in the website design to ensure the highest possible data quality for this type of project:

- Participants were limited to those who have an aquaponics system and entered details of this system. In any field there are those who consider themselves experts, but have never actually had any experience in the subject. Members who joined the website but did not add at least one aquaponics system were excluded from any analysis, including survey analysis.
- Data was validated on entry. Data entry was based on forms where fields were validated wherever feasible included drop down list, and range validity checks on input.
- Units of measure familiar with the participants were used. As this project goes across country boundaries, different members would be familiar with different unit of measures, such as temperature in Fahrenheit or Celsius, volume in gallons or litres and weight in pounds or grams. The system recorded the preferred units of measure for each participant, and displayed all information in these preferred units. This avoided errors in input, as well as making the results easier to understand by the participant.
- As all participants could view other participant's diaries, invalid data could be noticed by other participants.

5.3.1 Motivating Participants

In order to study the motivations of the participants there were no inducements given to participate although blogs were added to the site and updated to increase interest. In addition, their data was displayed in useful formats that include graphs, calculations of daily growth, as well as profit calculations where monetary data was entered.

However, efforts were made to value the participants and included fast response to questions and issues with the site, adding a photo diary when requested, and adding other tools to assist them such as a smartphone based tool to calculate the chemistry levels from a photo of the test tube, was added (Figure 15).

Figure 15. Smartphone Measurement of Colour Levels

The types of studies included in this project – the survey and the diary – were designed to allowed the participant to choose whether they wanted to contribute on a task that can be completed in a single entry (the survey) or whether they wanted to contribute on an on-going basis (the diary). This allowed participants who lacked the time or the motivation to contribute over a longer period of time to also contribute.

5.4. Results

5.4.1 Participation

35 members joined the site although only 25 of these entered details of their aquaponics systems and so became participants. A total of 35 systems were entered as some members had more than one system. In results that pertain to individual systems the results will be presented on a per system basis. However where the results pertain to the participant, such as the contribution types and length of contribution, the results will be presented per participant.

5.4.2 Location

The majority of the participants (11) were from Australia and the USA (6), as seen in Figure 16. However participants in the USA tended to have more systems per participant than the participants from the other countries, and as a result there are almost the same number of systems located in Australia (14) and the USA (13), also shown in Figure 16. When analysing data based on individual systems, Australia and USA can be compared to show the differences between two countries with a comparable number of systems.

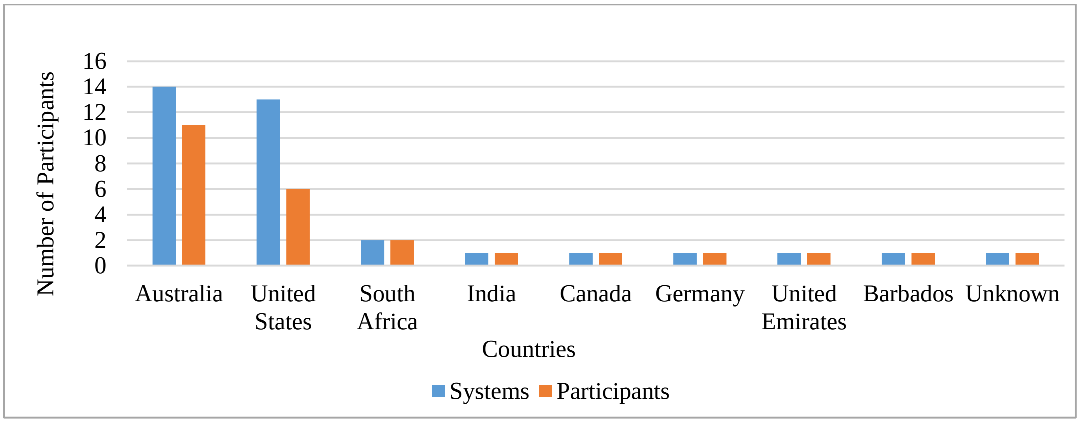


Figure 16. System and Participant Countries

5.4.3 Systems

Most of the systems were built outside (57%), although this was most noticeable in Australia where 62% are outside, compared to 46% in the USA with a further 20% built in enclosed areas, such as greenhouses.

It was found that by far the media filled systems were the most popular as seen in Figure 17 with 80% of the participants using this method. Only 6% used the NFT system, which is most commonly used by commercial growers. A number of participants built a hybrid, where the water was passed through both a media bed and a NFT or Raft system, before being returned to the fish.

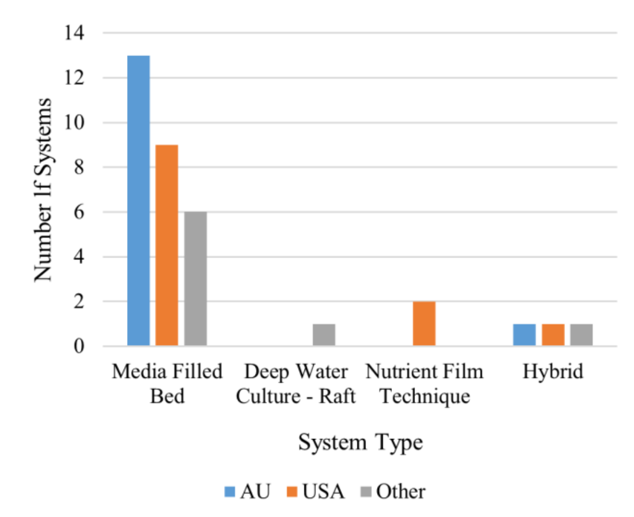


Figure 17. Types of Systems Built

It can be noted that Australian participants were particularly interested in media based system and all participants in Australia either had a media bed based system or a hybrid system that included a media bed.

With the dominance of media based systems, further information indicates that the most common media used was expanded clay. Other media included crushed rock, crushed bricks, gravel and black lava rock or a combination of the above.

The volume of the media bed indicates that systems range from very small (5 litres) to quite large systems (25,000 litres) as shown in Figure 18. Most of the participants had small systems of less than 1,000 litres.

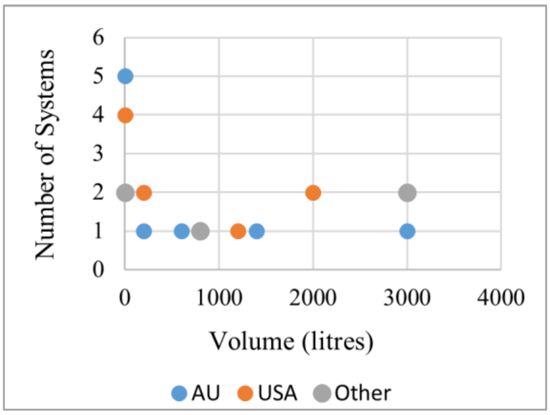


Figure 18. Volume of Media Beds (Litres)

5.4.3.1. Fish Tank

The sizes of the fish tanks also varied from small (20 litres) to very large (50,000 litres) as seen in Figure 19. For media based systems there is a relationship between fish tank size and media bed size. The size of the media bed needs to be sufficient to filter the waste from all the fish, and larger fish tanks tend to have more fish.

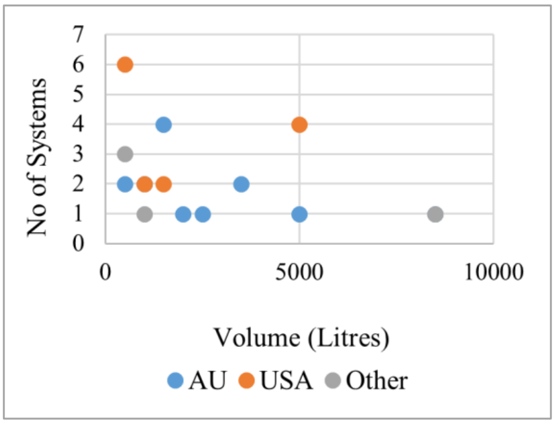


Figure 19. Volume of Fish Tank

Although it can be expected that NFT systems, which are more commonly used in commercial operations, would be larger on the average than the media based systems this is not reflected in the data, as seen in Figure 20. Further analysis of the data show that the all participants who had NFT systems ran multiple systems which included a media based systems.

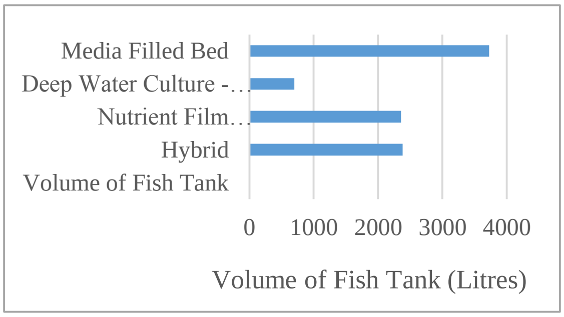


Figure 20. Average Volume of Fish Tank for Different System Types

5.4.4 Survey Results

5.4.4.1. Plant Survey

The plant survey contained 99 entries covering 39 different plant species. Figure 21 displays the success rating of all the plants grown.

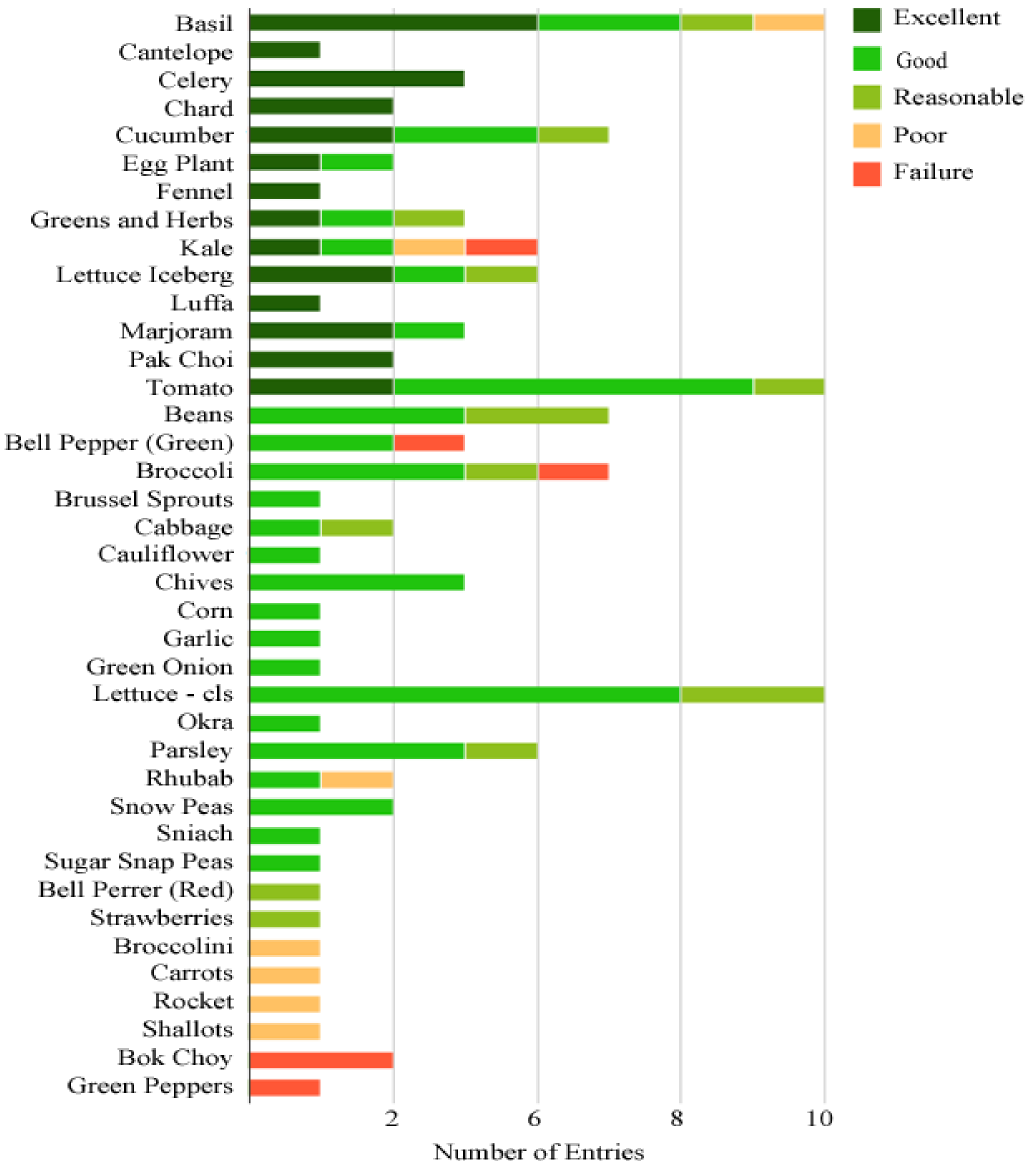


Figure 21. Overall Plant Success Rating

Basil was one of the most widely grown plants and in most cases successful although some failures are reported. Members can view details of specific plants to determine factors influencing success. For basil, the detailed view (Table 4) shows the poor growth was reported in a system in Florida and was attributed to freezing temperatures.

Table 4. Parameters that Affected Basil Growth

Species	Country	State	Climate	Season	Rating	Type	Media	Run as	Grow Lights	Hours Summer Sun	Hours Winter Sun	Comments
Basil	Australia	NSW	Temperate Mild	spring	Reasonable	Media Filled Bed	Expanded Clay	Flood and Drain with Timer	No	3-6	3-6	
Basil	Australia	NSW	Temperate Mild	spring	Good	Media Filled Bed	Expanded Clay	Flood and Drain with Timer	No	1-3	3-6	
Basil	Barbados		Tropical	spring	Excellent	Media Filled Bed	Other Media (describe in description)	Flood and Drain with Syphon	No	6-9	6-9	
Basil	Canada	Alberta	Warm Summer/Cold Winter	spring	Excellent	Deep Water Culture - Raft (DWC)	Not Applicable	Constant Flood	Yes	12+	12+	
Basil	Australia	NSW	Temperate Warm	spring	Excellent	Media Filled Bed	Expanded Clay	Flood and Drain with Timer	No	9-12	9-12	
Basil	United States	Florida	Sub-Tropical	Winter	Poor	Media Filled Bed	Crushed Rock or Gravel	Flood and Drain with Syphon	No	12+	12+	Freezing temps
Basil	Australia	nsw	Temperate Warm	spring	Good	Media Filled Bed	Crushed Rock or Gravel	Flood and Drain with Timer	No	9-12	6-9	
Basil	Australia	Queensland	Temperate - Hot	Summer	Excellent	Hybrid	Expanded Clay	Flood and Drain with Syphon	No	12+	6-9	Basil is a rocket! We planted as a companion to tomatoes and they just took off!

5.4.4.2. Fish Survey

The fish survey contained 31 entries from 16 participants. One participant added 9 entries with species including silver perch, trout, barramundi, bass, jade perch, eel tailed catfish (*Tandanum*), golden perch (yellow belly), tilapia and trout (Figure 22).

Members can also view a detailed report to see where the fish are grown, how long to harvest and any other relevant comments (Table 5).

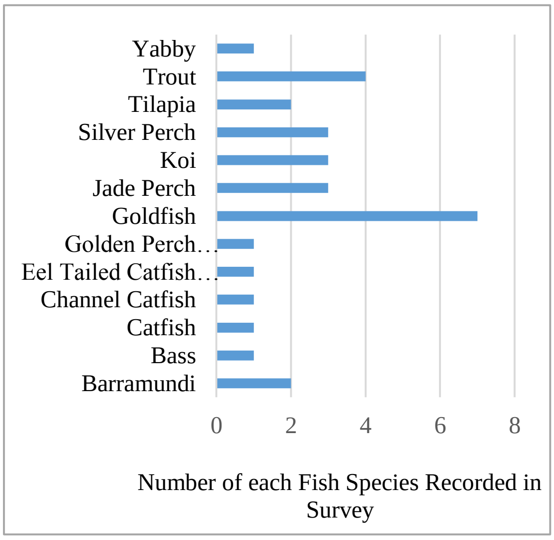


Figure 22. Fish Survey

Table 5. Fish Survey Details for Jade Perch

Species	Country	State	Climate	Heated	For Harvest	Added Weight	Harvested Weight	Months to Harvest	Comments
Jade Perch	Australia	NSW	Temperate Warm		Yes	10.00	450.00	8	Requires heating in this region
Jade Perch	Australia	Queensland	Temperate - Hot		Yes	5.00			
Jade Perch	Australia	QLD	Sub-Tropical		Yes				

5.4.5 Diary Results

Diaries were kept by 52% of the participants. There were 508 diary entries covering 18 systems with just over half for water chemistry, as seen in Figure 23.

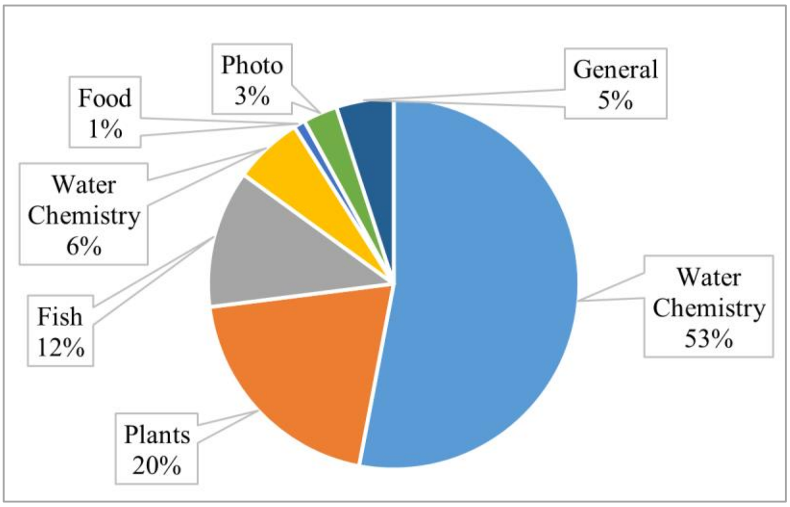


Figure 23. Types of Diary Entries

The fish records within the diary consisted of 24 entries recording the addition of fish, 20 for counting fish, 6 for harvesting fish and 7 for recording dead fish. The "counting" records allowed participants to record details of their fish and their growth after adding and before harvesting them. This also allowed for the recording of "missing" fish which were usually fish deaths. The cause of fish deaths varied, as seen in Table 6. Most deaths were due to mixed fish species rather than poor water quality. For example a participant reported silver perch deaths after trout were added to the same fish tank.

Table 6. Fish Diary

Batch		Number		Weight			Value			Comments
Date	Action	No.	Left	Ave	Gain	Daily	Total	Gain	Daily	
CHCAT1 - Channel Catfish										
14-May-14	add	6	6				-39.99			I ordered 4 fish and received 6. 3 albino and 3 blue. They look delicious.
25-May-14	count		5							One cat died, fins stripped bare.
16-Aug-14	count		3							The catfish have gotten aggressive and killed or eaten all the gold fish.
gold-duck - Goldfish										
31-Mar-14	add	3	3							Some goldfish from Ducks pond.
16-Aug-14	death	3	0							catfish killings
gold10 - Goldfish										
03-Jan-14	add	10	10				-1.00			Feeders until I can get some edible fish and crawfish
06-Jan-14	count		5							Half of the fish died. They look like they may have gotten sucked up by the pump. Put nylon over the pump to see if that helps. Fish have not eaten. I think that the over sized pump is creating too much current. Adding more grow beds and a sump tank
13-Jan-14	count		4							There was another death I forgot to list earlier.
16-Aug-14	death	4	0							catfish killings

Most of the diary participants had less than 100 fish, but one grew 1284 tilapia fish and fry in three different systems.

The most commonly grown fish were goldfish (19), followed by silver perch (15) and tilapia (13). Catfish, channel catfish, koi and trout were also grown. It is interesting to observe that, although goldfish are dominant in both the diary and the survey, tilapia are more common in the diary than the survey, while koi are less popular, as seen in Figure 24.

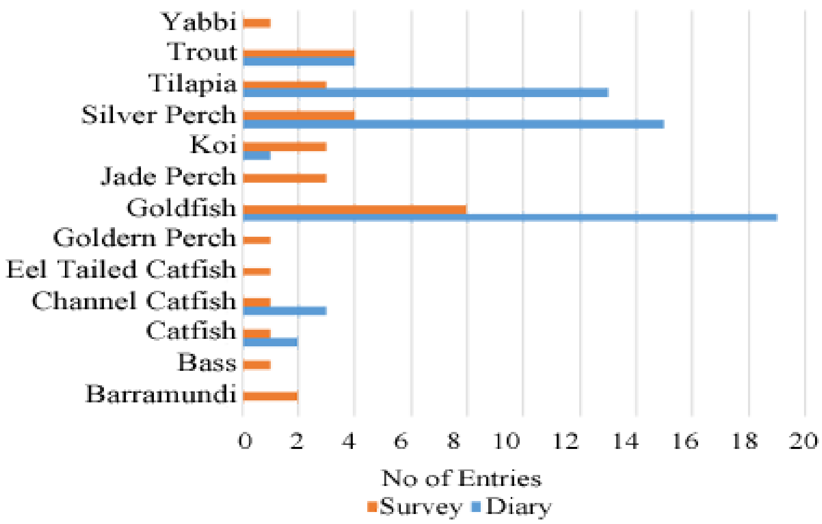


Figure 24. Comparing Fish Species Recorded in Survey and Diary

5.4.5.1. Plants Diary

The diary contained 98 plant records, consisting of 52 records describing the addition of plants and 46 for harvesting or partially harvesting the plants. The most commonly grown plants were kale, tomatoes and basil. Beans, broccoli, green pepper and strawberries were also popular.

The comments in the diary also recorded the experience of users, for example the following was recorded by one participant who attempted to clone some tuscan kale, "*Take successfully took root. I have concluded that cloning in aquaponics take little to no work*" (tlrobb).

Other issues were also recorded, such as inset attacks, as one participant said: "*A massive aphids infestation decimated the broccoli, which were growing well. I removed 3 of the worst*" (Downunder). This issue was also raised as a forum topic, for example "*I'm having a big problem with cabbage mites. They aren't a problem in my earth garden because I can just mix up some dish soap and water with some garlic oil and spray. But that would kill my nitrobacter's and likely my fish if it got into the water of my aquaponics. When the plants were small just put some plastic under them and sprayed carefully but now that they are big it isn't so easy to catch all the drippings and over spray. I also have box elder bugs and these little beetle like things that look like ladybugs (about the size of a pin head) but they appear to be eating the plants and not the mites.*" (tlrobb).

5.4.5.2. Water Diary

Six participants recorded water use, however only one recorded more than 3 water refills.

5.4.5.3. Fish Food Diary

There was little effort in keeping track of fish food, with a total of 7 records contributed by 4 participants. Although most were for commercially available fish pellets, there was some imaginative variations, such as "*Made batch of gel food with tuna, anchovies, clams, lentils, peas, cilantro, carrot, red pepper, kelp meal, pellet food*" (bevoutside).

5.4.5.4. Photo Diary

The photo diary was added during the experiment at the request of some of the participants. It contained 16 entries from 8 participants, and showcased mainly their systems. It was expected that this will assist the measurement of plant growth but participants did not make use of the diary for this purpose but utilised the diary to display their system location and design and other items of interest to them, such as water chemistry values (Figure 25).

Figure 25. Homemade Green House (from gene) and Pool Chemistry Results (pua)

5.4.5.5. General Diary Entries

The general category allowed the entry of information that did not fit into the other categories. This area also included maintenance information, such as "*Grow Bed No. 2 on the Ebb/Flow system acting up. Will have to switch back to a Bell Siphon system instead of the "S" Siphon I was using. Also found by changing my up right one inch siphon tubes from a schedule 40 pipe to a schedule 20 pipe I seem to get a better flow when bed is discharging. This part of my system I hope will be up and planted on Saturday. Will be using a Brick Chips on the bottom portion of these beds with a pea gravel on the upper two inches. Long time coming*" (Doc Eagle). Although it is difficult to use this unstructured data in analysis it provides an insight into the level of experimentation they undertake and the issues that arose.

5.4.6 Data Quality

The project was designed to minimize data quality issues. A comparison of the results of the plant survey and diary with the few published community studies listed in Table 2, indicate that the results are in line with expectations. The most common plants successfully grown (Figure 21) were basil, tomato, lettuce, and cucumber which were also the most common plants in the studies (Table 2). The most common fish grown was goldfish, followed by trout, compared to published studies where tilapia were the most common (Table 2). This could be due to most of the users being novices, and the advice to novices is to start with goldfish (Bernstein, 2011). In addition the majority of participants were located in Australia where tilapia is banned.

However, when auditing the data entered, it is noted that some of the participant's added data to comment fields, or as general diary entries when that data would have been of more value if added to the correct field. For example, one participant recorded the amount of fish food given as a comment when adding water chemistry records, and another included some plant harvests in the general diary section. The data added into comments were not included in any of the analysis of the aquaponics results.

As part of the project design, the participants self-selected the areas they wished to participate, and the data fields to which they contributed. While this provided insight into their areas of interest allowed it also meant that some questions could not be answered. For example, to answer any questions regarding the cost-effectiveness the system, the participants would need to consistently add the costs. Some participants added the cost of purchasing the fish, fish food and seedlings or seeds, but none added the value of the plants or fish they harvested.

5.4.6.1. Age of Systems

The oldest system in the study was started on 7th May 2011, followed by another on the 10th April 2012. All other systems were started in 2013 or 2014. A breakdown of the length of time the system was running on joining the project is shown in Figure 26. All the systems that were running less than 3 months had a diary, which can be compared to systems that had been running over 9 months where only 46% of the systems had a diary.

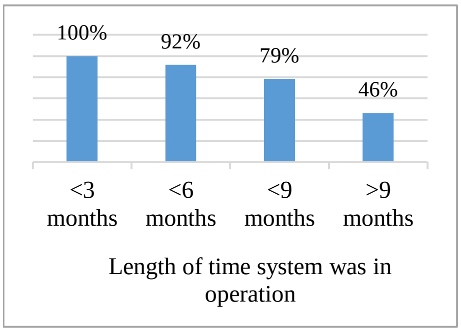


Figure 26. Percentage of Systems with a Diary Compared to the Age of the System

5.4.7 Participation in Diaries and Surveys

Just over half the systems had a diary entry and just over half the systems had a survey. In contrast, only 36% of the participants took part in the diary and 45% took part in the survey. The difference between these figures can be accounted for in that participants with multiple systems contributed data on each of their systems whereas those with a single system were less likely to contribute data on their system. Figure 27 shows the contribution by participant to the survey and diary.

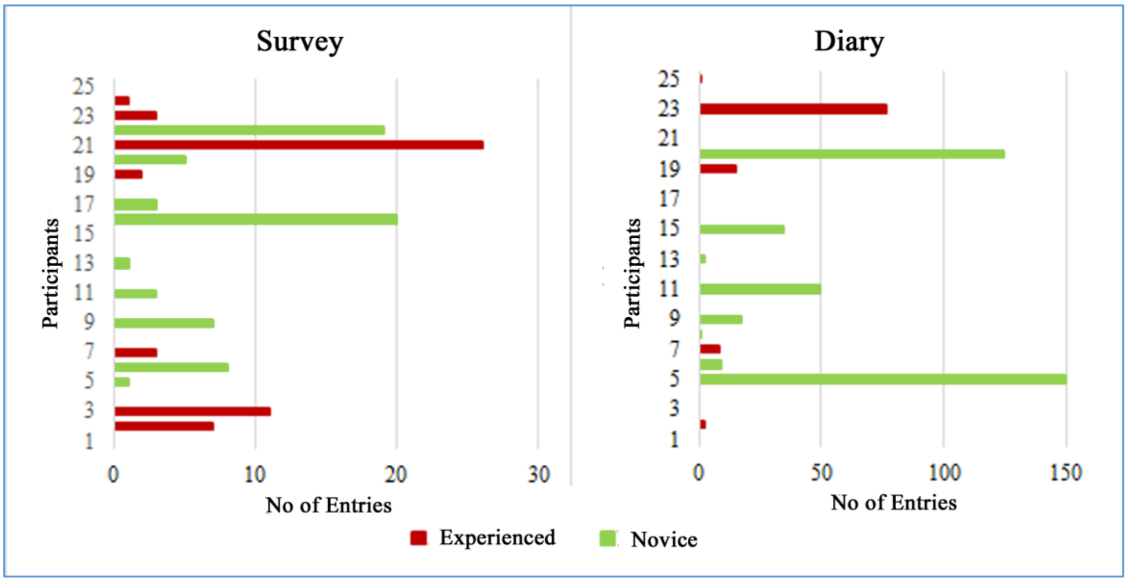


Figure 27. Number of Diary and Survey Entries by Experienced and Novice Participants

The average length of time participants contributed was 3.8 months. When excluding participants with only one entry, the length of time increased to 5.9 months.

5.4.8 Site Analysis

An analysis of the number of times participants accessed different areas of website showed that they accessed their diary 40% of their time, followed by the forum (24%) and the survey (16%). This showed that the diary was the main area of interest. Participants spent 5% of their time looking at other participants' diaries (Figure 28).

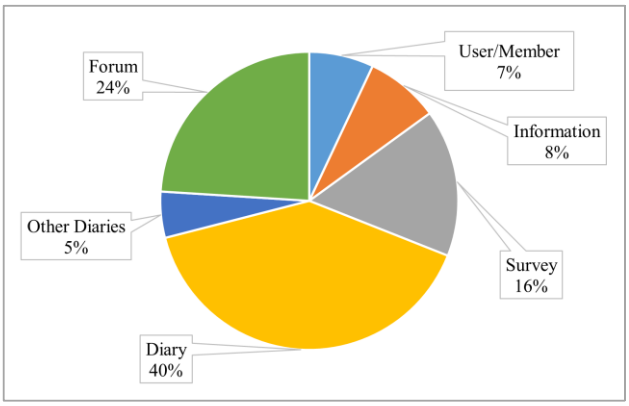


Figure 28 Site Pages Accessed by Members

5.5. Discussion

5.5.1 Benefits and Commitment

A study of characteristics of participants who took part in the survey or diary found that those who were novices were more likely to contribute to the diary, and those with more experience were more likely to contribute to the survey.

As well as contributing to the diary, participants with recent systems were also more likely to add frequent entries. This may be because the first few months are the most difficult time when setting up the system. Not only are the participants are inexperienced and unsure of how aquaponics work, the system itself is unstable until there is a balance of ammonia, bacteria and plant growth. Most fish deaths occur during this time of fluctuating water quality. Forums and courses suggest that new users regularly test key chemical indicators so that they can react if they are out of range (Bernstein, 2011).

The experienced users who were consulted before the study to assist with study design were also invited to take part in the diary but none of these experienced users contributed to the diary. They indicated that they used to take regular measurements, but now they know by simply looking at the health of the fish and plants if the system is correctly balanced.

This indicates that the participants who benefit most are those with newer systems, as expressed by one of them "*Thank you for doing this. I am just beginning my aquaponics adventure so this comes at the perfect time*". The active participation of participants new to aquaponics suggest that there may be a correlation between the willingness to take part in the research and the benefit to the participant.

5.5.2 Answers to Aquaponics Research Questions

This aquaponics research explored the following research questions (section 4.8).

5.5.2.1. Plants grown

Question: *What plants do well in aquaponics systems and what aspects of location, climate and system design influences which plants do well?*

The survey succeeded in providing a list of plants that grew well in aquaponics systems as well as those which did not grow well (Figure 21).

Some plants, such as kale and broccoli, were reported as growing very well in many instances, but failed in others. Details of these species, shown in Table 7 and Table 8 suggest insect attacks are a common cause of failure, highlighting the need for further research in insect control in an environment that restricts treatments to those that do not affect fish health

Table 7. Plant Survey – Kale

Species	Country	State	Climate	Season	Rating	Type	Media	Run as	Grow Lights	Hours Summer Sun	Hours Winter Sun	Comments
Kale	United States	Florida	Sub-Tropical	Winter	Poor	Media Filled Bed	Crushed Rock or Gravel	Flood and Drain with Syphon	No	12+	12+	super slow growing
Kale	United States	California	Temperate - Hot	Winter	Good	Media Filled Bed	Expanded Clay over Rock/Gravel	Flood and Drain with Syphon	No	12+	1-3	Watch for Iron lockout at high ph
Kale	Australia	QLD	Sub-Tropical	Summer	Excellent	Media Filled Bed	Crushed Rock or Gravel	Flood and Drain with Syphon	No	9-12	9-12	Grew very well
Kale	Australia	Queensland	Temperate - Hot	Summer	Failure	Hybrid	Expanded Clay	Flood and Drain with Syphon	No	12+	6-9	Kale got hit by aphids and just did not take

Table 8. Plant Survey - Broccoli

Species	Country	State	Climate	Season	Rating	Type	Media	Run as	Grow Lights	Hours Summer Sun	Hours Winter Sun	Comments
Broccoli	Australia	NSW	Temperate - Hot	spring	Good	Media Filled Bed	Expanded Clay	Flood and Drain with Timer	No	6-9	3-6	
Broccoli	Australia	NSW	Temperate Warm	Autumn	Good	Media Filled Bed	Expanded Clay	Flood and Drain with Timer	No	9-12	9-12	
Broccoli	United States	Florida	Sub-Tropical	Winter	Reasonable	Media Filled Bed	Crushed Rock or Gravel	Flood and Drain with Syphon	No	12+	12+	slow growing
Broccoli	Australia	QLD	Sub-Tropical	Summer	Good	Media Filled Bed	Crushed Rock or Gravel	Flood and Drain with Syphon	No	9-12	9-12	Summer planting hasnt worked out, not heading.
Broccoli	Australia	Queensland	Temperate - Hot	Summer	Failure	Hybrid	Expanded Clay	Flood and Drain with Syphon	No	12+	6-9	Aphids attacked and we countered with a home-made repellant, but the growth was poor and stunted

Despite the few records received, which hinder any accurate conclusion, this survey provides valuable information to the aquaponics community that is not currently easily obtainable from the forums and suggests that a wider scale survey would be of benefit.

5.5.2.2. Fish grown

Question: *What fish are grown in aquaponics, how long does it take to grow these to "plate" size and is this influenced by location, climate and system design?*

The results of this survey are shown in Figure 22. It can be observed that geographic location appears to be the most significant indicator of species selection. According to this survey Australia was the only country amongst the participants in this research where silver perch, jade perch, barramundi, bass, trout and yabbi are grown. Catfish are grown in both Australia and the United states. There are only two entries for tilapia, one by an Australian participant who added tilapia, not because he grows tilapia, but to note that they are banned in Australia, leaving only one valid entry for Barbados. Goldfish is the only fish recording being grown in all the countries in this study.

However, the survey is not only too small to be reliable, but also appears to conflict both with published data or comments on the popular aquaponics forums. The only large scale aquaponic survey shows that tilapia is the most common fish, grown in 55% of the systems followed by ornamental fish, catfish and perch (Love et al., 2014). This discrepancy may be due to the fact that 80% of the respondents in the international survey were US based, with only 8% from Australia, in contrast to this survey where only 30% of the fish records were from the US and 63% from Australia. Since Australia is reported to have half the worldwide aquaponic systems, a more accurate estimate is likely to lie somewhere between these two surveys.

In addition, there was little data recorded to answer the question as to how long the fish takes to grow to "plate" size. One participant (RubertofOZ) recorded that Silver Perch takes 18 months to grow to plate size, Trout 5 months, Barramundi 6 months and Jade Perch 8 months (although the latter two required the water to be heated). He also records that Eel Tailed Catfish (Tandanus) which is a slow growing premium table fish takes 18 months. In contrast another participant (hemps) claims that his trout took 9 months to grow to harvest size.

5.5.2.3. Water efficiency

Question: *How water efficient is aquaponics compared to conventional agriculture?*

Only one participant collected sufficient data to calculate both the total water usage as well as the resulting plant mass. This participant's water diary (see 6.2.1) showed that 131 litres of water were used to grow each kg of harvested salad greens which can be compared with an average of 322 l/kg in soil based agriculture (Mekonnen & Hoekstra, 2012). This is a 40% reduction in water use. Past research has suggested that aquaponic systems use around 30% of the water required in soil agriculture (Lennard, 2006). Although further research is needed to determine the various factors that influence water usage it appears that aquaponic does uses significantly less water than conventional agriculture.

5.5.2.4. Recording Data over Time

Question: *Will the citizens who have built and run their own system be prepared to enter data over time into a detailed diary that includes all information related to the system such as system design, location, climate, fish grown, plants grown, water chemistry and fish food?*

There has been considerable interest in recording data in a diary, including fish, plants grown and tracking water chemistry. There is less interest in tracking water usage and fish food and no interest in tracking the economic aspects of the systems. Participants who kept diary records recorded data for an average of 4.36 months, which is longer than most of the studies in Table 2.

5.5.3 Other Observations

This is the first published study into investigating home based aquaponic systems on a global scale and comparing these systems with research based either at the university or in the community. The experiment has suggested answers to some of the initial aquaponics research questions, although in most cases more data is needed to be confident with those results. In addition to addressing the specific research questions, the following observations can be made.

Goldfish were the most common species grown by the participants in this research, and yet are not the most common species appearing in other research (Table 2) and in other surveys (Love et al., 2014). A possible reason for this discrepancy is that the participants that took part in the diary were predominately novices, compared to the general aquaponics community. As forums recommend that goldfish be used in new systems to stabilize them before adding fish for harvest it would be expected that a greater number of participants grew goldfish as indicated by one of the participant who recorded "*Goldfish used to prove liveable conditions prior to introducing channel catfish to raise for harvest*".

One issue raised by the participants but not addressed in this research was how to treat insect attacks. Care needs to be taken that anything sprayed on the plants or added to the water affects neither fish health nor beneficial bacteria growth. Forums have suggested a number of garlic/chilli based sprays, as well as the introduction of beneficial insects, such as lacewings. One of the participants introduced lacewings with apparent success. Yet another utilized a garlic/chilli spray with limited success. The control of insects in such a sensitive environment is an area that would benefit from further research.

Since most commercial fish food contains commercially caught fish for protein, the use of commercial pellets as food detracts from the claim that aquaponics is a sustainable way of growing fish. Further research into high quality protein fish food is warranted. It can be noted that several forum discussion groups suggest that users can innovate with other food sources, such as soldier fly larvae. One of the participants mixed their own fish food mixture and provided her recipe.

5.6. Conclusions

This study of aquaponics confirms that plants and fish can be grown together with minimal effort. New aquaponics users find it easy to start their own system, and harvest their first crop within weeks. In addition the claim that aquaponics systems are very water efficient has been confirmed.

Most of the systems were small with fish tanks of less than 1,000 litres and use the media bed technique.

It was found that basil, tomatoes and lettuce were the plants most commonly grown with basil the most successful. Broccolini, carrots, rocket, shallots, and green peppers were less commonly grown and were not successful. However even commonly grown plants such as basil were unsuccessful in either cold temperatures or few hours of direct sun.

This information is valuable to new and future aquaponics users. The study also found that aquaponics users were prepared to keep and share detailed accounts.

The following chapter builds on this research and investigates how the participants in this project researched.

Chapter 6: Exploring how Citizens Research

6.1. Introduction

> *"Citizen Science should ideally move away from using citizens on unequal terms and toward treating citizens as scientists on equal terms. Indeed, if anything, acts of information centralization should embrace the concepts of open access and freedom, allowing all to conduct science (Shyamal, 2007). Data compilers should make use of centralized data to produce scientific results in exactly the same way as anyone else should be allowed. After all, science should be verifiable and repeatable" (Lakshminarayanan, 2007).*

Citizens who are not trained in science and science methodology are interested to be involved in scientific discovery, as seen by the rise in citizen science projects. However, the question arises as to whether, without specific science education training, citizens can contribute in all aspects of research at the level expected by scientists and, if not, whether there is a way that projects can be designed, including appropriate training, that allow them to contribute at a higher level science research.

This project enables the participants to collect similar data to that collected in the university and community based studies, and to share this data in a structured manner on-line with other participants. The results from an aquaponics point of view were presented in Chapter 5 and provide data useful to the field of aquaponics. This chapter analyses the data available from the current project to explore the type and level of science conducted by the citizens. The definition of scientist varies considerably, as well as what scientists do (Schwab, 1960). The Oxford dictionary definition of a scientist is "A person who is studying or has expert knowledge of one or more of the natural or physical sciences". "Expert knowledge" is further defined as "having or involving a great deal of knowledge or skill in a particular area" so the definition of scientists can be extremely wide. The Webster dictionary adds the need for scientific training and defines a scientist as "a person who is trained in a science and whose job involves doing scientific research or solving scientific problems". An alternative definition of scientist is someone who uses the "scientific method" which is defined as a "method or procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement and experiment, and the formulation, testing and modification of hypotheses" (Oxford Dictionary). A hypothesis is further defined as "a supposition or proposed explanation made on the basis of limited evidence as a starting point for further investigation" (Oxford Dictionary).

This analysis uses the definition of someone who uses the scientific methods as the definition of a scientist, and the quality of the research is measured against research published in scientific, peer-reviewed publications.

6.2. Methods

Two different methods explored how citizens researched. The primary method was to observe their actions as reflected in the web site as they researched either on their own systems, or other participant's systems and these observations are the basis of answering the core research question on their willingness and ability to conduct all aspects of the scientific research. The secondary method was to conduct a post-project survey on their experience to determine the effect of participating in the project on the participants themselves.

6.2.1 Research by individuals on their own systems

The contributions of individual participants were examined and those with comprehensive diary entries were selected. The collected data was examined and compared to similar aquaponics studies that were listed in Table 2 to extract differences in quality of data and differences in approach.

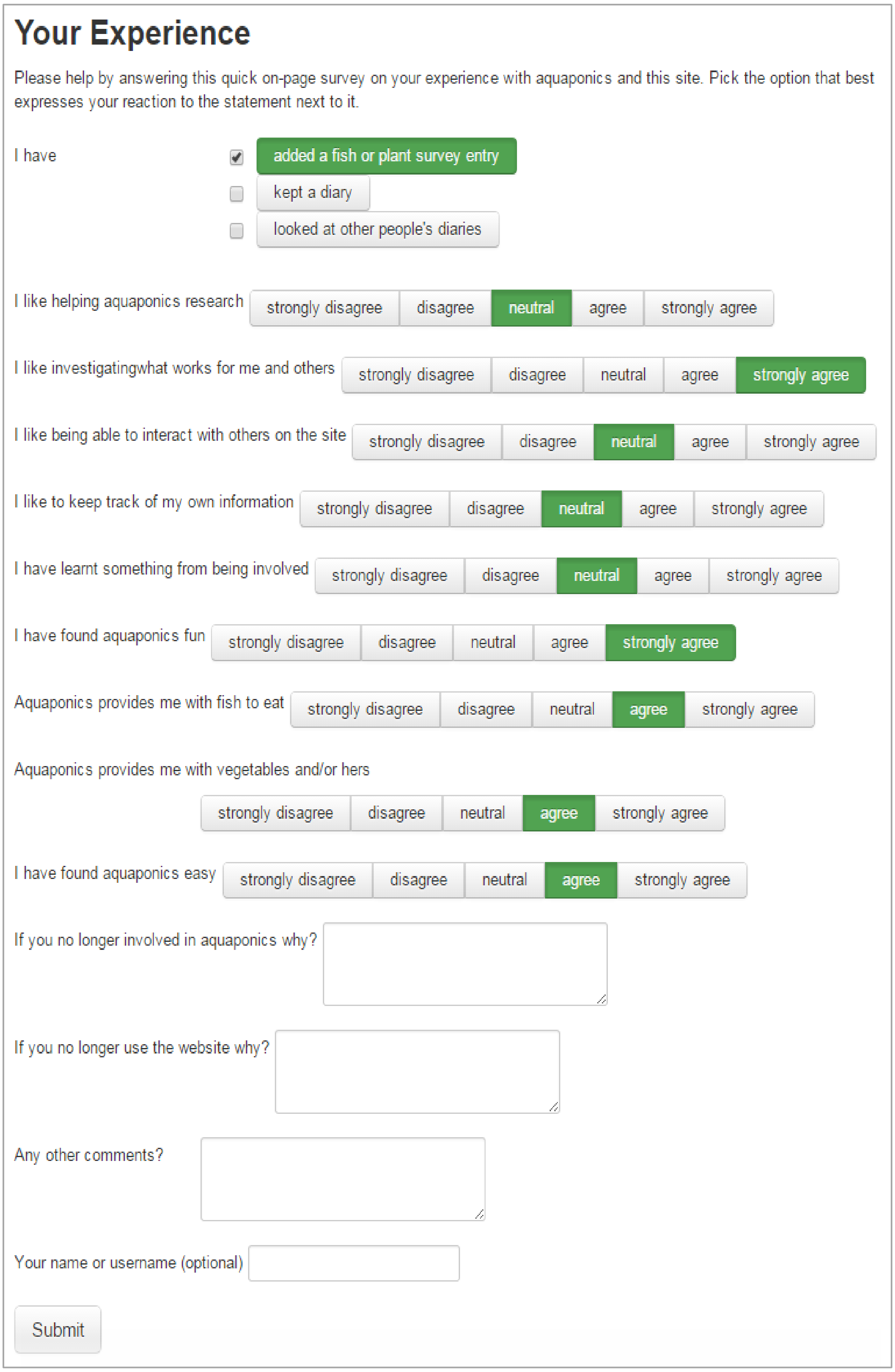
6.2.2 Participants creating new knowledge

The questions posed on the forums were the basis of any hypothesis that were made by the participants. The questions were examined as well as the way the participants utilised experimentation and the collected data to answer or refute the questions. Their actions were compared to what would be acceptable using the scientific method.

6.2.3 Surveying Participants for their views

A post-project survey was conducted to ascertain the views of the participants on their experience. All members who joined were emailed a link to the survey (Figure 29) and invited to respond. Responses were anonymous, although they could indicate their username or nickname if they wished.

A Likert scale was chosen for this survey as it is easy for the participants to read and complete as well as being likely to produce a highly reliable scale (Bertram, 2007). The survey used was divided into three sections. The first related to their research interests, the second their aquaponics interests, and the third allowed them to provide additional comments. In addition, they were asked to indicate the ways they contributed to the project which allows their involvement to be compared with their experience. The small number of potential participants, for the survey precluded the possibility of a pilot survey to validate the questions. In addition the numbers involved are insufficient to produce statistically valid conclusions. However the results can be used to inform the direction of further research.



Your Experience

Please help by answering this quick on-page survey on your experience with aquaponics and this site. Pick the option that best expresses your reaction to the statement next to it.

I have
- [x] added a fish or plant survey entry
- [ ] kept a diary
- [ ] looked at other people's diaries

Statement					
I like helping aquaponics research	strongly disagree	disagree	**neutral**	agree	strongly agree
I like investigatingwhat works for me and others	strongly disagree	disagree	neutral	agree	**strongly agree**
I like being able to interact with others on the site	strongly disagree	disagree	**neutral**	agree	strongly agree
I like to keep track of my own information	strongly disagree	disagree	**neutral**	agree	strongly agree
I have learnt something from being involved	strongly disagree	disagree	**neutral**	agree	strongly agree
I have found aquaponics fun	strongly disagree	disagree	neutral	agree	**strongly agree**
Aquaponics provides me with fish to eat	strongly disagree	disagree	neutral	**agree**	strongly agree
Aquaponics provides me with vegetables and/or hers	strongly disagree	disagree	neutral	**agree**	strongly agree
I have found aquaponics easy	strongly disagree	disagree	neutral	**agree**	strongly agree

If you no longer involved in aquaponics why?

If you no longer use the website why?

Any other comments?

Your name or username (optional)

Submit

Figure 29. Post Project Survey of Aquaponics Experience

6.3. Results

6.3.1 Research by Individuals on their Own Systems

Although most participants collected and recorded "systematic observations" and "measurement" as shown by the results in Chapter 3, most did not collect sufficient data about their system to allow detailed analysis. Of a total of 508 diary entries, 90% were from the top 5 contributors. Figure 31 shows the number and type of entries added by the top contributors.

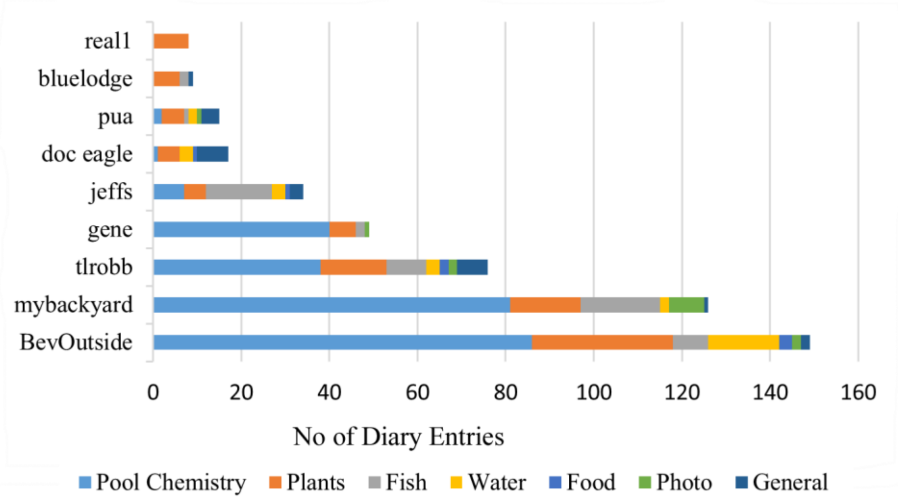


Figure 31. Diary Contributions by Top Nine Contributors

Only one participant, BevOutside, collected comprehensive data in all areas of the diary. In particular, she was the only participant who consistently recorded water usage as well as the amount of plants harvested. For some other system, such as Downunder, it would be difficult to consistently record water usage as this is an outside system where rainfall adds to the water in the system. Other participants concentrated on areas of interest to them. Jeffs concentrated on fish records, including fish food, yet did not collect regular pool chemistry results and recorded plants on only 4 occasions. Jeffs raises tilapia and uses the diary to track his tilapia and recorded numerous fish harvests.

BevOutside is an interesting case study of what can be achieved by individuals recording detailed information on their system over time. The information included here comes entirely from her contributions on the web and is available for viewing by all members. BevOutside lives in Canada

Figure 30, BevOutside's Indoor System

and has built her own system to provide salad greens in winter (Figure 30). She started her system on the 17th December 2013 prior to joining the site on the 15 January 2014. The system consisted of a 100 gallons (378 litres) fish tank and a 250 gallons (946 litres) media bed. She built her system using the popular media bed for growing food (used by 78% of participants) and is using expanded clay pebbles for media (used by 46% of media users). She is using a flood and drain system, where the whole media bed is flooded and then drained to keep the water moving. Flood and drain is also the most common method used in media beds (86% of media bed users). She is using a syphon to manage the timings (71% of flood and drain participants, others use a timer). Although she has designed and built her system herself, she has researched the most common methods and incorporated them in her design. She has opted to grow goldfish rather than fish for food. Goldfish are considered an ideal way of starting up a new system. She added goldfish at four different dates, and has a total of 13 goldfish, all of which survived.

She kept detailed entries for water quality (Figure 32). She has a constant water temperature of 21°C and a very high pH level (over 8). As usual for new systems, there was a fluctuation in ammonia and nitrates until the system stabilised itself, with the correct balance of fish waste, bacteria and plant growth. Unlike most new systems, which have increasing nitrite levels during the first few weeks until the levels of bacteria (*Nitobacter*) are sufficient to convert nitrites into nitrates, her system always measured zero nitrites. This could be because she noted that she "*added filter floss from cycled aquarium*" which probably transferred this bacteria to her aquaponics system and fast tracked bacteria production. As reflected in almost all the diaries, after running for 4 weeks her ammonia and nitrite levels are low, and remain low. Her nitrate levels are high and remain high for a number of weeks, which was apparently not problem for the fish

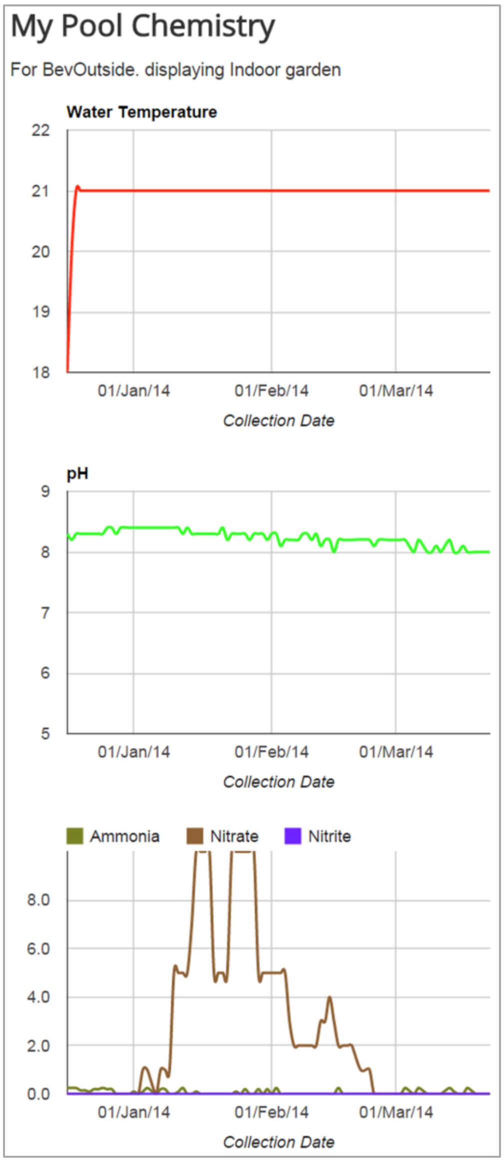


Figure 32. Water Chemistry

(although this was added a possible research question on the forum). The nitrates are essential for plant growth and the high nitrates reflected there are more nutrients in the system than the plants can utilise. As the plants grew larger they used more nutrients and the nitrate levels decreased.

She kept detailed diaries of her plants, fish and water use (Figure 33).

Water Diary

For BevOutside. displaying Indoor garden - Volume in L

Date	Volume	% Added	Comments	Tank Size
4-Jan-14	120L	31.75%	25% water change	378
17-Jan-14	15L	3.97%	Treated with Muriatic Acid to reduce ph to 6	378
22-Jan-14	15L	3.97%	ph 6	378
27-Jan-14	15L	3.97%	Added 6 ml muriatic acid to drop ph to 6.0	378
31-Jan-14	15L	3.97%	Added 6 ml muriatic acid to make ph 6.6	378
3-Feb-14	15L	3.97%	ph 6.0	378
6-Feb-14	15L	3.97%	water change	378
10-Feb-14	15L	3.97%	top up	378
12-Feb-14	15L	3.97%	water change	378
15-Feb-14	15L	3.97%	top up	378
19-Feb-14	15L	3.97%		378
24-Feb-14	15L	3.97%		378
5-Mar-14	15L	3.97%		378
14-Mar-14	15L	3.97%		378
17-Mar-14	15L	3.97%		378
22-Mar-14	15L	3.97%		378

Fish Diary

Batch		Number		Weight			Value		
Date	Action	No.	Left	Ave	Gain	Daily	Total	Gain	Daily
Goldfish 1 - Goldfish									
19-Dec-13	add	4	4	12.00			-8.00		
03-Feb-14	count		4	18.00	6	0.13			
02-Mar-14	count		4	20.00	8	0.11			
Goldfish 2 - Goldfish									
29-Dec-13	add	4	4	12.00			-4.00		

Plant Diary

Batch		Number		Weight			Value			Com
Date	Action	No.	Left	Wt	Gain	Daily	Total	Gain	Daily	
Planting1 - Greens and herbs, various										
17-Dec-13	add	0	0	1.00			-1.00			Seeded thickly for baby salad greens
27-Jan-14	harvest	4	4	6.00	6	0.15				Basil 6 grams - woohoo!
31-Jan-14	harvest	0	0	60.00	66	1.47				salad greens, celery, dill
01-Feb-14	harvest	0	0	37.00	103	2.24				salad greens
03-Feb-14	harvest	0	0	37.00	140	2.92				37 grams salad greens pruned all yellowing or shrivelled leaf plants, mostly arugula
04-Feb-14	harvest	0	0	40.00	180	3.67				

Figure 33. Extracts of BevOutside's Plant, Fish and Water Diaries

In the water usage diary, she recorded water entries for the three month period totalling 225 litres of water. In her plant diary she recorded that she harvested a total of 1,713 g of salad greens which she grew from seed planted when first setting up the system. These diaries show that a total 131 litres of water were used to harvest each kg of salad greens. As this excludes salad greens not yet harvested, this value may be considerable lower if the record included the unharvested greens.

As her main objective was to provide fresh salad greens during winter, she seeded her system thickly at the start for baby salad greens, and harvested her first basil 5 weeks later. She harvested salad greens most days following her first harvest. Specific types of greens mentioned in her diary are basil, celery, dill, rapini, kale and broccoli, although most of the entries are simply “salad greens”. In addition, she recorded fish food in the water chemistry diary, rather than in the fish food diary.

After just over 3 months entries ceased, as she stated "*Spring has sprung, and we are just now losing the snow here, so my attention has turned outdoor*".

6.3.2 Group Research

As well as being interested in research into their own systems, an analysis shows that participants not only viewed data from other systems but used this data to formulate and test their own hypothesis. The participants were invited to suggest research questions on a forum. Four different topics were suggested:

1) How does pH level affect the health of the plants?
2) Does rain affects the nitrate levels in outside systems?
3) Does high nitrate levels affect fish?
4) How to cool systems in summer?

The participants focused on the first and last topic with no discussion recorded on the other two.

6.3.3 Group Research - How does pH levels affect the health of plants?

Although aquaponics forums recommend pH levels of between 6 and 7, four of the participator's diaries show constantly high pH levels of over 8 with the others within the recommended range. The question then arises as to whether high pH level affects the health of the plants.

As there were 4 systems recording high pH levels of over 8 and 6 systems with levels under 8, the plant growth in these systems can be compared. Although most of the plant diary records recorded adding of plants, few recorded harvesting of plants so plant health needed to be determined visually.

Two of the participants with high pH did not believe that high pH affected their plants, with comments such as:

- *"most of my Kale is fine but some have yellowing leaves"(tlrobb)*
- *"my plants look health and my fish are thriving so no problem" (Bevoutside)*

As yellowing leaves could be an indication of low iron levels, it is difficult to dismiss that comment when concluding that high pH levels are fine.

In addition another participant with high pH levels added supplementary nutrients, including iron, which could counteract the effect of the high pH levels. The effect of supplementary nutrients as well as pH levels could be another research question.

6.3.4 Group Research - How to cool my systems in summer

This question was raised by a participant in California, USA who supplied a picture of his outside system as seen in Figure 34.

Although only a single participant was interested in this problem, it is possible to observe his discussion, experimentation and outcomes. The question was included under the cross-participant section, as it was posted as such on the forum, and would ideally be answered by the group.

Figure 34. System with Heat Problems

The participant trialled a number of possible solutions:

- burying the fish tank to take advantage of the constant temperature of the earth,
- position it in the shade,
- surrounding media beds with reflective insulation,
- adding more shade with shade cloths and
- removing the sump lid to increase evaporation (thus decreasing the temperature).

He also considered using porous terracotta pipes to increase evaporation but did not test this option. As seen in Figure 35 water temperature was rising faster than the outside air temperature, and his actions succeeded not only in slowing down the rise in temperature, but actually in decreasing the water temperature while the outside temperature continued to rise. As the tank was always buried and in the same position in the shade, it appears that one or more of his other actions would have contributed to this success. As he did not record when these actions were taken it is difficult to ascertain which action contributed to the temperature decrease.

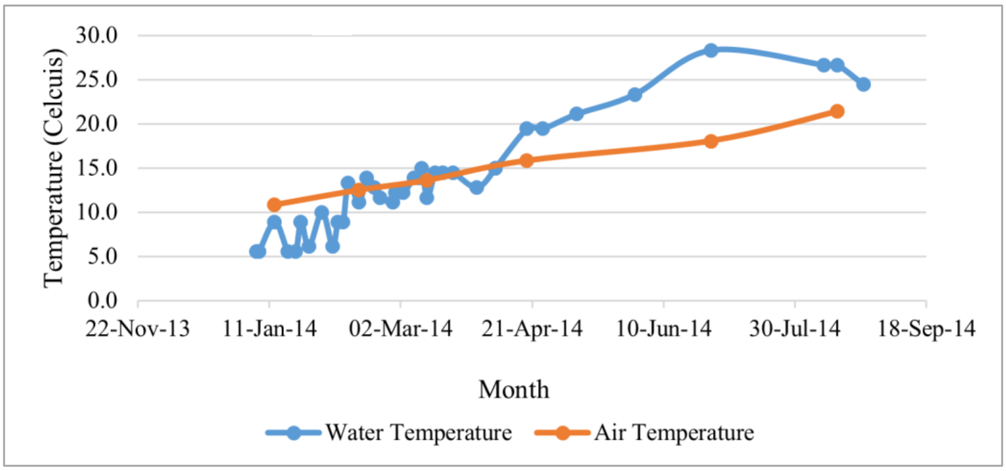


Figure 35. Water Temperature Compared to Air Temperature

6.3.5 Post Project Survey

A total of 13 responses (45% of those surveyed) were received in the post-project survey. Details of each individual response is shown in Appendix B.

The survey responses were collated in categories based on whether the participant contributed to the plant and fish survey, kept a diary, or viewed other participants' diaries. As some participants satisfy the criteria for more than one category, they are included in each of those categories. The number of responses to each question, in each category and on each scale is also shown in Appendix B as well as the percentage of responses.

Table 9 shows the descriptive statistics for the survey, by category. The median values indicate positive answers to all questions in all categories.

The questions (Q6-Q9) relating to their interest in aquaponics show that all groups found that aquaponics was fun (Q6), with a mean for all categories of 4 or over. The other high scoring category was that aquaponics provided vegetables to eat (Q8). These answers show that providing fish to eat (Q7) was significantly less important than providing vegetables. These two questions also showed a larger range, indicating that the participants had different reasons for being involved in aquaponics.

The lowest mean score of 3 was obtained with the question "I find aquaponics easy" (Q9) by those who kept a diary. A contributing factor may be that a greater proportion of diary contributors are novices as discussed in Chapter 5, and it is possible that the reason they kept a diary was because they were unsure of how aquaponics worked. In comparison, those contributing only to the survey showed the least interest on most dimensions, other than they found aquaponics easy (Q9). It may be because they found aquaponics easy they felt no need to keep a diary of their system or contribute to further research.

The research interests questions (Q1-A5) showed that those who kept a diary had the most interest in research, indicating a correlation between the efforts they were prepared to invest in the project, and their interest in research. These was also the category that learnt most from their involvement (Q5). Those who did not keep a diary scored the least in learning from the system. Those who kept a diary were also the category that scored highest on wanting to keep track of their own system (Q4).

Table 9 Descriptive Statistics for Post-Survey Interest

	Median			Mode			Range			Inter-quartile Range		
	Plant & Fish Survey	Kept a Diary	Viewed Other Diary	Plant & Fish Survey	Kept a Diary	Viewed Other Diary	Plant & Fish Survey	Kept a Diary	Viewed Other Diary	Plant & Fish Survey	Kept a Diary	Viewed Other Diary
Q1	3.5	4.5	3.5	4	4	4	4	3	4	1.0	1.0	3.0
Q2	4.2	4.8	4.0	4	5	4	2	4	2	1.0	0.8	1.0
Q3	3.8	4.5	3.8	4	4	4	5	3	4	1.0	1.0	2.5
Q4	3.9	4.8	3.6	5	5	2	3	3	3	2.0	0.8	3.0
Q5	3.8	4.8	3.8	3	5	3	2	3	2	2.0	0.8	1.5
Q6	4.3	4.5	4.0	4	4	4	2	4	2	1.0	1.0	1.0
Q7	3.7	3.3	3.8	3	3	3	3	5	2	1.5	2.3	1.5
Q8	4.1	4.5	3.8	4	4	4	3	5	3	1.0	1.0	1.5
Q9	3.6	3.0	3.8	4	3	4	2	4	3	1.0	1.5	1.5

Research Questions

Research Interest		Aquaponics Interest	
Q1	I like helping aquaponics research	Q6	I have found aquaponics fun
Q2	I like investigating what works	Q7	Aquaponics provides me with fish to eat
Q3	I like being able to interact with others	Q8	Aquaponics provides me with vegetables
Q4	I like to keep track of my own information	Q9	I have found aquaponics easy
Q5	I have learnt something from being involved		

A further categorisation is shown in Figure 36 and divides the participants into categories based on their contribution – those who contributing only to the survey, only to the diary, to both the survey and diary, and to neither the survey nor diary. This graph shows that those contributing only to the diary scored highest on almost all the questions. Those contributing to both survey and diary scored higher on the category of keeping track of their own system. Those keeping contributing to neither the survey nor diary scored the highest on wanting to keep track of their own information. It appears that this group keep track of their own system outside of this project.

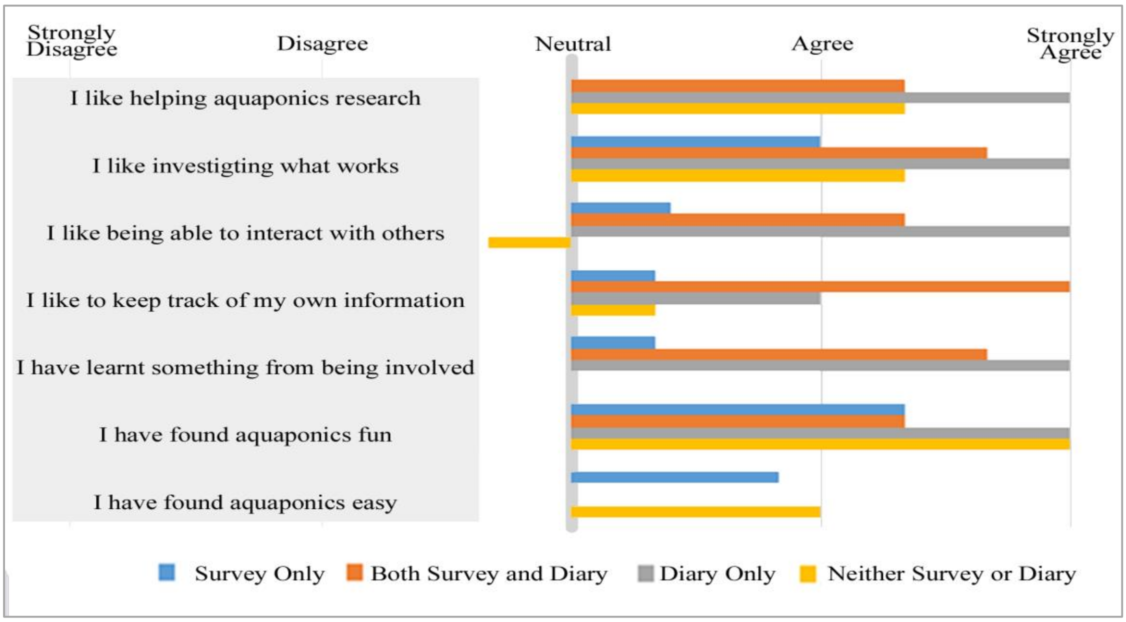


Figure 36. Post Survey Interest by Diary and Survey Participants.

6.4. Discussion

The analysis in this Chapter shows some similarities to the research in the peer reviewed literature, but also significant differences as discussed below.

6.4.1 Study Objectives

The peer reviewed studies listed in Table 2, for example (Rakocy et al., 2003) had a clear objective with measureable outcomes in contrast to the participant studies where the most common objective expressed by the participants was their desire to obtain fresh organic vegetables grown locally and the next most common objective to avoid fish deaths. This was in spite of the recruitment of participants making the research objective clear. As a result, participants appeared to concentrate on how their system performed, and used that system to evaluate the performance in aquaponics in general, rather than analysing all the diaries in detail, as observe in section 6.4.2.

6.4.2 Length of Study

The projects published in the peer reviewed literature listed in Table 2 range in time from 13 days to 10 months, with an average time of 3 months. The case study presented here covered a period of 3 months which is a similar period. The average length of all studies, which excluding those with only a single entries was 5.9 months. The length of times is comparable with those in peer reviewed literature.

6.4.3 Selectivity in Data Collected

The type and amount of data collected was determined by individual participants. Only a single participant collected the whole range of data, while others concentrated on various aspects, such as the water quality or fish. While this hinders the comparison of the performance of the various systems it can be noted that scientific studies also tend to concentrate on a specific aspects, rather than overall performance.

6.4.4 Comparing Variables in Multiple Systems

Most of the peer reviewed studies compared 2 or more systems, as seen in Table 2, allowing them to vary a single variable to determine its influence. For example, the core study on how pH levels (Tyson et al., 2008) affect nutrient intake and growth of cucumbers required 6 identical systems to be run in the same location, with controlled adjustment of pH levels to 5, 6, 7 and 8 with two additional systems with pH levels of 7 and 8 utilising additional foliar applied nutrients. The citizen science research included 10 systems which recorded pH levels, of which 4 had consistently high levels of pH (above 8). However as these 10 systems are not designed identically and are run in different locations with varying environmental factors, the pH level is not be the only variable that could affect the outcome. This is in contrast to scientific studies with attempt to control the other variables.

24% of the participant had more than one system, so they would be able to compare the system in similar conditions. Four participants had 3 systems, and two others with 4 and 5 systems respectively. However these participants did not collect sufficient data on each of their systems for realistic comparisons.

6.4.5 Comparing Results with Edge Cases

In the above scientific study, a wide range of pH levels are tested, including levels that are unlikely to be successful, for example systems with pH levels of 5 and 6. In contrast, no system in this study averaged a pH less than 6.8, although two systems reached as low as 6.4 on occasions. The remaining systems averaged between 7 and 7.8. The desire to build a system that works precludes them from testing the full range of values that would often be tested in the laboratory.

6.4.6 Data Precision

While the scientific study controlled the pH to be steady at the required level, each of the experiments in the citizen science study had varying pH levels (Tyson et al., 2008), although most systems stayed within a range of ±0.4. This shows that the results of this citizen science study are less precise than the scientific study with fixed levels.

6.4.7 Types of Measurements

Water chemistry is significant parameter in most case studies, as well as the scientific studies, but variations occur in the chemicals measured. The core measurements taken by the participants were temperature, pH, ammonia, nitrites, and nitrates. The participants used chromotrapic reagents that are commercially available for use in testing aquariums at home. In some instances the professionals also used similar reagents. However, many of the scientific studies were able to utilise a wide range of test equipment which is out of the reach of most aquaponics users, such as spectrophotometer, PAR (Photosynthetically Active Radiation), quantum sensors and multi-parameter probe (Enduta et al., 2011; Hanson et al., 2008; Palm et al., 2014; Yamamoto & Brock, 2013). These instruments allowed them to calculate nutrients within the plant biomass itself as well as within the water. The measurement of the concentration of nutrients in the plant biomass is beyond the tools available to the participants, who rely on growth and visual inspections of the plants to determine their health. The main measurement that was collected in most professional studies, but not in most home aquaponics experiments, is Dissolved Oxygen (DO), where there is no easy cheap off-the-shelf test kit. The "test" used by most home aquaponics users is observation - if the fish are not gasping at the surface of the water, then there is sufficient dissolved oxygen.

The utilisation of alternative measurement techniques does not indicate that the research is inferior, provided the accuracy is sufficient for the studies' objectives. The use of alternative means of measuring water quality has also been used in university research, such as in the University of Toronto's water monitoring system study, which replaced chemical markers of water quality to biological markers due to budget cuts (Savan et al., 2003). In the above example, the use of aquatic test kits provides data of sufficient quality, but the use of gasping fish is insufficiently accurate to measure dissolved oxygen levels.

6.4.8 Data Quantity

The data collected by this approach is dependent on the number of contributors who are willing to continue to contribute. As neither advertising nor inducements were used in this project the number of contributors was too low for high reliability despite providing valuable insights, both into aquaponics and how they researched.

6.4.9 Analysis and dissemination of results

The above case study (6.2.1) collects similar information and is of comparable quality to the McGill University study (Bishop et al., 2009) and the Byspokes study (Viladomat & Jones, 2011). The diaries within that case study show water consumption required for plant growth was 131 litres per kg (excluding plants not yet harvested) that is comparable with 132 litres per kg of harvested plants in the Byspokes Report.

Although all the data to analyse usage was readily available, there was no discussion by the participants that collected the data nor the other participants on how water efficient the systems were shown to be. The participant could have discussed this as a general comments, or within the forum.

The responses from participants in the pH level discussion shows that they discussed only their own system and experience, and does not indicate that they performed any analysis of the data collected by other participants. In fact they ignored data from their own diary that would have affected the hypothesis. Instead, they answered this hypothesis on their own observations and experience “it works for me so it must be ok”. This is consistent with studies on self-validation of knowledge that found that “it works for me” is the most common basis of knowledge creation. However personal, experiential knowledge requires stronger validation to become professional knowledge (Hargreaves, 1999).

This lack of analysis by participants may be due to the study design, rather than the interest or ability of the participant to analyse their data, and further research would be valuable to determine how to enable the participant to contribute in analysing their data.

6.4.1 Dissemination of results

Scientific discovery is authenticated by peer review and published in journals and at conferences. In contrast the research done by aquaponic users was primarily for the personal use, and disseminated on personal blogs.

For example, https://northernaquaponics.wordpress.com/ is a personal blog written by one of the participants to describe her aquaponics experience.

The information in blogs vary in quality from very bad to very good. Without a process of authenticating community research and providing a way of disseminating the information, it is likely that partnerships with professionals will be needed. Further research is needed as to how to facilitate the dissemination of citizen science results, if done entirely by citizens, and ways to validate these results.

6.5. Conclusions

This analysis shows both the strength and capability of the citizens experimenting, but also the significant differences, driven mainly by varying objectives, varying access to resources and the lack of a process where they can validate and share their research.

The lack of access to expensive test equipment limits the areas of experimentation. For example, it is unlikely that home aquaponics users will be able to measure the nutrient quality of the vegetables, but they will be able to measure water quality. This implies that citizens can collect and analyse some data to the standard needed for scientific research, but there are limits to the types of research they can do. However, limitations also apply to professional scientists who are also limited by budgets and available equipment.

The spread of systems, across many different regions with many different designs adds richness, but, unless the number of participants is very large, it is unlikely to be able to extract sufficient similar systems to replicate results and estimate errors in the analysis. However these variations would allow the other factors affecting performance to be analysed if the dataset collected was large. The need for quantity as well as quality to correct the larger variation in collected data has also been investigated in citizen science based on bird observations (Munson et al., 2010) and lessons learnt from that study is applicable to other studies.

The analysis of the individual system (6.2.1) showed research results at a comparable level to published research based on single systems although the results were not in a format that could easily be disseminated. However the analysis on multiple systems lacked the rigour and analysis to be comparable to any of the other studies.

Chapter 7: Discussion and Conclusions

7.1. Research Questions

The key question explored in this thesis was whether citizens involved in a citizen science project can contribute beyond the usual areas of data collection and data analysis to all aspects of the science process. The result of this research shows both the interest and methods that citizens used when conducting "scientific" research and uncovers significant limitations that need to be addressed.

The analysis of how well the citizens researched is based on the aquaponics citizen science study.

A detailed discussion of aquaponics outcomes were discussed in section 5.5 and shows that the plant survey produced a valuable list of plants and how successfully they were grown and, and in addition allows users to investigate details of the system and environment that caused problems. In addition the results supported the assertion that it is highly water efficient. However the fish survey did not contain sufficient useful information due to insufficient records.

Aquaponics users are shown to be willing to add data over time into a diary for further analysis.

Research in the field of citizen science attempted to answer the following questions regarding the actions of those who took part in the aquaponics research:

1. *Will they "recognize and formulate" a question or problem to be answered?*

   The citizens did recognize problems and formulated these as questions on the forum, including questions such as the effect of high pH levels and how to cool the systems.
   The question they posed on appropriate pH levels is also directly raised in the scientific literature (Tyson et al., 2008). In addition, the pH levels were a key item measured in most of the studies, with the objective of keeping the pH level within appropriate ranges with the common range used being between 6.5 and 7.5.

With data showing a proportion of the systems exhibiting high pH levels, of over 8, with most under 7.5 the available data could be used to confirm or deny this question.

The other questions were not easily answered by the type of data collected, for example how to cool a system, nor discussed in any of the articles on aquaponics. As only a single participant encountered this issue it was a suitable topic for group research. However this may inform future research that would allow aquaponics to be utilized in more regions.

2. *Will they "collect data" by observation and experiment?*

Just over half of the participants contributed to the diary, showing a willingness to collect detailed structured data over time to be used for research. In addition, at least one of the participants experimented with modifying their system design to seek answers to his question.

A number of the participants collected data at the same level as the community researchers (Bishop et al., 2009; Viladomat & Jones, 2011) as shown in 6.2.1. This data allowed similar findings, for example one of the participants collected data showing that she used 131 litres per kg of harvested plants, which is comparable to the 132 litres per kg reported by Viladomat & Jones, (2011). However most of the participants limited the type of data they collected which in turn limited the usefulness of the data for research, for example they may have recorded pool chemistry reading, but not water use.

As the core objective of the participants was to have a successful system that provides them with fresh herbs and vegetables, they experimented with systems designed to operate in the optimal range. For example, the study on pH levels included different systems with pH levels of 5, 6, 7, and 8 (Tyson et al., 2008). Based on recommendations of pH levels that are likely to be acceptable in aquaponics books and forums (Bernstein, 2011) the pH levels were restricted to 6.1-8.8, with the majority being between 6.5 and 7.5. This limits the ability to identify edge cases, due to no, or insufficient data being collected at the edges of the "acceptable range".

Another limitation was that each system demonstrated a range of values for each of the measurement types, whereas most of the scientific studies kept measurements within narrow ranges. The larger range of measurement values was also found in the community studies (Bishop et al., 2009; Viladomat & Jones, 2011). Although these ranges limit the questions that can be answered, they can answer similar questions to those in the community studies, for example evaluating whether they are more efficient than soil based systems in providing vegetables.

3. *Will they systematically analyse the data to test the question or problem to be answered?*

There is no evidence of systematic analysis of the data, and it appears their answers were based on their own feeling and experience rather than by systematic analysis of the data.

The depth of data analysis by the participants is a key difference in the way they "researched" the data they collected. Research into how to encourage and train citizens in systematic analysis would be key to using home based experimentation to improve their "scientific thinking".

4. *Will they share the data as a group to allow research across data with different input parameters?*

The citizens did collect and share their data, with 38% of the post-project survey responders claimed to have looked at other participant's data. However there is little evidence that they utilized this data to find answers to the questions that they posed.

For research questions, such as the effect of high pH levels, the discussion shows that, instead of comparing the group of systems with high pH levels and those with low pH levels, the participants with high pH levels become defensive and discussed their view that they systems was doing well, and the high pH did not have a detrimental effect although they also made an effort to decrease them to the "acceptable" range. There was no discussion about the crop yield or water usage difference between the two groups.

This highlights an issue with a research design where individuals who are also the researchers have personal interests in a portion of the research, and will need to be mitigated against in the study design.

For many other questions, such as the effect of location and climate on system performance, there was insufficient data collected to compare systems with different input parameters.

5. *Will citizens learn from the shared data?*

   The post-project survey shows that, of those who indicated that they looked at other participant's diaries, only one participant highly agreed with the statement that they learnt from their experience, although those who kept diaries highly agreed that they learnt from their own data. It appears that contributors learnt more from their own diary, than from viewing shared data.

6. *Will citizens use this data to come up with new knowledge, and if so how is this done?*

   The results presented here do not resolve this question although there are indications that taking part and collecting data on their own system was beneficial to them in learning about and managing their own systems.
   However the research uncovered insights into how individual citizens experimented in comparison with aquaponics experiments appearing in peer reviewed papers as discussed in 6.4

7.2. Concluding Remarks

Utilizing citizens who are keen to experiment in projects in which they have a personal interest is a way of extending their scientific abilities and interests, as well as assisting overall research. Aquaponics provided an informative basis on which the key question as to how the citizen scientists research could be explored. At the same time their experiment added significantly to the informal aquaponics research as currently available in aquaponics publications and blogs.

The way the participants experimented with the scientific method highlights the possibilities as well as challenges with projects where citizens are involved in all areas of scientific discoveries. These challenges highlight areas which need to be addressed to enable citizens to research at higher levels so that they can be more than “science assistants”.

7.3. Recommendations

As this research was an in-depth study of the actions of individuals researching rather than a broad survey of the field, the small numbers provided valuable insights into their approach, and can be used as a starting point for future research.

The most significant challenges that need to be addressed in future studies are:

1. **Clear scientific objective.**

   Even though the invitation to join the site clearly indicated that the objective of the project was collective research, it appears that the real interest of participants was in collecting information on their own systems for their own benefit. While this interest benefits research, the resulting project differs little from other citizen science projects where citizens collect data to be used by scientists for research purposes. As it would be unrealistic to expect all participants to contribute more to the project than their data, perhaps a hybrid project objective would be more realistic, where most participants collect data for their own purposes but a few participants also research the jointly collected data to contribute the development and testing of hypothesis. The project could be designed to recognise these participants in some manner and provide them with further resources to assist them in their endeavour.

2. **Direction in how to analyse the data.**

   The way participants analysed the data showed that the analysis was based on their experience, rather than on systematic analysis of the data. The question arises in how to empower the citizens to analyse the data in a scientific manner. More research is required to address this issue, and is likely to involve strategies, such as training, guidance and tools to assist them in this task. It is possible that alternatives to university based research, such as “knowledge production” could be the basis of this analysis, Knowledge production is an approach that is more applied, problem-focused, trans-disciplinary, heterogeneous, hybrid, demand-driven, entrepreneurial, accountability-tested, embedded in networks (Hargreaves, 1999) and could provide insights into how to address this area.

3. **Assistance with disseminating the results**.

The dissemination of knowledge outside R&D environments has been referred to as “the unsolved problem” (Hargreaves, 1999) with changes in report structure and format making little impact. Other than utilising professional scientists to disseminate the results, which accepts the proposition that citizens cannot fulfil all the tasks of scientists, an alternative method of disseminating and evaluating new knowledge is needed.

This research contributes towards enabling citizen scientists to be on more equal terms than scientists by exploring how they approached all aspects of the scientific process, and identifying the limitations and challenges involved. These challenges and limitations can be minimised by selecting suitable areas of research, careful project design, and assistance with analysis methods and tools, but will require in addition new ways of qualifying and disseminating the knowledge created by the citizens.

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Appendix A. Participants Quoted

While the research was based on the contribution of all participants, the following are specifically quoted in this thesis.

Nickname	Country	Survey	Diary
Bevoutside	Canada	✓	✓
Downunder	Australia	✓	✓
Doceagle	USA	✓	✓
Gene	USA	✓	✓
Jeffs	USA	✗	✓
Pua	Germany	✓	✓
tlrobb	USA	✓	✓
RubertofOZ	Australia	✓	✗
hemps	Australia	✓	✓

Appendix B. Post Project Survey

Table 10 Responses to Post Project Survey

Response No.		1	2	3	4	5	6	7	8	9	10	11	12	13
Added Survey		Y	Y	Y	N	Y	Y	N	N	Y	Y	N	Y	Y
Kept Diary		N	Y	N	N	N	Y	N	N	N	N	Y	Y	N
Viewed Other Diaries		Y	Y	N	N	N	N	N	Y	Y	N	N	Y	N
Research Interest	Q1	3	4	3	5	4	4	4	4	1	4	5	5	3
	Q2	3	4	4	5	4	5	4	4	4	4	5	5	5
	Q3	0	4	3	1	3	5	4	3	4	4	5	4	3
	Q4	2	5	3	5	4	5	3	2	4	4	4	5	3
	Q5	3	4	3	1	3	5	4	4	3	5	5	5	3
Aquaponics Research	Q6	3	4	4	5	5	5	5	5	4	5	5	4	5
	Q7	3	3	5	5	4	2	3	4	4	3	3	5	4
	Q8	4	4	5	5	5	5	3	5	2	4	5	4	4
	Q9	4	2	4	3	3	3	4	5	4	4	3	4	4
no longer in aquaponics		N	N	N	N	N	N	N	N	Y	N	N	N	N
no longer uses site		N	N	N	N	N	N	N	N	N	N	N	N	N
comments				*		**								

Questions

Research Interest

Q1 I like helping aquaponics research

Q2 I like investigating what works

Q3 I like being able to interact with others

Q4 I like to keep track of my own information

Q5 I have learnt something from being involved

Aquaponics Interest

Q6 I have found aquaponics fun

Q7 Aquaponics provides me with fish to eat

Q8 Aquaponics provides me with vegetables

Q9 I have found aquaponics easy

Comments

* I think research is important and I would like to share more and learn more from others. I think it is a time management thing, but I just keep forgetting to log-on...maybe you could have an opt-in email reminder for slackers like me...

** Do not add even a tiny bit of salt to a system where fish are ill (even if well below ppm limits). Take the fish out and salt bath them in separate tanks... Also, AP is novelty unless going industrial scale, though building a system from absolute scratch is a brilliant place to start.

Table 11. Post Project Survey Responses by Participation Type

Questions		Strongly Disagree			Disagree			Neutral			Agree			Strongly Agree		
		Plant & Fish Survey	Kept a Diary	Viewed Other Diary	Plant & Fish Survey	Kept a Diary	Kept a Diary	Viewed Other Diary	Kept a Diary	Viewed Other Diary	Plant & Fish Survey	Kept a Diary	Viewed Other Diary	Plant & Fish Survey	Kept a Diary	Viewed Other Diary
1. I like helping aquaponics research	#	1	0	1	0	0	0	3	0	1	4	2	2	1	2	1
	%	11%	0%	20%	0%	0%	0%	33%	0%	20%	44%	50%	40%	11%	50%	20%
2. I like investigating what works	#	0	0	0	0	0	0	1	0	1	5	1	3	3	3	1
	%	0%	0%	0%	0%	0%	0%	11%	0%	20%	56%	25%	60%	33%	75%	20%
3. I like being able to interact with others	#	0	0	0	0	0	0	3	0	1	4	2	3	1	2	
	%	0%	0%	0%	0%	0%	0%	33%	0%	20%	44%	50%	60%	11%	50%	0%
4. I like to keep track of my own information	#	0	0	0	1	0	2	2	0	0	3	1	1	3	3	2
	%	0%	0%	0%	11%	0%	40%	22%	0%	0%	33%	25%	20%	33%	75%	40%
5. I have learnt something from being involved	#	0	0	0	0	0	0	5	0	2	1	1	2	3	3	1
	%	0%	0%	0%	0%	0%	0%	56%	0%	40%	11%	25%	40%	33%	75%	20%
6. I have found aquaponics fun	#	0	0	0	0	0	0	1	0	1	3	2	3	5	2	1
	%	0%	0%	0%	0%	0%	0%	11%	0%	20%	33%	50%	60%	56%	50%	20%
6. Aquaponics provides me with fish to eat	#	0	0	0	1	1		3	2	2	3	0	2	2	1	1
	%	0%	0%	0%	11%	25%	0%	33%	50%	40%	33%	0%	40%	22%	25%	20%
8. Aquaponics provides me with vegetables	#	0	0	0	1	0	1	0	0	0	5	2	3	3	2	1
	%	0%	0%	0%	11%	0%	20%	0%	0%	0%	56%	50%	60%	33%	50%	20%
9. I have found aquaponics easy	#	0	0	0	1	1	1	2	2	0	6	1	3	0	0	1
	%	0%	0%	0%	11%	25%	20%	22%	50%	0%	67%	25%	60%	0%	0%	20%

Appendix C. Publications

Submitted to Peer Reviewed Journal

R. Follett and V. Strezov, Application and Publication Patterns of Citizen Science in Scientific Research. *PLOS One* (Submitted 5th March 2015)

Application and Publication Patterns of Citizen Science in Scientific Research

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Abstract

The rising utilization of citizen science for scientific discovery depends on the increased acceptance of this method by the scientific community. Using the Web of Science and Scopus as the source of peer reviewed articles, an analysis of all published articles on "citizen science" confirmed its growth, and found that significant research on methodology and validation techniques precede the rapid rise of the publications on research outcomes based on citizen science methods. Biodiversity, phenology, water monitoring and astronomy are often the topics of citizen science projects. Of considerable interest is the growing number of studies relying on the re-use of collected datasets from past citizens science research projects, either individually or across multiple projects for new discoveries, such as for climate change research. The extent to which citizen science has been used in scientific discovery demonstrates its importance as a research approach. This analysis not only informs the scientific community on the growth of citizen science and where this growth is occurring, but also highlights the significant research that is being done on this method that can be utilized when using the citizen science approach and may stimulate ideas for the application of citizen science to new areas of research.

Introduction

Public involvement in scientific discovery can be tracked through recorded history [1] with the earliest records dating back 1,910 years for locust outbreaks in China [2]. Recent times has seen a significant increase in public involvement in scientific research, now referred to as "Citizen Science". Alan Irwin [3] has been one of the first to use the term "Citizen Science" in 1995 in the context of describing expertise by lay people, and this term was soon modified to describe a research technique using members of the public to gather or analyse scientific data [4]. Citizen science is defined by the European Commission Green Paper as "general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort, or surrounding knowledge or their tools and resources" [5].

Citizen science engages the public in scientific projects that are difficult to conduct solely by scientists who lack the resources to gather or analyse data on a large scale [6]. Citizen science engages interested volunteers to monitor wildlife [7], to classify images [8], to transcribe old records [9] and to contribute to other projects. Project objectives range from supporting scientific investigations within academic institutions to increasing the interest and knowledge of the general population on science and ecology [10].

Citizen science projects, also known as case studies, can be classified in several different ways. An initial classification for citizen science projects was based on the type of volunteer involvement, dividing case studies into [4, 12, 13]:

- Contributory, where the participants contribute to data collection, and sometimes help analyse the data and disseminate results.
- Collaborative, where citizens also analyse samples, data and sometimes help design the study, interpret the data, draw conclusion and disseminate the results.
- Co-created, where citizens participate at all stages of the project, including defining the

Submitted to Peer Reviewed Journal

R. Follett and V. Strezov, Exploring the participation by novices and experts in a citizen science project in aquaponics. *Public Understanding of Science* (Submitted 8th April 2015).

Exploring the Relationship between Benefits and Commitment in a Citizen Science Project in Aquaponics.

Abstract

Citizen science has successfully enabled many volunteers, in partnership with scientists, to advance science. A challenge with projects that require volunteers to participate over longer time periods is to retain their interest. A possible motivation to continue to participate is to ensure that the volunteers directly benefit from the results of this research, as well as being able to contribute to global knowledge and understanding. This paper presents a citizen science project in aquaponics system, which investigates the relationship between benefit to the citizens and their willingness to be involved over a longer period of time in optimising the aquaponics system performance.

1. Introduction

The increased internet usage by the public drives the growth of a research methodology known as Citizen Science, defined by The European Commission Green Paper (2013) as "general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort, or surrounding knowledge or their tools and resources".

Citizen science engages the public in scientific projects that are difficult to conduct solely by scientists due to the lack the resources to gather or analyse data on a large scale [1]. Project objectives have ranged from supporting scientific investigations within academic institutions [2] to increasing the interest and knowledge of the general population on science and ecology [3]. Citizen Science projects have engaged interested volunteers in monitoring wildlife [4], classifying images [5], transcribing old records [6] and contributing to other projects [7].

Prior research on typology has classified citizen science projects [8] into five groups 1) projects initiated by citizens investigating local issues using scientific tools, 2) projects initiated by scientists aimed at conservation by observing and measuring local environmental factors, 3) projects involving citizens analysing data collected by scientists from the physical environment, 4) virtual projects that are purely on-line with no physical elements, and 5) projects aimed at educating citizens. Another potential application of citizen science is involving citizens to run own scientific experiments at home and contributing to a global database of the results.

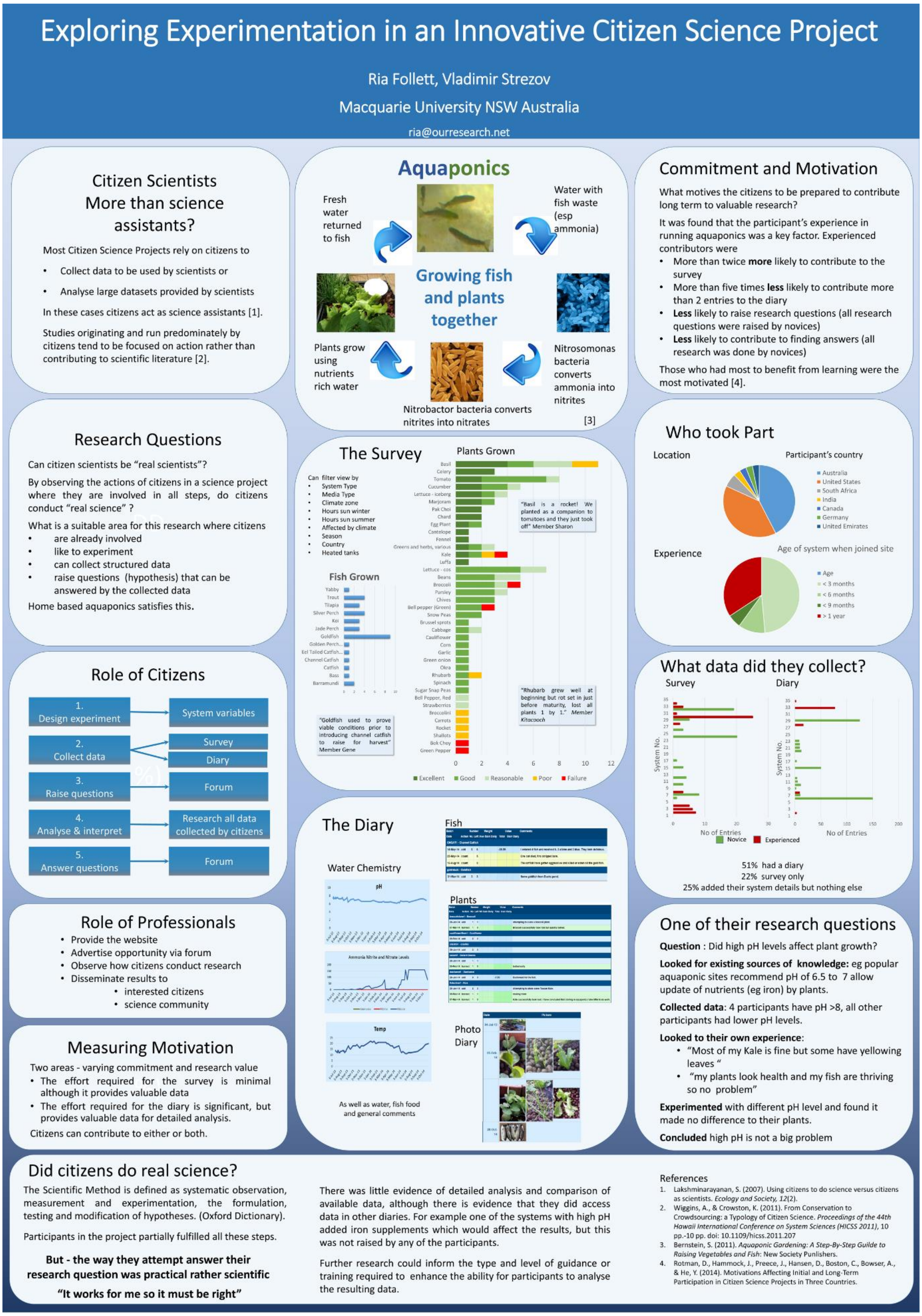
Citizen science projects from many of these typologies can be reused for new additional research [9] providing a rich scientific resource. The most prolifically used citizen science database comes from the eBird project, which has collected information about the distribution and abundance of birds, taking advantage of the global network of birdwatchers. By mid-year 2013 over 140 million observations have been submitted by 150,000 volunteers who spent 10.5 million hours in the field collecting data [10]. The eBird database is freely available to researchers. An outstanding question is whether, by providing volunteers with easy and free access to the collected database, volunteers would be more likely to continue with the project and whether they will also contribute to the project by discovering new observations from the data.

Successful citizen science projects rely on attracting interested volunteers. Studies on the motivation of volunteers working on wildlife surveys [11] [12], astronomy [13] and virtual citizen science [14] projects find that common motives tend to be prior interest in the field, the desire to help increase scientific knowledge in that area, and the meeting people with similar interests. The motives of participants in wildlife surveys [11] also included seeing wildlife, increasing their own knowledge about wildlife, and being able to contribute while doing an activity they were already participating in. In astronomy [13] motives for citizens participation also included the ability to see galaxies that few people have seen before, enjoying looking at beautiful galaxy images, amazement at the vast scale of the universe and being able to contribute to original research.

As the key to successful citizen science projects is motivated citizens, new subject areas that may benefit from this approach are those where there are citizens with prior interest, willingness in improving

Published Conference Proceedings

R. Follett and V. Strezov, Exploring Experimentation in an Innovative Citizen Science Project, *Citizen Science Conference*, San Jose, California, USA, 11-12 February 2015.



Published Extracts (abstracts) of Conference Papers

R. Follett and V. Strezov, Citizen Science Partnerships between Universities and the Community, *2014 Engagement Australia Conference*, Wagga Wagga, Australia, July 21 - 23, 2014.

Citizen Science Partnerships between Universities and the Community

Ria Follett, Macquarie University
Vladimir Stezov, Macquarie University

Introduction

The European Commission Green Paper (2013) defines citizen science as "general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort, or surrounding knowledge or their tools and resources".

There are many examples of successful projects delivering innovations and research breakthroughs, such as Oxford University's Galaxy Zoo project (http://www.galaxyzoo.org/#/story), which attracted over 150,000 volunteers (Cardamone et al., 2009) or Cornell University's bird lab project (http://www.birds.cornell.edu/page.aspx?pid=1609) that involved 200,000 citizens (Hochachka et al., 2012).

In most projects the public either interprets data provided by the scientist or collects data for the scientist. In both these scenarios, the scientist utilizes the public as science assistants (Lakshminarayanan, 2007).

My research hypothesis explores the willingness and ability for the public to transcend the role of science assistants and to develop their own science by analysing the collected data and discovering new knowledge. This reflects the key motivations for involvement being "excited to contribute to original scientific research" (Jordan Raddick et al., 2013) and wanting to "make a positive contribution to conservation" (Hobbs & White, 2012).

This hypothesis was tested with a citizen science project in aquaponics. Home aquaponic users build their own systems, and experiment with them. This is an eminently suitable environment for the users explore their own research questions and answers.

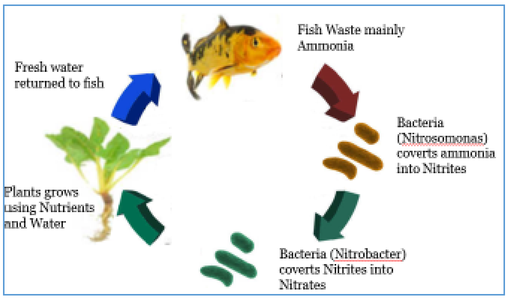


Figure 1. Schematic of an aquaponics system

Aquaponics is a combination of aquaculture and hydroponics. Water is cycled from the fish tank (containing fish producing fish waste) through media (containing bacteria converting fish waste to plant nutrients) and filtered water returns to the fish tank (Fig 1). Plants grow using these nutrients. This is a simple system that requires no chemicals for plant growth, recycles water and releases no waste into the environment (Nichols & Savidov, 2012).

Methods

Active aquaponic forums provide a mechanism to reach the target participants. A request for volunteers was placed on three aquaponics forums in Australia and USA during January 2014. Only volunteers who ran their own aquaponics systems and accepted the Macquarie University Ethics conditions were accepted and took part online at www.ourresearch.net.

Appendix D. Consent Letter

Faculty of Science

MACQUARIE UNIVERSITY NSW 2109

Australia

Participant Information and Consent

Aquaponics Research by Aquaponics Users – a Citizen Science Project

You are invited to participate in a study of aquaponics. The purpose of the study is to find out what is find out how aquaponics systems are used in practise, and make this information available to participants to analyse and come up with new facts.

The study is being conducted by Ria Follett, Department of Environment and Geography, (contact +61 (0) 2 9850 7978, email) being conducted to meet the requirements of Master of Philosophy under the supervision of A/Prof Vladimir Strezov (contact +61 (0) 2 9850 6959, email) of Department of Environment and Geography.

If you decide to participate, you will be asked to enter details of your aquaponics system, and participate in any or all of the following experiments:

The information will be collected on the web and you may contribute as much or as little information as you like. You will have access to the information entered by all the participants via the same web site. You are invited to draw conclusions from the data, and post this on the forum for discussion between the participants.

You should participate using a pseudonym to protect your privacy. This can be entered on the next page. The only information collected that could potentially identify yourself will be your email address. This will be used only for communication from the site administrator or researcher. This personal information will be kept confidential, except as required by law. No individual will be identified in any publication of the results except when the participant explicitly elects to jointly publish a paper on their findings with the researcher.

Participation in this study is entirely voluntary: you are not obliged to participate and if you decide to participate, you are free to withdraw at any time without having to give a reason and without consequence.

The ethical aspects of this study have been approved by the Macquarie University Human Research Ethics Committee. If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Director, Research Ethics (telephone (02) 9850 7854; email ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

I am 18 years old or over, and I have read and agree to participate based on these conditions.

Appendix E. Ethics Approval

MACQUARIE UNIVERSITY

Katherine Wilson <katherine.wilson@mq.edu.au>

Approved

1 message

Faculty of Science Research Office <sci.ethics@mq.edu.au> Tue, Aug 20, 2013 at 10:19 AM
To: Dr Vladimir Strezov <vladimir.strezov@mq.edu.au>, Dr Ria Maren Frieda Follett <ria-maren.follett@students.mq.edu.au>
Cc: Prof Richie Howitt <richie.howitt@mq.edu.au>, Ms Katherine Wilson <katherine.wilson@mq.edu.au>

Dear Dr Strezov,

RE: Ethics project entitled: "Aquaponics research by Aquaponics users - a citizen science project"

Ref number:5201300594.

The Faculty of Science Human Research Ethics Sub-Committee has reviewed your application and granted approval, effective (19/08/2013). This email constitutes ethical approval only.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf.

The following personnel are authorised to conduct this research:

Dr Ria Maren Frieda Follett
Dr Vladimir Strezov

NB. STUDENTS: IT IS YOUR RESPONSIBILITY TO KEEP A COPY OF THIS APPROVAL EMAIL TO SUBMIT WITH YOUR THESIS.

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).

2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 19 August 2014
Progress Report 2 Due: 19 August 2015
Progress Report 3 Due: 19 August 2016
Progress Report 4 Due: 19 August 2017
Final Report Due: 19 August 2018

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

5. Please notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites:
http://www.mq.edu.au/policy/

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of approval to an external organisation as evidence that you have approval, please do not hesitate to contact the Ethics Secretariat at the address below.

Please retain a copy of this email as this is your official notification of ethics approval.

Yours sincerely

Richie Howitt, Chair
Faculty of Science Human Ethics Committee Secretariat
Professor Richard Howitt (Chair, Dept of Environment & Geography)
Katherine J. Wilson, Research Administrator
Faculty of Science
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