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Unmanned Aerial Vehicles and Biosecurity: Enabling Participatory-Design to Help Address Social Licence to Operate Issues

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Abstract: Forest health can be adversely affected by invasive organisms. Biosecurity measures to prevent the establishment of harmful invasive organisms at national points of entry (e.g., airports or shipping ports) are vital to protect forest health. Innovations in pest eradication technologies are being developed based on their efficiencies and effectiveness. However, the question of whether people find them acceptable is rarely considered. In New Zealand, research is underway into the use of highly targeted pesticide spraying using unmanned aerial vehicles (UAVs) as a novel technology to eradicate pest species that impact forest, food, and fibre sectors. Public approval for such technologies, however, can be a critical aspect for their success. A tool can be technically effective (achieve eradication), but uptake may be impossible if communities do not trust the technology. We developed a method for enabling discussions about the use of UAVs and their acceptability in general before being operationalized for biosecurity. This paper presents an investigation of how "participatory-design", an often tactile, visual, and inclusive process of community engagement can improve the acceptance of technology use in the public sphere. We asked people, both scientists and citizens, to evaluate the acceptability of a range of UAV uses (including biosecurity) along a continuum and then explored the reasons for their placement. Key criteria for acceptable and unacceptable uses were subsequently developed to help technology designers and operators consider aspects of social acceptability during design processes. Our tool and approach facilitated discussions around technology acceptability that were subsequently adopted by our technical design team for the development and the use of acceptable UAVs for biosecurity. This research shows how systematic approaches to design can help uncover and mitigate social acceptability issues through inclusive design under increasing threats of biosecurity, whether related to challenges of trade or climate change.

Keywords: forest health; biosecurity; invasive pests; unmanned aerial vehicles (UAVs); social licence to operate; participatory design

1. Introduction

Tree health is an important part of New Zealand's economic, social, and cultural value system [1]. The steep rise in the rate of international trade and movement of people over the last century has increased the risk of biosecurity threats and their potential to incur large economic, social, and environmental costs [2]. Climate change processes increase this risk with the potential spread and establishment of pests and diseases to new areas [3,4]. As such, New Zealand's forest conservation estate and primary production sectors are concerned with potential risks from invading exotic plant pests (insects and pathogens). While New Zealand's exotic forest plantations form the base of a multi-billion dollar industry [5], the importance of New Zealand's indigenous forest is immeasurable. This is partly due to the high value related to tourism but especially because of the strong cultural ties that most New Zealanders have to the natural landscape [6].

In New Zealand, biosecurity officials receive over 10,000 reports of suspected new pests and diseases every year, many of which could impact forests [7]. Urban ports and airports are typically high-risk areas and can serve as hubs for invasive organisms to establish and spread. Managing these invaders when they are first discovered is a vitally important step to preventing pests from becoming established. However, managing incursions in densely populated urban environments presents an array of technical and social challenges that will rise as urban growth continues and international movement of cargo and passengers increases [2]. To help address technical challenges, there is growing emphasis on the development and the use of new technologies such as improved surveillance and more targeted chemical spraying using unmanned aerial vehicles (UAVs) to improve efficacy and efficiency of biosecurity measures [8]. However, comparatively little attention has been paid to the potential social acceptability associated with the use of such technologies and how consideration of these social issues can be brought into the technology design process [9].

This paper presents an investigation of how principles of "participatory-design" can be used to enable discussion that underpins the connection between social considerations and technology design. The study is relevant to the protection of forest health through management of invasive disease and pests but is not limited to the forestry sector, as the findings are also useful in other biosecurity settings. Specifically, this study presents the findings of a participatory design methodology aimed at: (i) elucidating citizen and scientist perceptions of a range of different UAV applications, including biosecurity measures, along a social licence to operate (SLO) spectrum; and (ii) using these results to bring social issues into discussion with the technical design team.

We begin by providing some context to the wider research programme, and then we introduce the reader to forestry and conservation use of UAVs and the concept and the meaning of SLO. We then detail the methodology of, and results from, a participatory design approach to improve the acceptability of UAV biosecurity technologies. Results show how tactile and visual attributes of the participatory-design processes elicit a range of perceptions in a quick, accessible, and engaging way to support consideration of UAV acceptability. We discuss how the engagement process can build epistemological bridges across social and technical science disciplines in biosecurity research to generate criteria for acceptability early in the technology design process. Finally, we offer considerations for other researchers looking to investigate social implications of technological design across a range of sectors.

1.1. Our Research Programme

New Zealand prioritises biosecurity efforts [10] and has garnered international acclaim for the successful eradication of pest species, including the great white butterfly [11] and the painted apple moth [12]. Despite such successes, the use of broadcast aerial spraying over urban areas as a method for eradication (as was the case for the painted apple moth in 2006) has been met with public opposition [13]. Ensuring the continued effectiveness of spray-eradication methods while addressing issues of public acceptability has become vital for a well-functioning biosecurity system, as social acceptability can affect utilisation of technologies [10].

The research outlined in this paper sits within a wider programme, "*A toolkit for the urban battlefield*" aimed at addressing the challenges of technical success and social acceptability through the development of innovative technical and social research. The technical strands of the programme looked at improving technologies that support eradication—including both chemical application and ecological eradication methods. The ecological methods were based on habitat manipulation, understanding of population dynamics, and surveillance. The chemical applications looked at how we can deliver more efficient and targeted methods of eradication using improved spray technology coupled with UAVs to reduce pesticide usage and total areas sprayed [14,15]. Collectively, this research aimed to reduce the amount of pesticide spraying required whilst maintaining efficacy and efficiency.

The overarching aim of the accompanying social research was to develop effective tools for integrating New Zealand community perspectives into biosecurity technologies and operations. Specifically, this work included (i) the development of a planning and assessment tool for biosecurity agencies involved in managing general surveillance programmes [1], and (ii) a facilitation and engagement tool for helping to ensure that design and operation of new technologies take account of social and cultural acceptability issues. This paper covers the latter and discusses the approach and the lessons from research undertaken to explore how to include social acceptability perspectives into the design and the use of UAVs for biosecurity, including aerial sprays to eradicate pests and surveillance for early detection. A systems focus was taken on the technical design phase of UAVs for biosecurity while also allowing for wide application of that tool to help improve the acceptance of technologies and their use in the public sphere.

1.2. UAVs as a Means of Targeted Biosecurity

UAVs or drones, as they are also known/often referred to, are rapidly emerging technologies used across civilian, commercial, and military sectors. UAVs are self-propelled airborne devices that have no on-board pilot and have the potential to offer greater flexibility, accuracy, and efficiency for a wide range of practical uses [9]. Since their early inception as military applications during the Second World War [16], UAV technology has expanded to accommodate recreational, commercial, scientific, agricultural, surveillance, and other applications. Within the biosecurity sphere, the use of UAVs provides opportunities for improved and automated surveillance, monitoring, and targeted eradication of invasive pests and pathogens [2]. Already, the integration of UAV technology has shown promise across a range of conservation, biodiversity, forestry, and biosecurity sectors in New Zealand and globally. For example, UAVs have been used for a variety of applications, including forest and wildlife monitoring and surveillance [17–19], seed dispersal for forest restoration [20], possum control [21], and crop spraying [22,23].

To date, the development and the use of UAVs for biosecurity measures is still predominantly in the "early adoption" phase with most of the effort focused on testing and fine-tuning technological aspects to improve UAV efficiency, range, responsiveness, and accuracy [9,24]. However, there is a growing appreciation that some of the biggest hurdles to the use of many biosecurity technologies are social and organisational. For example, with respect to UAV design, current research highlights the need to improve public engagement [25] and address concerns particularly around privacy and surveillance [25–27]. A failure to address factors such as these can influence community perceptions of technologies, resulting in some cases in wide scale rejection of the use of the technology where they live, work, or recreate. By way of example, in New Zealand, the use of aerially-applied 1080 (Sodium Fluoroacetate) bait for the control of possums has attracted fierce public opposition. This community acceptance or rejection of operations is commonly referred to as SLO.

1.3. Social Licence to Operate

SLO is an important and sometimes overlooked consideration for the successful uptake of new technologies that overlap with the public domain and describes the process of acquiring ongoing and informed consent of affected communities and stakeholders [28]. Issues around social licence are often found in relation to extractive industries such as mining, forestry, and fisheries, but they also relate to policies and practices in a range of areas including biosecurity response operations [29,30].

SLO has been a term in use in forestry since the 1990s in Australia, US, Canada, and New Zealand, which recognises that the success of forest management depends upon adequate public acceptance of environmental and sustainable development practices. Lacey et al. [31], in Australia and New Zealand, noted that SLO must often be negotiated in the face of a range of (sometimes conflicting) social values and perspectives. As the term has moved through different sectors and operations, it has become increasingly about generating community benefits and adequately regulating the development of sectors, including agriculture, forestry, and energy [32]. Over time, the use of the term has moved from social acceptability of operations to broader acceptance of industries. Issues of trust and fairness as well as new modes of governance for more sustainable and democratic relationships between sectors and society have become increasingly important [32].

In a review of social and economic dimensions of biosecurity, Marzano, et al. [33] identified the need for better integration of social and biophysical dimensions of tree health management. In New Zealand, responses to biosecurity operations in urban settings indicated the need to include community perspectives and to more meaningfully engage with the community as stakeholders [30]. Māori engagement in biosecurity governance, as Treaty of Waitangi partners with the New Zealand Crown, has been a particular concern [34]. Not only is there a need to build understanding between decision makers and their stakeholders [30], the recognition of conflict around management of invasive species shows a greater need for engagement. Risk communication that promotes trust and confidence in biosecurity response operations is needed [35]. Understanding the plurality of values and the need to engage across a range of viewpoints to effectively address social issues in response to invasive species is requisite [36]. Accordingly, the acquisition and the maintenance of SLO can be a crucial aspect of successful technological design; a tool can be technologically perfect (e.g., achieve eradication of an invasive species) but fail if communities distrust it or oppose it. SLO is increasingly recognised by stakeholders and affected communities as a prerequisite to development [37]. Indeed, recent efforts to manage and integrate civil UAVs with society have looked to shift focus from "*citizens' acceptance of civil drone development*, towards the *development of drones that are acceptable to citizens*" [25] (p. 1391).

1.4. UAV Spraying Technology Design and Social Licence

Given that UAV technology is rapidly diversifying into previously unoccupied niches, and that the success of much of this technology is likely dependent on obtaining an SLO, surprisingly little is understood about public perception and acceptance of UAVs. Of the relatively few studies that have investigated public perception of UAVs [24,25,27], we are not aware of any that adopted or investigated the use of participatory-design techniques to go beyond just asking what potential users want. Furthermore, these questions are typically asked at the end of the technology design process, not the beginning or before they are operational.

Our own participatory design study aimed to see how we could work with a range of stakeholders in our social research to uncover their perceptions of UAV applications, including biosecurity measures, to help shape the definition of our emerging UAV technologies and operational protocols. Early efforts to uncover social perceptions through hui (focus groups) were not as successful as we hoped, because participants spent much of the time debating context and scale of addressing the problem. For example, issues around why we accept imports of goods and products (such as cars) from parts of the world that carry a high biosecurity risk took precedence over managing incursion response. In turn, this lack of clarity on what perceptions of technology implied rather than the context of their use sidelined efforts to raise discussions of social and cultural issues within technical research teams. One challenge was to integrate social thinking with the technical design aspects of our research, as interdisciplinary work, in the process of designing and developing technologies through research.

2. Materials and Methods

2.1. Participatory Design Methodology

Against this background, the concept and the pilot study described here sought to explore a methodological process that could provide a more stimulating and creative opportunity for a range of our research stakeholders to contribute to the design process of UAVs for biosecurity. Our participants included scientists working in other parts of the programme and other New Zealand citizens that were not aligned with the programme in any way. The study explored more active ways of involving these key stakeholders as design collaborators. This was in keeping with the move towards seeing user-driven innovation as the rationale for participatory design. In such participatory design, a key issue is to create ways for users to become partners, sharing their perspectives and experiences to help shape the development and the design of emerging technologies into new products or usable systems [38]. This research approach has its origins in action research, which can be characterised as a research method that has constructive change in the field being investigated as a primary aim [39]. A second common characteristic of action research is the collaborative relationship between researcher and participants and the joint undertaking of the research [40]. The present study recognised stakeholders as not just being agencies and operators that "use" these biosecurity surveillance and eradication technologies but also the communities that live in the areas in which operations are carried out.

However, as French, et al. [41] observe, the common space for collaboration in business is dominated by methods that are aligned to traditional practice, and these methods are often used in ways that are not particularly collaborative and do not encourage creative or open thinking. Similarly, while the use of traditional social science knowledge elicitation techniques such as surveys, interviews, and focus groups are commonly used in biosecurity and conservation spaces to elicit information, they are not necessarily best suited to facilitate participatory design where people discuss and explore their thinking in relation to a particular problem or challenge of technology development. Simply asking people questions is not enough. For example, it is often hard to get people to join in the design process when they feel they do not have enough experience or knowledge from which to make a meaningful contribution [42]. Similarly, recent work by Marzano et al. [33] noted that stakeholders did not really want to be involved in design until there was something tangible or built to engage with. In this regard, open and interactive participatory design techniques offer a platform for users and stakeholders to better communicate their perspectives than traditional surveys or discussions would otherwise allow [43,44]. From this perspective, we need to use of a range of methods that go beyond words to provide approaches that can unlock participants' thoughts and perspectives through the additional use of visual and other sensory prompts [41].

2.2. Interactive Research Design

In our pilot research study, therefore, we looked at how best to involve and engage a range of participants in sharing their relevant thoughts and experiences around UAVs in a space that aligned with their own experiences and values. We were looking for an approach that enabled people to contribute to the design process in a way that reflected their values and considerations around the technology in question (the wider set of cases of UAV use that included biosecurity uses) yet was easy and enticing to participate in. The underlying method involved sorting flash cards along a social licence continuum and discussing values and concerns around the new technology (UAVs) that made the exercise real for participants.

Surveys were conducted in English with 25 adults from three New Zealand urban centres: Christchurch, Nelson, and Auckland. Participants included a mix of research scientists (from a range of science and engineering disciplines including biophysical and social science) and citizens (teachers, bureaucrats, managers, and retirees). Twelve of the 25 participants were aged between 26–67, and just over half (14) were female. Within the group, five were technical researchers actively involved in design of UAV technology for biosecurity purposes. The aim of this research was to assess the use of participatory design methods that could encourage participants to engage in wider thinking around social acceptability of UAV use in urban areas for biosecurity (primarily spraying and surveillance for invasive pests of trees and shrubs) in relation to other uses of UAVs. In this way, understanding could be generated around participants' perceptions of UAVs for biosecurity relative to UAV use generally.

UAVs designed to carry out a variety of civilian, commercial, and military applications were identified and compiled into a list of 13 broad categories of current use. A comprehensive search of reputable technology-focused websites was undertaken to explore the range of current UAV applications to validate this list. In representing this range, care was taken to ensure that the description of each category was (i) broad enough to encapsulate similar or related activities, (ii) easily recognisable or understood, and (iii) suitably different from each other. A name and brief example/s (short enough to fit on a small flash card) were provided for each UAV category. While our list was near complete, given the rapid expansion of UAV technology and usages, there were no doubt some specific UAV activities that were not captured in the categories below:

- Cargo delivery (e.g., door to door delivery of online purchases)
- Military combat use (e.g., UAV carrying aircraft ordinance such as missiles)
- Military reconnaissance (e.g., scouting, intelligence gathering)
- Search and rescue (e.g., airborne lifeguards, disaster site inspection)
- Hobby and recreational use (e.g., private photography/videography)
- Surveying (e.g., topographical mapping, geophysical surveying, archaeological mapping)
- Conservation (e.g., pollution monitoring, anti-poaching, locating wildlife)
- Commercial surveillance (e.g., livestock monitoring, wildlife mapping, home and infrastructure security, road patrol)
- Law enforcement (e.g., surveillance, crowd monitoring)
- Commercial and motion picture filmmaking (including newsgathering and journalism)
- Light show [e.g., UAVs equipped with light emitting diodes (LEDs) for aerial displays as an alternative to fireworks]
- Active biosecurity (e.g., targeted spraying for urban pest control)
- Passive biosecurity (e.g., surveillance, identification of pest species)

The 13 UAV category flash cards were used as the key component of a tactile, visual, and interactive survey designed to provoke thought and discussion. Participants were also provided with a visual SLO spectrum ranging from "very unlikely to gain public acceptance" (red) through to "very likely to gain public acceptance" (green) (Figure 1). The survey comprised three main questions aimed at initiating thought and discussion around the acceptability of different UAV applications.

(a) Have a think about how likely it would be for each category of UAV use to gain public acceptance or approval. Please place each category (card) on the SLO spectrum, indicating its likelihood of gaining public acceptance or approval.
(b) Consider the categories of UAV use that you think would be least likely to gain public acceptance or approval (those nearer the red end of the arrow). Please give reasons why you think these would be less likely to gain public acceptance or approval.
(c) Consider the categories of UAV use that you think would be most likely to gain public acceptance or approval (those nearer the green end of the arrow). Please give reasons why you think that these would be more likely to gain public acceptance or approval.

The *Toolkit for the urban battlefield* programme used a peer reviewed professional development process to ensure that social research ethical matters were discussed and planned for the duration of the research programme. For this pilot study, participation was voluntary, and project background (from researchers) and consent (from participants) were provided verbally, anonymity was provided, and the results are presented as collective scores rather than individual responses. Comments captured in notes during the discussion are used to illustrate reasons for acceptability or unacceptability of UAV uses.

Figure 1. Example of unmanned aerial vehicle (UAV) use categories placed along the social licence to operate (SLO) spectrum.

Tactile surveys were conducted face to face between a single surveyor (and some also had a note taker) and individual participants. Participants were encouraged to move the cards around on the continuum as they thought about their responses. Answers provided for questions b and c by participants were recorded in text by the surveyor (or note taker). Often, the questions naturally led to further related lines of thought or discussion points initiated by the participant and shaped by the experience of thinking and placing cards in the continuum. The length of the discussion was at the discretion of the participant, with surveys ranging from 10–30 min in length. Subsequent thoughts and discussion points were also recorded by the surveyor or the note taker as text. A photograph was taken of the resulting sort for each participant.

2.3. Quantitative Analysis: Relative Scores

For each completed survey, UAV categories were assigned a relative score depending on where they were placed along the continuum. The SLO spectrum was partitioned into 13 sections, with a minimum assigned score of 1 to those placed at the far left of the spectrum (red: "very unlikely to gain public acceptance") and a maximum score of 13 to those placed at the far right of the spectrum (green: "very likely to gain public acceptance"). Any cards that directly overlapped were assigned the same score. The means and the standard deviations for each relative score were calculated in the statistical software R.

2.4. Qualitative Analysis: Negative and Positive Themes of UAV Uses

The NVivo^{TM} (version 12, 2018) software programme was used to sort and code participant responses into two parent categories (nodes) relating to (1) the negative aspects or concerns associated with UAV uses (sourced from responses to question b) and (2) the positive aspects associated with UAV uses (sourced from responses to question c). A process of constant comparison was used to classify, compare, group, and refine segments of the text to identify key themes within the data and a code frame developed [45]. Several themes were identified as clustered concerns around acceptability and unacceptability. Text was coded to themes and independently inspected by a second researcher to ensure thematic coherence.

3. Results

3.1. Quantitative Analysis: Relative Scores

UAVs associated with search and rescue, conservation, and surveying efforts were scored consistently higher on the SLO spectrum by participants relative to other UAV categories (Figure 2). By comparison, UAVs used for military activities were the least favourable among the 25 participants. Cargo delivery proved to be the most polarising of the UAV categories (standard error of 3.21), with relative scores for that category ranging from as low as 1 to a high of 12 out of a possible 13. The two UAV categories related to biosecurity scored markedly differently, with surveillance ranking as the fourth most favourable category while UAVs for targeted spraying ranked eleventh.

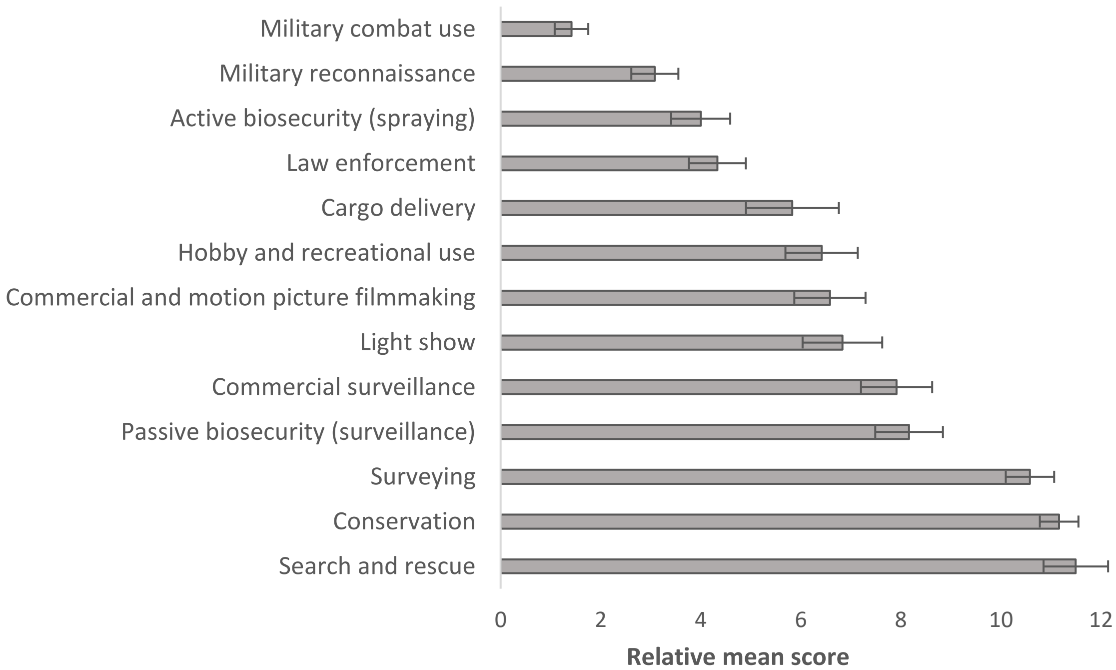

Figure 2. Relative mean score and standard error bars of how the category would be favoured by the public for each of the 13 UAV categories from 0 = least favourable to 12 = most favourable.

3.2. Qualitative Results: Negative Aspects of UAV Uses

Several reoccurring concerns regarding the use of UAVs emerged during discussions with participants and were identified as themes. The safeguarding of privacy and personal identity was of particular importance, with participants concerned over the potential for certain types of UAVs to intentionally or inadvertently spy or invade people's personal or private space (Table 1).

UAVs for military use, law enforcement, hobby use, and targeted spraying were discussed within the context of privacy invasion. Furthermore, a mere increase in the presence of UAVs, regardless of their use or capabilities, was enough for some participants to consider that the sense of privacy of the public was likely to be undermined. Parallel to potential privacy issues were concerns over the security of personal information and goods. Some participants associated the collection of public information by UAVs with the potential for population monitoring and surveillance, illegal activities involving incrimination, and fraud, effectively leading to a loss of privacy rights.

Table 1. Examples of key phrases used to describe the five most prominent themes associated with participants' perception of the negative aspects of UAVs, both for biosecurity-specific uses and for the other 12 use categories that were explored.

Theme	Description	Examples of Key Phrases Used by Participants for Biosecurity UAV Uses	Examples of Key Phrases Used by Participants for Other UAV Uses
Privacy	Concerns over the safeguarding of personal identity, space, and freedom.	*"I see privacy issues associated with spraying, hobby use and military use."*	*"Drones for law enforcement and military combat use is an invasion of privacy."* *"Big brother society. Unseen repression. International infringement on rights keeping people in check."* *"Law enforcement drones would need to be well labelled, or well-marked. Otherwise they could be used for spying."* *"Whether drones are actually watching you, it feels like they are."*
Ethics and Security	Concerns over the dehumanizing nature of military drones and the safeguarding of data or personal goods.		*"Ethical nightmare associated with some of these [UAV] uses."* *"[UAVs] for military combat use it dehumanizes the situation the victims are no longer real."* *"Making the military even less humane killing by machine."* *"Potential for unwanted data collection on people."* *"Incriminating without people's knowledge."* *"Control of population by the government."* *"Potential for fraud [associated] with cargo delivery."*
Lack of familiarity	Concerns over a lack of information, transparency, or public consent.	*"I don't know enough about spraying I have a lack of trust [for it]. Seems like too much potential for things to go wrong."*	*"Lack of transparency. The public [are] not included in military decision making."* *"Issues around who manages the application and the lack of ability for public to have a say."* *"Need to get acceptance from the public good information needs to be put forward familiarity and knowledge."*
Annoying or invasive	Concerns over increased visual and noise pollution.		*"Drones can be annoying, buzzing around your head. Should be used as little as possible as they are very invasive and noisy."* *"Don't want drones flying around at every event. [They're] noisy, invasive and take away from the natural environment. [They] detract from the experience."* *"Some of these uses are unnecessary and frivolous activities"* *"Risk of congestion and increased noise levels if usage increases, say, for door to door deliveries."*

Table 1. *Cont.*

Theme	Description	Examples of Key Phrases Used by Participants for Biosecurity UAV Uses	Examples of Key Phrases Used by Participants for Other UAV Uses
Chemical spraying	Concern about poisons in urban environments, and risks of contamination	*"I'm not a fan of spraying. Don't like the idea of drones carrying spray poison over urban spaces."* *"Active biosecurity through drone spraying has potential as a tool, but there are high associated risks especially when considering the effects that wind and weather may have on the efficacy of drone spraying."* *"Spraying, I just don't support this activity."* *"Spraying (biosecurity)–very unlikely to be accepted, due to past experience. Even water sprayed can have a psychological impact–fear. Some advanced warning on how/when it's safe to enter after spraying could help shift perception."*	

Ethical concerns were voiced by some over the dehumanising role of military combat drones, with those participants arguing that killing may become easier when carried out by remote control. Not all participants, however, saw an ethical dilemma with military UAVs but rather saw it as a necessary aspect of state defence. Seldom were strong ethical concerns extended to other categories of UAVs. This included UAVs for biosecurity; in fact, biosecurity uses were more often associated with public good, such as for conservation purposes or environmental protection. A lack of public familiarity with certain UAV activities was viewed by some participants as a significant barrier to gaining public acceptance, trust, or approval. These participants stressed the importance of consulting the public or acquiring public consent before carrying out UAV activities. Having some advanced warning about how safe or when it was safe to enter an area after being sprayed was seen as one way of helping shift perceptions or allay concerns about safety. A proportion of participants described UAV activities associated with hobby and recreation, cargo delivery, and light shows as seemingly frivolous and having a greater potential to annoy by increasing visual and noise pollution of the airways. Finally, safety concerns associated with the potential use of sprays was voiced by five of the 25 participants.

Biosecurity uses for monitoring of tree health or surveillance of biosecurity risks were seen as more acceptable than applications of sprays. However, this depended upon whether surveillance was in an open rural space or in the close confines of urban neighbourhoods. Urban surveillance ran the risk of privacy issues without some means of clearly identifying the UAV with a biosecurity operational role, perhaps in some familiar colours such as the Westpac search and rescue helicopter. Use of UAV for spray applications was less acceptable, although one noted that it could be made more acceptable if there was advice given as to when the operations were being undertaken so that people could take their own precautionary measures, such as bringing pets or children inside or closing windows.

3.3. Qualitative Results: Positive Aspects of UAV Uses

UAV activities that scored high on the SLO spectrum according to participants were typically those that benefited the wider public rather than the individual, benefited the environment, and/or improved efficiency (Table 2). Of these, improved efficiency and improved human safety were most commonly discussed. UAVs that were deemed good were those that could reduce the need for manpower, survey larger areas, access difficult locations, or focus subsequent efforts. These attributes were typically associated with, but not exclusive to, public service activities such as search and rescue, conservation, surveying, and biosecurity surveillance efforts. Familiarity of a particular UAV use was also a key determinant for the likelihood of it receiving participant approval.

Biosecurity uses that improved efficiency, such as scanning commercial assets for biosecurity risks or helping focus manpower in more efficient ways during surveillance, were seen similarly to other improved efficiencies involving better management of time for finding lost people or livestock. Benefits to the environment were also supported as acceptable uses of UAVs to minimise air pollution or prevent contamination of plants or crops. Passive biosecurity surveillance was also seen as an activity that generated wider benefit on multiple fronts of social, environmental, and economic domains or being of general benefit to society rather than the individual.

Table 2. Examples of key phrases used to describe the five most prominent themes associated with people's perception of the positive aspects of UAVs, both for biosecurity-specific uses and for the other 12 use categories that were explored.

Theme	Description	Examples of Key Phrases Used by Participants for Biosecurity UAV Uses	Examples of Key Phrases Used by Participants for Other UAV Uses
Improved efficiency	Reducing the need for manpower.	*"Better more efficient way to monitor wildlife, commercial assets or scan for biosecurity risks"* *"Help improve efficiency. Allows you to focus man-power once drones have located livestock, lost people, wildlife or biosecurity risk."*	*"Streamlines things. Easier to search with UAVs than sending out a team of people also cheaper."* *"Quicker. Likely to find people faster. Less need for manpower."* *"Improved efficiency. Allows you to focus manpower once drones have located livestock, lost people, wildlife or biosecurity risks."* *"More convenience and possibility better time management for people."*
Improved human safety	Access unsafe environments. Locate people in peril.		*"[UAVs] can be used to save lives and improve safety."* *"Can help with search and rescue. Less risk of further injuries or human lives lost."* *"Being able to safely access some gnarly locations."*
Benefits the environment	Tool to improve biosecurity and conservation efforts.	*"Biosecurity to minimize air pollution, prevent contamination of important plant species and crops"*	*"[UAVs] for biosecurity to minimise air pollution and prevent contamination of important plant species and crops. It's preservation of animal life, especially endangered species."* *"Another improved tool to help protect the environment."* *"They can get images of where pests will be and locate them and control them."* *"Drones for conservation, does environmental good with no obvious negative aspects."*

Table 2. *Cont.*

Theme	Description	Examples of Key Phrases Used by Participants for Biosecurity UAV Uses	Examples of Key Phrases Used by Participants for Other UAV Uses
Wide franchise	Activities that benefit the public, not the individual. Benefits to social, environmental, or economic domains may overlap.	*"These drones, the ones to do with conservation, search and rescue, surveying and passive biosecurity provide benefits to society. No real downsides"* *"Perceived wider benefit to society,* i.e., *not commercial, but for Search and Rescue, passive biosecurity, conservation, surveying uses"*	*"Good for both the environment and economy."* *"Can be used to save lives and improve the environment."* *"Wide public application, not just for individual benefit."* *"If you take care of the land, you take care of the people."*
High public familiarity	Transparency, public engagement, and access to information.		*"More likely to accept activities that are more likely to be transparent and involve good public awareness."* *"Certain activities are already happening now. So, there is a social awareness of UAVs for these purposes."* *"It's [important] that they're not being used in a public location, or that the public know they are being used."* *"Information about some [UAVs] is given over the media."*

4. Discussion

Lack of consideration of social and cultural issues in biosecurity technology design has been found to be a major issue [46–48]. This is true particularly in the forest sector [14,49,50]. Indeed, lack of stakeholder input has been highlighted as a significant factor adversely affecting public acceptance of biosecurity operational issues and technologies [29,30]. Evidence relevant to designing more effective innovation systems involving greater user input has shown promise for avoiding this [51]. Not only does the exchange between user and designers offer opportunities for sharing perspectives, but the engagement can lead to higher levels of interest in the problems being addressed and expand the relevance of knowledge generated. For example, the design of technologies and protocols for their operation can help develop practical actions for acceptable technology use in specific operational settings such as urban environments.

Yet, one of the constraints of engaging the public as stakeholders is that people often feel they do not have an adequate level of knowledge about a topic to be able to comment on its implications. Often, people are unaware of the knowledge they hold precisely because their opinions are seldom asked. Instead, current decision-making systems are set up to rely only on "expert knowledge" providing a "solution". However, the question around acceptability of UAV technology development and use is relevant for all citizens, not just scientists. Thus, we addressed this question to scientists and non-scientists both as citizens to elicit an understanding of public acceptability of UAV technologies for biosecurity purposes. In particular, we were able to engage some of our biophysical research team members in discussions around public acceptance of technology issues to help them develop thinking in these areas. Participatory design approaches with greater emphasis on ensuring different people can contribute help by making it feasible to bring science and non-science interpretations of risk to bear on ethical and practical aspects of the situation in question.

4.1. Design Lessons

When given the opportunity to reflect on multiple different uses of technology, we found it was not just the technology that people were concerned with but how and what it was used for. This helped us engage our technology designers and their end users with questions of design and use protocols. Some feedback related directly to the build of the technology around issues such as noise and colour. Other issues could be used for protocol design considerations, such as looking to delineate areas of use more clearly, and a third set of issues and feedback contributed to operational communication and engagement design in areas such as building awareness and notification of use in an area. We found some uses were more acceptable than others, and the reasons cited were related to public good, limiting annoyance, and where greater efficiencies result. These were all relevant for biosecurity operations. Articulating these aspects provided a new set of guides for our technology designers for developing socially acceptable UAV technologies for biosecurity. Other areas of interest for those developing UAV technologies are the levels of familiarity, information provision, and engagement of people prior to their use. Although these findings are directed at biosecurity uses for UAVs, they support the literature on technologies acceptance with the public, including the need for structures and practical approaches for technology assessments [52]. Vanclay et al. [53] note that social concerns around agricultural technologies need to become part of the thinking for governments and primary industries sectors for endorsing and regulating technology development and use. However, tools for including these considerations during technology design processes have not yet been developed.

Here, we identified several criteria that people use to judge whether a UAV may be acceptable or not using a tactile, interactive survey. Our design-centred approach using a range of UAV uses highlights the advantage of getting a wider range of responses than if we had just asked people about biosecurity. Thus, we could examine how to design biosecurity UAV use with the benefit of building on a wider range of emotional and rational responses around acceptable UAV use. Clearly, human safety is a main concern, with search and rescue leading the acceptable uses of UAVs, and privacy follows through as a second major concern. The use of UAV for biosecurity shows greater acceptance for surveillance than spraying. However operational protocols such as engaging households in the spray schedule can help people take their own precautions, potentially increasing their acceptability. One further potential level of tolerance for UAV biosecurity uses is where they create efficiencies leading to less exposure to risk or reduced costs for achieving an outcome, such as pest eradication. This would suggest that combining ecological tools such as habitat mapping with targeted UAV spraying may be more acceptable for minimising environmental risk and increasing eradication potential. In general, the criteria for what makes UAV use acceptable provides a useful guide for those developing technologies for tree health and biosecurity purposes. Improved efficiencies, human safety, benefits to the environment, and wide franchise are all potential measures for supporting the use of UAVs in biosecurity. High public familiarity such as the colours and the logo of the well-known (in New Zealand) Westpac search and rescue helicopter is another potential means for generating acceptability.

4.2. Methodological and Tool Lessons

The use of participatory tools for environmental management is not new [54]. However, enabling discussions in the process of technology innovation is a special case of participation conducted earlier in the research development process. The design of interactions and conditions to help create relaxed environments for participants to think about and share their perspectives is central to participatory design. Within these spaces, a range of tools and artefacts can be used to guide participants through the creative process, fostering engagement and collaboration with the technology being explored. The point of participatory design is that it allows stakeholders to become an active part of the creative development of a technology by interacting directly with design and research teams. It builds on the belief that all people are creative and that stakeholders (in this case New Zealand citizens), as experts of their own experiences, can bring different–and important–points of view that inform design and innovation direction. Some involved in participatory design process in non-biosecurity fields [55,56] recognise the need to initiate design discussions early in the process of technology development. We struggled as an integrated research team to open up those discussions with biophysical researchers who wanted to have validation of their research concepts before engaging others. This limitation led us towards our tactile survey for considering acceptability issues as early as possible in technology development.

Participatory design is a method that can be used in all stages of the design process but especially in ideation or conceptual phases. Partnering with users ensures their inclusion in knowledge development, idea generation, and concept development on products with the ultimate goal being how to best serve these same users. Participatory design activities make use of visual and tactile materials to help people access tacit and implicit aspects of their lives and to make and communicate associations and experiences [57]. Understanding the value of images to overcome misunderstanding and enable clearer and more comprehensive interactions has been appreciated in social and cultural research for some time [55], although it remains marginal to written word methods [58]. Images, sketches, and figures are more accessible and evocative compared to written words, and participants can attribute their own experienced meanings to them more freely.

4.3. Carrying the Conversation Forward

One of the more significant outcomes was the way in which our programme leaders and biophysical research team members embraced the participatory design tool. They picked up the tactile and the visual technique of thinking about the social acceptability of different UAV uses with flash cards and the SLO continuum (Figure 1) and used it in their own interactions with research partners and stakeholders. Having this tool as a mobile set of images and words on cards enabled conversations to take place about the acceptability of technologies that were otherwise very difficult to create. The participatory design tool was presented at workshops as an interactive display by biophysical researchers and enabled a more open setting for social and technical researchers to discuss aspects of social acceptability together with the technical performance of the scientific innovations.

Perspectives of non-scientists on UAV technologies may differ from those involved in biosecurity science research. In the first instance, citizens may have little interest in biosecurity until they are directly affected, e.g., by an incursion response. We attempted to find a means of facilitating a conversation that people (potentially) have little interest in or do not quite know how to connect with. The tactile survey was effectively a boundary object through which different meanings of the problem setting could emerge. We found that having a tactile, creative approach to thinking about social acceptability of technologies and different uses is a novel way of addressing the problem. Furthermore, the survey tool enabled our technology designers to have conversations with their stakeholders, developers, or users, which further opens discussions about technology acceptability. It also created a space to think about how technologies can be made more acceptable in operations, e.g., by addressing some of the concerns people may have through operational protocols. For example, one of our survey participants said an unacceptable use of a UAV such as chemical spraying could be made acceptable if they were advised of the times of spraying so that they could ensure any additional safety measures could be taken by residents, such as closing windows.

In this way, this approach can be seen as a cost-effective and useful way of beginning an iterative conversation between biosecurity operational managers, technology and communication designers, and stakeholders (some without much previous biosecurity experience or knowledge) that can contribute towards a human-centred design process that emphasizes social and cultural considerations as a key foundation in the process.

5. Conclusions

In this paper, we explored how social researchers can move beyond text-based interviews and surveys as means to gather perspectives of social acceptability. We added participatory design as a research method for bringing more consideration of these issues into biosecurity technology and operational research. Design thinking can help biosecurity innovation in two ways, linking social and technical considerations (1) in the use or operational aspects of technologies and (2) in the wider awareness raising dimensions of biosecurity.

However, equally importantly, we developed a tactile and visual tool and approach for thinking about engagement in future technology design. This approach is one that can be used to support other problematic conversations in design practice for articulating the conditions in which technologies are more likely to be acceptable and those which will require more effort to operationalise because of social constraints. This aspect of thinking about acceptability along a continuum is not one that had previously been discussed in the literature. We think this is a fruitful area for further development to facilitate the right kinds of protocols for implementation of technologies deemed acceptable. However, we also see that allowing a wider group of stakeholders to input into the design of technologies is a positive direction in research that can support steps towards innovation that is more sustainable, democratic, and responsive to public values. Such approaches will be more important as the challenges of responding to higher levels of risk and uncertainty with climate change and the volume and the nature of threats to forests biosecurity are demonstrated with changes in pests' geographical range and emergent diseases.

We bring three aspects together on (i) acceptability of UAV technology design and (ii) of UAV for biosecurity specifically, (iii) using participatory design methods in this paper to support the one aim of introducing acceptability issues into technical design discussion to help think about innovation in biosecurity tool development. The aspects discussed here as potential criteria for developing acceptable biosecurity UAV uses would need to be further tested with a wider set of participants. However, the development and the application of a participatory design tool for supporting questions about technology acceptability was an effective way of uncovering these perspectives against the constraints experienced as part of this research programme in integrating social and technical aspects of biosecurity innovation.

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