frontiers | Frontiers in Ecology and Evolution

TYPE Original Research
PUBLISHED 10 July 2023
DOI 10.3389/fevo.2023.1106750

OPEN ACCESS

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RECEIVED 24 November 2022
ACCEPTED 06 June 2023
PUBLISHED 10 July 2023

CITATION
Ticehurst JL and Kruger H (2023) Systems thinking for general surveillance programs – using leverage points to guide program management. *Front. Ecol. Evol.* 11:1106750. doi: 10.3389/fevo.2023.1106750

Systems thinking for general surveillance programs – using leverage points to guide program management

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With the increasing threat of pests, weeds and diseases to agriculture, the environment and our way of life, governments are becoming more reliant on general surveillance to fill biosecurity surveillance gaps. That is, engaging people from all walks of life in the monitoring and reporting of pests, weeds and diseases. It is often thought that instigating a general surveillance program simply requires the development of reporting tools and creating awareness of the program among intended target groups, but this is a simplistic view. This paper explores whether a broader approach identifies better ways to implement general surveillance programs to meet their goals and remain sustainable over the long-term, and therefore assist in program management. A systems thinking approach was used to identify the components within general surveillance programs, and their interactions. These components are the actors or people involved and their relationships; infrastructure like reporting tools and resources; formal and informal rules; and species or diseases of interest and their environment (included to account for the biophysical context). We explored what helped and hindered the design and implementation of general surveillance programs, drawing on international literature and the experiences of people in nine case studies from across Australia and New Zealand. Systems thinking helped to identify leverage points in the case studies, including feedback loops and information flow paths, and facilitated thought on how they can be used to improve programs. For example, sharing knowledge and experiences of actors from throughout the program being notifiers (i.e. the people who report pests, weeds and diseases), laboratory or herbarium staff, funding bodies, policy makers and others, built trust and ownership in the program and facilitated learning and self-organisation. This increased the capacity for innovation, adaptation, and continual improvement, leading to ongoing program benefits. Approaching program management using systems thinking helps structure program monitoring and evaluation and better target effort and resources to improve performance. However, this requires a dedicated program coordinator (or coordination team) with adequate resources to identify challenges and opportunities and adapt the program accordingly.

KEYWORDS

systems thinking, program coordinator, leverage points, feedback loops, information flow

1 Introduction

Biosecurity risks are increasing across the globe due to climate change and increased travel and trade (Brugere et al., 2017). Surveillance is an important tool to manage biosecurity risk. In this paper general surveillance, sometimes known as passive surveillance, refers to engaging people from all walks of life in the monitoring and reporting of pests, weeds and diseases. In addition to targeted surveillance (i.e. surveillance that is rigorously designed and undertaken by trained biosecurity staff), general surveillance is playing an increasingly important role around the world. For example, general surveillance of mosquitoes is used to complement active surveillance across Europe (including the Netherlands, UK, Germany, Spain, Portugal and Spain) (Kampen et al., 2015). The United Kingdom government aims to engage an 'army' of local volunteers to detect and monitor pests (Environment Audit Committee, 2019). The New Zealand government has a goal that by 2025 80% of the population will be able to easily understand what they need to do if they see a suspect pest or disease (New Zealand MPI (Ministry of Primary Industries), 2018). Most of Australia's current biosecurity strategic plans mention the role of general surveillance and community engagement in meeting their biosecurity goals (e.g. Department of Agriculture and Water Resources, 2018; Department of Agriculture, Water and the Environment, 2021).

Increasing community awareness is often a strong focus to instigate and maintain general surveillance programs but research suggests that achieving long-term effectiveness is more complex than that. Passive surveillance (reporting of fortuitous finds) has increased due to raising community awareness (Brooks and Galway, 2008; Witmer et al., 2009; Bronner et al., 2014). However, Campbell et al. (2017) found that people's awareness of exotic species in the marine environment in Tasmania did not reflect their ability to correctly identify those species. Maru et al. (2017) found that barriers to general surveillance reporting of foot and mouth disease in Australia also included not recognising the disease, not knowing the reporting requirements, a lack of motivation to report and low-trust relationships between farmers and vets. Hester and Cacho (2017) report that false positives, the inaccurate identification of a species by the people who report pests, weeds and diseases (i.e. notifiers), can hamper the cost-effectiveness of general surveillance programs due to the need for follow-up field inspections. Similarly, Munakamwe et al. (2018:193) found that targeting those most likely to "encounter, correctly identify and report the target weeds" was more effective than broad *ad hoc* notifier engagement, because less time was wasted by laboratory staff dealing with out-of-scope species. Anderson et al. (2017) posit that successful surveillance systems require considerations for community and stakeholder engagement, as well as design, resourcing and diagnostic services. Various factors may hinder reporting other than a lack of awareness, including a lack of capability (e.g. to take samples correctly), logistical difficulties, peer pressure to not report neighbours, fear of losing social reputation or facing social stigma, potential costs, loss of time, and being inconvenienced (Kruger et al., 2020). This suggests that community engagement and awareness-raising is only one part of an effective general surveillance program.

A system is a set of connected elements that operate to achieve a behaviour, function or purpose (Meadows, 2008). Systems thinking is a formal process used to structure thought to help identify and understand systems, predict their response, and adapt them to produce desired effects (Arnold and Wade, 2015). Systems thinking acknowledges that due to the interactions between system components and consequential change through time, systems are greater than the sum of their parts (Meadows, 2008). Change in one part of the system can create unintended impacts elsewhere, or in the whole system performance due to these connections.

Innovation systems are a particular type of system focused on bringing new products and processes into use, under the guide of institutions and policies (Rajalahti et al., 2008). Wieczorek and Hekkert (2012) present this as a framework with components being actors and the interactions between them, infrastructure and institutions. Here actors are the people and organisations involved in the system, and the interactions describe the cooperative relationships, links, and networks between them. Infrastructure includes the physical components, such as databases and technology; knowledge including expertise and know-how; and financial support. Institutions range from hard formal rules, laws and regulations; to informal customs, habits, norms and routines of people (North, 1991; Wieczorek and Hekkert, 2012; Nettle et al., 2013). Biosecurity research has considered the interactions between various components including resourcing and program effectiveness (Cacho and Hester, 2011); links between actors, sharing knowledge and governance (Conrad and Hilchey, 2011); and reporting tools, data integration, institutions and program effectiveness (Crall et al., 2012). More recently nuanced impacts have been explored, such as data users' confidence in data that the general public collected, and legal issues around confidentiality (e.g. Brugere et al., 2017; Anand, 2018).

Interaction between all stakeholders is a key for successful innovation to facilitate knowledge integration. Sharing knowledge between actors can help manage uncertainty in the program (Van Bueren Ellen et al., 2003), but it must be of high quality to learn how stakeholders truly operate (Nettle et al., 2013). It allows people to focus on their area of expertise, while understanding the perspectives of other people from throughout the system and how their respective ways of operating impact each other. Klerkx and Leeuwis (2008) describe it as engaging people in joint learning and negotiation. Such a collaborative approach to innovation facilitates self-organising (Klerkx et al., 2010; Biggs et al., 2015; Eelderink et al., 2020). This means that participants can problem-solve within the group to maintain function, if all actors are sufficiently empowered to participate and the group has the power to act (Klerkx and Leeuwis, 2009b; Klerkx et al., 2010).

A lack of connections between key actors can be a barrier to effective industry-led biosecurity initiatives (Kruger, 2017). Freely sharing information between actors can be hampered by their different perspectives, backgrounds and personal values (e.g. norms, values and incentives), and a lack of empathy towards others (Nooteboom, 2008). A lack of awareness of who the other actors are, and what they have to offer; or an inability to access and share new knowledge, can also hinder information flow between them (Klerkx and Leeuwis, 2009a). Truly collaborative efforts require trust to share information without retribution (Nettle et al., 2013) and trust to accept and work with uncertainty and risk as new information and processes are explored (Nooteboom, 2008), for example, with the resourcing of new processes and products (Klerkx et al., 2010).

In the innovation systems literature, guidance is required to help keep complex, uncertain and dynamic systems functioning (Klerkx and Leeuwis, 2008; Klerkx and Leeuwis, 2009a; Klerkx et al., 2010). Titles for this guidance role include innovation broker, knowledge broker (Klerkx et al., 2012), innovation intermediary (Kilelu et al., 2011), program leader (Nettle et al., 2013), and in this paper, program coordinator. The program coordinator must provide support across all stages of the design, delivery and evaluation of the project cycle (Hockings et al., 2006). This guidance role has changed through time from one of supplying information, to facilitating collaboration, and more recently to enabling co-development and partnerships between actors (Klerkx et al., 2012). From the literature, functions associated with program coordination include defining problems, aligning goals between players, helping to access capital and material resources, coordinating action, managing process, and supporting institutional change. Other roles are around stakeholder engagement like connecting networks and enhancing interactions, bridging and translating knowledge, building capacity and providing training (Klerkx and Leeuwis, 2008; Klerkx et al., 2010; Kilelu et al., 2011; Klerkx et al., 2012; Nettle et al., 2013). For example, the range of tasks carried out by the program co-ordinator in the successful co-development of innovation in the dairy industry included building understanding, forging partnerships, negotiating action, designing strategies for change, managing rising risks, identifying knowledge gaps for research and innovation, and completing integrated research (Nettle et al., 2013).

There is increasing agreeance that systems thinking is important when dealing with complexity (Nguyen and Bosch, 2013; Arnold and Wade, 2015) and it has been promoted as an approach to support natural resource management (Bosch et al., 2007). The purpose of this paper is to explore whether systems thinking is a useful way to consider general surveillance programs, particularly for program management. The research aims were to: identify the main system components within general surveillance programs and the interactions between them; identify leverage points, including feedback loops and information flow, to see if they are valuable to general surveillance programs; and consider how program coordinators could utilise systems thinking to improve program effectiveness.

This research paper is complimented by Kruger et al. (under review), which presents a more detailed analysis of what has been learnt about resourcing general surveillance programs using systems thinking. To avoid unnecessary duplication these papers cross-reference each other.

2 Materials and methods

This section describes the systems thinking framework used for this research and introduces key systems thinking concepts explored. This is followed by a description of the case study analysis.

2.1 Research framework for systems thinking

Here it is assumed that each general surveillance program is an innovation system, according to the definitions of systems (Meadows, 2008) and innovation systems (Rajalahti et al., 2008) discussed above. That is, a general surveillance program consists of a network of people (e.g. notifiers, scientists, communication staff, data managers, trade experts, policy-makers, etc.) brought together to implement new processes (i.e. the reporting, identification/ diagnosis and response of suspect finds) under the guidance of institutions and policies, such as biosecurity legislation and species priority lists, to achieve a purpose (i.e the protection of agricultural industry, the environment and the social fabric they support). We consider each general surveillance program as a single innovation, rather than grouping all programs as one type of innovation. This is because although each program may extend from a common idea or goal, innovation (ie. new methods, ideas, products, etc) is undertaken to adjust it to the local context (including social, environmental, institutional, and economic) to remain effective and fit for purpose. For example, the Weed Spotter Network Queensland and Weed Spotters Victoria both adhere to the Weed Spotters general surveillance framework presented by Morton (2007), yet they have evolved to vary in structure and process (Ticehurst et al., 2022).

The framework shown in Figure 1 was used to structure the case study analysis. The framework, based on Wieczorek and Hekkert (2012), also includes a component that accounts for how differences specific to species, diseases and their environments, influence the performance of a general surveillance program (e.g. Hester and Cacho, 2017).

2.2 Leverage points – a systems thinking concept

There are many systems thinking concepts, such as leverage points, the most limiting factor and knowledge integration which have been discussed with reference to general surveillance programs (Kruger et al., 2022). However, this paper focuses on leverage points because of their strong potential to assist in cost-effective program management. This section describes different types of leverage points, including feedback loops and information flow, drawing from Meadows (1999); Meadows (2008) and Angheloiu and Tennant (2020).

Leverage points are parts of the system where a small change in one part can result in substantial change to the whole system (Meadows, 2008). Recognising the presence and type of leverage points can help to guide intervention strategies that result in great benefit (Nguyen and Bosch, 2013). Meadows (1999) presents 12 points of intervention, ranked in order of likely effectiveness of change. Angheloiu and Tennant (2020) simplify these into four groups: parameters, feedback loops, system structure and mental models. Parameters, feedback loops, system structure and mental models are described below, highlighting some of Meadows' intervention points that exist in each group. Parameters

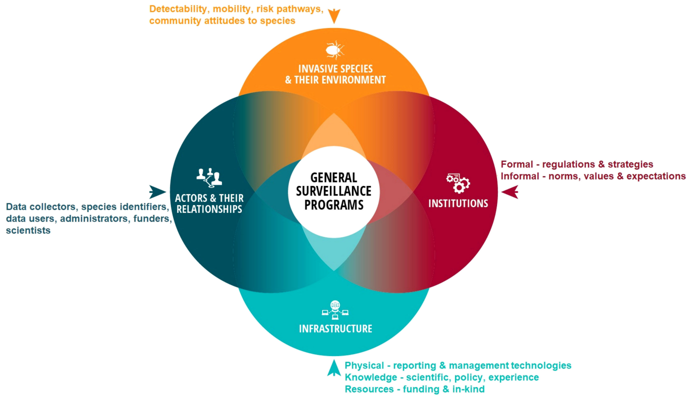

FIGURE 1
The structural components of general surveillance programs, used to structure the Nvivo analysis of participant interviews.

(interventions 10 to 12) are more tangible to measure and attract greater resource investment, but deliver small or incremental change. Changing mental models is harder to do, less tangible to measure and gets less focus from science and policy compared to other interventions (Abson et al., 2017; Fischer and Riechers, 2019; Angheloiu and Tennant, 2020). However, they have superior influence over the performance of a system compared to the other leverage points, and may lead to more transformational change. Figure 2 shows how the Meadows (1999) and Angheloiu and Tennant (2020) classifications intersect. It illustrates the range in tangibility and potential impact of the different leverage points, and the range in investment across them.

Parameters include constants, and numbers such as subsidies, taxes and standards, as well as buffers to manage flow (Angheloiu and Tennant, 2020). These are popular intervention points but often only influence a small number of people when considering the whole system. They rarely change behaviour because of their narrow focus. Examples include: the 2023 Weed Equipment Subsidy for landholders on Kangaroo Island, Australia to purchase equipment to manage target weeds (PIRSA, 2023); the Herbicide Subsidy for landholders in the Burdekin Shire in Queensland which enables them to access support to control particular pest plants with a current Property Biosecurity Plan (Burdekin Shire Council, 2021); and the Biosecurity Response Levy (*M. bovis*), which dairy farmers in New Zealand pay to fund the *Mycoplasma bovis* programme for response to incursions (Dairy, 2023).

Feedback loops are the second group of leverage points (Angheloiu and Tennant, 2020). Not all feedback loops are leverage points, because their impact may not be substantial. However, feedback loops can be targeted as a leverage point to either promote positive impact or avoid negative impact. Feedback loops are where the impact from change in one component of a system flows through the system to later impact upon the original component. Feedback loops contribute to the dynamic nature of systems. Feedbacks can be positive, creating reinforcing or diminishing effects (*Intervention 7*), or negative, having a stabilising or balancing effect (*Intervention 8*), and their effect on a system may be delayed (*Intervention 9*). Feedback loops can lead to undesirable (usually unintended) or desirable outcomes. An

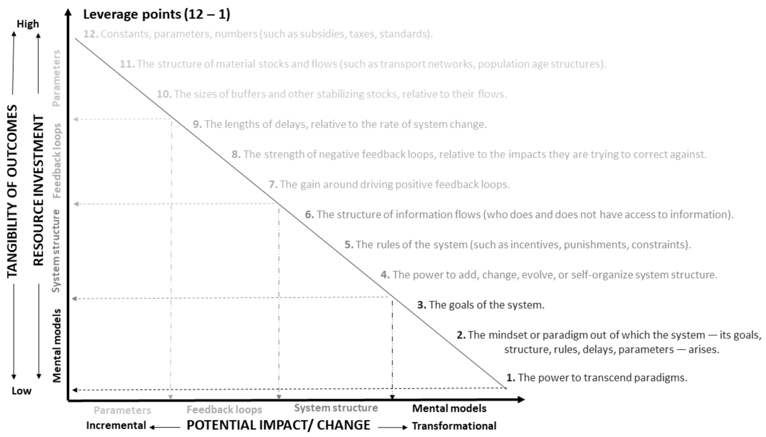

FIGURE 2
Scale of leverage points within a system. Adapted from Meadows, 1999; Abson et al., 2017; Fischer and Riechers, 2019; Angheloiu and Tennant, 2020.

example of a feedback loop is introducing a new insect as a biological control for a pest plant. Initially the insect population may surge as the pest plant provides ample food supply. As the pest plant species declines, so too will the insect population, in response to the decline in food supply.

System structure refers to interventions that capture the structure and rules of the system, and the ability to change them (*Interventions 4, 5 and 6*) (Angheloiu and Tennant, 2020). These describe leverage points that have greater influence over behaviour. For example, the structure of *information flow* (*Intervention 6*) is the process of sharing knowledge, experience and data. Information can be shared vertically between actors (i.e. top-down or bottom-up between, for example, managing and on-ground staff), or horizontally (i.e. between people fulfilling the same role and/or at the same level in different geographical locations). A simple example of sharing information is asking for and receiving comments from stakeholders on a planning document which helps shape or change the scope and content of the document to be fit for purpose. Once implemented, these documents can influence behaviour. This happens for many biosecurity policy documents in Australia, such as for the New South Wales Department of Primary Industries Statutory review of the Biosecurity Act 2015 (NSW Department of Primary Industries, 2023).

The institutions (rules) of a system can be used to influence behaviour (*Intervention 5*). Changing the rules of a system changes the boundaries of acceptable and likely behaviour. By changing the rules or structure, a system can adjust to threats and opportunities and evolve over time to continue to function. A poignant example is the recent global exposure to the SARS-CoV-2 virus (i.e. COVID-19). Governments around the world developed and enforced new rules to influence human behaviour, like placing restrictions on people leaving home, to slow the spread of the respiratory disease and allow time to adapt to the threat.

Mental models include the goals of the system and the mindset that underpins the goals, structure, rules and parameters of the system. Mental models (*Interventions 1*, *2* and *3*) essentially guide other lesser points of intervention (*Interventions 4 to 12*) and contain unstated assumptions or beliefs that have great influence over system performance. Mental models can be complex (e.g. Suit-B et al. (2020) but they can be useful, such as in informing the development of a biosecurity risk strategy for a local peri-urban area in New South Wales, Australia (Gilmore, 2009).

2.3 Case study analysis

The suitability of systems thinking for understanding and coordinating general surveillance programs was explored with a multiple case study approach. Case studies offer strong and reliable findings grounded in different sources of empirical evidence (Gustafsson, 2017) and allow for comparison between programs. The case studies provide examples of different contexts, adaptations, coordination approaches, biosecurity sectors and geographic scope, so the findings are relevant to general surveillance programs around the world. They also vary in their structuredness, which is the way a pest, weed or disease and region are targeted for surveillance, the tools and training provided for detection and reporting, and the period of surveillance (Welvaert and Caley, 2016).

There were nine case studies in total. Eight were specific general surveillance programs from Australia and New Zealand, selected in consultation with the project steering committee (representing policy-makers, researchers, industry and general surveillance programs), and the last explored Indigenous engagement for general surveillance. All programs were successful in achieving their surveillance goals and remaining fit-for-purpose. There were two case studies from each of the animal, weed, marine, and plant biosecurity sectors. The case studies are:

- Northern Australia Biosecurity Surveillance Network (NABSnet) which engages private vets for animal disease surveillance across northern Australia,
- Rural Practitioners Enhanced Disease Surveillance Program (RPEDSP) which is a similar animal disease surveillance program to NABSnet, operating in South Australia,
- Weed Spotter Network Queensland (WSNQ) which is a community-based weed surveillance program in Queensland,
- Weed Spotters Victoria (WSV) is a similar weed surveillance program,
- FishWatch allows the community to report suspect finds in the marine and fresh waters of South Australia,
- State-Wide Array Surveillance Program (SWASP) which is conducted in the marine ports of Western Australia,
- Pantry Blitz MyPestGuide® (Pantry Blitz), which uses lures to detect Kaphra beetle in pantries across Western Australia,
- Plant health component of the New Zealand General Surveillance biosecurity hotline (NZGS), where the general public reports suspect plant pests and diseases, and,
- Indigenous community engagement case study which explored how to best engage this community in general surveillance.

More detail about the case studies and the field work completed for each is presented in Table 1. Additional information is also available in Kruger et al. (under review), and Kruger et al. (2022).

Data for each case study was collected from available literature (including website material and unpublished reports) and in-depth, semi-structured interviews with actors from across the system. Actors included people in charge of data collection, analysis, use, storage and management; of species identification or disease diagnosis; and program coordinators, researchers, technology developers, and others depending on the case study involved. The focus was to learn what about the program worked well and not so well from their perspectives. Indicative interview questions are available in Supplementary Material 1. Key findings were presented to case-study based focus groups for verification and to fill gaps. People outside of the case studies, but with extensive experience in general surveillance programs or components of them, were also interviewed to fill gaps and contribute to verifying emerging themes. In five case studies an online survey was distributed to notifiers asking about motivations for participating, what about the program works well, and what are barriers to participation. Indicative survey questions are given in Supplementary Material 2. In total there were 93 interviews, 50 people attended focus groups, and 503 people responded to the notifier survey (total from Table 1). The collection, management and analysis of field data was done in accordance with the Australian Privacy Act (1988) and guided by the essential ethical principles for research involving humans (NHMRC, 2018). The general requirements for consent were adhered to as outlined in the National Statement on Ethical Conduct in Human Research (NHMRC, 2007).

Interviews were analysed using the NVivo software platform. The structure of the analysis (i.e. coding frame) was based on the four main components of the research framework, with sub-headings based upon the descriptions given in Figure 1. The text in each interview transcript was coded under the relevant headings, so the key themes that emerged from across interviews were evident. Survey responses were analysed in MS Excel and key themes were identified. This identified program components and enabled the interactions between them to be mapped. In this paper each case study was interrogated for evidence of leverage points (described above) within and between each of the structural components of the research framework (i.e. Figure 1). Research findings from interviews, focus groups and surveys were discussed with key case study representatives. For each case study flow diagrams were developed to structure thinking around the interactions between program components. The first step was to define the focus and scope of the diagram (e.g. the impact of introducing a new process to the program, how data flows once a sighting has been reported, etc). The innovation framework (Figure 1) helped identify the key components within the program that were important and within scope. The interactions between components were then represented by arrows showing the direction of influence. We also considered the program processes in-depth, how they had evolved through time to remain effective and identified the occurrence of systems thinking concepts.

3 Results

To manage the length of this paper, the results presented are the minimum required to address its research aims. More detailed and expansive information about the case studies and the research

TABLE 1 Case study backgrounds and fieldwork completed.

	FishWatch, SA	Pantry Blitz, MyPestGuide®, WA	New Zealand General Surveillance (Plant Health)	Northern Australia Biosecurity Surveillance Network	Rural Practitioner Enhanced Disease Surveillance, SA	State-Wide Array Surveillance Program, WA	Weed Spotter Network Queensland	Weed Spotters Victoria
Acronym/ Abbreviation	FishWatch	Pantry Blitz	NZGS	NABSnet	RPEDSP	SWASP	WSNQ	WSV
Overview	Anyone can report potential pest sightings or suspect fishing activities	Anyone places sticky traps in their pantries to monitor for Khapra beetle for a month	Anyone can report potential pest, weed or disease sightings via a hotline	Private vets are subsidised to undertake significant disease investigations	Private vets are subsidised to undertake significant disease investigations	Ports deploy and retrieve settlement arrays in summer and winter that capture marine organisms for identification	Interested people are trained to spot and report priorities weeds when they work or play in the outdoors	Interested people are trained to spot and report priorities weeds when they work or play in the outdoors
Structuredness	Low	High	Low	Low to Moderate	Moderate	High	Moderate to high	Moderate
Sector	Marine	Plant	Plant	Animal	Animal	Marine	Weeds	Weeds
Main purpose	Early detection	Early detection Supports trade	Early detection Supports trade	Early detection Supports trade	Early detection Supports trade	Early detection	Early detection	Early detection
Number of people consulted during field work								
Semi-structured interviews	7	8	10	9	11	10	11	10
Attendees at focus group	4	6	5	7	5	6	8	9
Survey responses	NA	338	NA	5	5	NA	72	83

NA, Not applicable; SA, South Australia; WA, Western Australia. An additional 8 interviews were conducted with indigenous engagement experts from across Australia, and 9 interviews were conducted with people outside of the case studies, but who have extensive experience in designing, implementing or monitoring general surveillance programs or important components of them.

findings, including the results of the case study notifier surveys, is available in the associated research report (Kruger et al., 2022). This section identifies the components of each case study program according to the research framework and gives examples of the interactions between the components. Case study examples of different types of leverage points are also described.

3.1 Case study components

Tables 2–4 present the case study program components according to the research framework, that is the actors (Table 2), infrastructure (Table 3), and institutions and species and their environment (Table 4). The tables highlight the diversity between programs and the high number of components in each program. Some programs had a single coordinator (RPEDSP, SWASP, & WSV) who facilitated the program across all components. In some programs coordination happened across two levels, i.e. the broader program administration (FishWatch coordinator, NABSnet administrators & the WSNQ coordinator) and people in an engagement support role (e.g. Fishcare, NABSnet advisor and WSNQ regional coordinators). Some programs had a coordination team (Pantry Blitz and NZGS). There were a varying number of actor groups in each program from four in the NZGS hotline to ten in the Pantry Blitz. Programs used several modes of notifier engagement, including program newsletters, a website, and in-person meetings, forums and training sessions. Reporting tools included hotlines (FishWatch, NZGS & WSV), apps (Pantry Blitz, WSNQ & FishWatch), emails (FishWatch, Pantry Blitz & WSV), websites (FishWatch, Pantry Blitz & WSV) and sample submission (NABSnet, SWASP, RPEDSP & WSNQ). All programs contributed to, or were underpinned by, biosecurity legislation and operated under various procedures, guidelines and processes. The number of focus species for the programs ranged from one for the Pantry Blitz (i.e. Khapra beetle) through to an undetermined number, such as for the NZGS hotline. However, the NZGS program at times used campaigns to target specific species (e.g. Brown Marmorated Stink Bug).

3.2 Interactions between components

There were many interactions identified between and within the general surveillance program components of the case studies. This section presents some examples highlighting the breadth of interaction between components and how challenges were addressed and opportunities pursued to keep the programs functioning well.

Actors & their relationships to Infrastructure (Physical). This interaction captures how people utilise the physical infrastructure, i.e. the technology and tools, they would use to make reports of suspicious pests, weeds and diseases. The physical infrastructure must be easy for people to make a report, because they are largely volunteers. For example, the quote below highlights that an app for Indigenous rangers to make reports, was designed to be familiar to previous processes, and easy to use.

> *"But once they got the app in their hands, it was an easy road from there. …, it was a very picture-based app that you can select which activity you wanted to. And you were presented a form that looked similar in terms of the data that we were capturing to what they had been used to anyway." [Indigenous case study interviewee]*

Actors & their relationships to Infrastructure and Institutions. The Pantry Blitz case study provides a good example of how the connection between people involved in the program, knowledge infrastructure, and the processes and rules used to guide the program, functioned to achieve the program goals. In this case processes were put in place, such as staff to triage incoming reports, so notifiers received prompt feedback about their submission (i.e. within 24 hours). A prompt response, which often contained interesting information about the species reported, helped to increase people's knowledge, and maintained engagement.

Actors & their relationships, Institutions and Invasive species & their environment. Interactions between the species that people were most likely to report, and the priorities for funding organisations helped define the program scope and influenced the structure of programs. For example, WSNQ had a broad scope with the program focusing on 240 restricted and prohibited weed species. To help manage reports across many species, the program coordinator engaged 22 volunteer regional coordinators as a friendly face for notifiers with regionally specific experience. People sometimes discussed suspect plants with their regional coordinators before making a formal report (i.e. the regional coordinators triage the reports). However, in WSV the focus was much narrower (only 8-12 State Prohibited Weeds), they received fewer reports, and submissions were effectively triaged directly by the state-based coordinator.

Infrastructure and Invasive species & their environment. Reporting tools and methods needed to be suited to the environment they were used in to function effectively. In several case studies people spoke of the special considerations for reporting from remote areas. In the animal case studies (NABSnet and RPEDSP) it took time to transport animal samples from remote areas to the laboratory for diagnosis. Car fridges, cold store containers and ice-packs helped samples stay in suitable condition for analysis. A laboratory staff member recounts the challenge as follows.

> *"It's just the time delay. The longer it takes for the samples to get to us, the less useful they are. Chilling is ideal, but even then, if the courier decides to slow it down, take two days instead of one day, or three days instead of two, there's no guarantee that the ice pack that's actually in with those samples is going to stay cold for that amount of time."*

Poor internet connection in remote areas challenged the use of online reporting tools for Indigenous ranger programs and the

TABLE 2 Key case study Actors.

Actors	FishWatch	Pantry Blitz	NZGS	NABSnet	RPEDSP	SWASP	WSNQ	WSV
Main notifiers	General public	Anyone	Anyone	Private vets in northern Australia (Qld, NT & WA)	Private vets	Government Port Authorities & Industry Ports	Interested people	Interested people
	Recreational & commercial fishers						Professionals with related role	Professionals with weeds background
Species/ disease Identifiers	PIRSA Biosecurity Officers	DPIRD diagnostic experts & triage staff	Plant Health and Environment Lab	Qld, NT and WA government laboratory pathologists	Mainly private laboratory (Gribbles VETLAB)	DPIRD Biosecurity Officers & eDNA Frontiers	Qld Herbarium	Agriculture Victoria specialists
	External experts if required							Herbariums if needed
Coordination	FishWatch coordinator	MyPestGuide® (MPG) Coordinator and team	Engagement team	NABSnet advisor	Disease Surveillance Manager	SWASP management	Coordinator Volunteer regional coordinators	Coordinator
	Fishcare coordinator		Incursion Investigation team	DAFF NABSnet administators				
Main data users	PIRSA Biosecurity Officers	DPIRD	New Zealand Ministry of Primary Industry	Animal Health Australia	Animal Health Australia	DPIRD Aquatic Biosecurity Team	Biosecurity Qld	Agriculture Victoria – HRIP team
	Research scientists	Australian Govt		DAFF - NAQS		Ports	Australian Virtual Herbarium	Australian Virtual Herbarium
	Australian Gov.	Community		NABS Animal Working Group	PIRSA	Australian Gov.	Atlas of Living Australia	
						Genbank & BoLD		
Other key players	Fishcare volunteers	Industry groups	Industry bodies, e.g. Kiwifruit Vine Health	Animal Health Australia	PIRSA district vets	Curtin University	Community	Regional Biosecurity Officers
	Call centre staff			Communication support consultants	Primary producers		Local gov.	
		MPG App developers		Primary producers	Animal Health Officers			
		WA Museum						
		Incident team						

DAFF, Australian Department of Agriculture, Fisheries and Forestry; DPIRD, Western Australian Department of Primary Industry and Regional Development; Gov., Government; Qld, Queensland; RHIP, High Risk Invasive Plants; NABS, Northern Australia Biosecurity Surveillance; NAQS, Northern Australia Quarantine Strategy; NT, Northern Territory; PIRSA, Primary Industries and Regions, South Australia; WA, Western Australia.

Pantry Blitz. Below an Indigenous case study interviewee recalls how their reporting app was refined.

> "*We went in the Darwin remote areas to trial the app, and even though it worked offline in some of the other areas, some of the remote areas in Darwin, it didn't work. Then we had to make some setting changes for it to work offline. And then in the end, they are collecting the data offline. They're able to send it back to us [when internet connection returns].*"

Program coordinators ensured that everyone's needs mentioned above were met.

Infrastructure, Invasive species & their environment, Actors & their relationships and Institutions. Interactions between all four research components were evident. For example, programs needed sufficient scientific rigor (i.e. scientific knowledge) to meet its surveillance goals, and to maximise the chance of detecting the target species. However, processes needed to be kept quick and simple to maintain notifiers' engagement, discussed above. A trade-off was required between scientific integrity and notifier engagement and the program coordinator played a crucial role in facilitating this. In the SWASP, staff accepted a reduction in scientific integrity to enable the ports to participate. The quotes below reflect how the best scientific sampling regime, informed by hydrodynamic modelling, was adjusted in collaboration with port staff to be more practical.

TABLE 3 Key case study infrastructure (physical, knowledge and resources).

Infrastructure	FishWatch	Pantry Blitz	NZGS	NABSnet	RPEDSP	SWASP	WSNQ	WSV
Physical - Main reporting pathways	Fishers app (Recreational & commercial)	MPG-Reporter App	Hotline	Private vets request SDI permission from NABSnet Advisor	Private vets request SDI permission from PIRSA district vet	Sample submission	Weed Spotters app	Program website
		MPG Admin portal					Specimen submission	Hotline
	Email & website	Email & website		Sample submission	Sample submission			Email address
		Specimen submission						
Physical - support equipment		Traps with lure		Producer post-mortem kits		Settlement arrays	Plant press	
		Instruction sheet		Cool storage		Cool storage		
Knowledge & engagement	Annual Biosecurity Forum	Science Week campaigns	Campaigns	Annual face-to-face Master Class	Relationships between PIRSA district vets and private vets	DPIRD annual port visits	Face-to-face workshops	Initial training (face to face or online)
		Promotion at events	Print, digital & social media advertising	NABSnet Advisor	Booklet with basic requirements	DPIRD surveillance reports to ports	Handbook	Calendar
	Fishcare volunteer Newsletter	Weekly newsletters during Blitz	Outreach activities	Monthly Newsletter	Animal Health Manual	Port WA Environmental Working Group	10 newsletters p.a.	3 newsletters p.a.
	Media releases	Community website	Website	NABSnet website			Website	Targeted recruitment
		Media		Network of stakeholders			App User Guide	
Resourcing (Funding)	PIRSA & service level agreements with departments and industries	National Science Week	NZ Ministry for Primary Industries	DAFF	SA Disease Surveillance program, PIRSA	Ongoing funding by DPIRD Biosecurity and ports	Biosecurity Queensland & Department of Environment and Science	Agriculture Victoria - State Prohibited Weeds budget
		Boosting Biosecurity Defences project		Subsidy for private vets for SDIs	Animal Health Australia			

DAFF, Australian Department of Agriculture Fisheries and Forestry; DPIRD, Department of Primary Industry and Regional Development; PIRSA, Primary Industries and Regions South Australia; SDI, Significant Disease Investigation; WA, Western Australia.

"We know that we can do so much more, but then we run the risk of disengagement from the ports, because then it would become more onerous and cumbersome for … [the ports] to actually do the work. We've all accepted that this is not the most rigorous biosecurity program, but it's a biosecurity program that we previously did not have in every port, and we can now have stakeholder engagement in every port." [SWASP management]

"[SWASP management] are very practical, sensible about where we should deploy the monitoring arrays. … [They] realise we are implementing the program within an operational port environment, and it may not always be possible to put them in the most ideal location." [Port authority interviewee]

Interactions between components were mapped by drawing diagrams involving various variables with interactions between them. Figure 3 depicts data flow through the WSNQ, from the notifier, known as a Weed Spotter, to the Herbarium for identification, and into various internal databases (HERBRECS) and external databases (WILDNET, Atlas of Living Australia, Australasian Virtual Herbarium), where it is publicly available. Biosecurity Queensland staff respond to necessary finds. Similar

TABLE 4 Key case study institutions and considerations for invasive species and their environment.

<table>
<tr><th colspan="2">Component</th><th>FishWatch</th><th>Pantry Blitz</th><th>NZGS</th><th>NABSnet</th><th>RPEDSP</th><th>SWASP</th><th>WSNQ</th><th>WSV</th></tr>
<tr><td rowspan="5">Institutions</td><td rowspan="3">Key external institutions[1]</td><td>Environment Protection Act 1993</td><td>Biosecurity and Agriculture Management Act 2007</td><td>New Zealand Biosecurity Act 1993</td><td>Northern Australia Quarantine Strategy 1989</td><td>Livestock Act 1997</td><td rowspan="3">WA Ports Authority Act (1999)</td><td>Queensland Biosecurity Act 2014</td><td rowspan="3">Catchment and Land Protection Act (1994)</td></tr>
<tr><td>Fisheries Management Act (2007)</td><td rowspan="2">Western Australia's Biosecurity Strategy 2016-2025</td><td rowspan="2">Biosecurity 2025 Direction Statement for New Zealand's biosecurity system</td><td>Northern Australia Biosecurity Framework 2016</td><td rowspan="2">Veterinary Practice Act 2003</td><td>DES QLD Strategic Plan 2019–23</td></tr>
<tr><td>New Biosecurity Act under development</td><td>Northern Australia Biosecurity Strategy 2020</td><td>Queensland Biosecurity Strategy 2018-2023</td></tr>
<tr><td rowspan="2">Key internal institutions</td><td>Specific species call flows for call centre</td><td>Instruction sheet</td><td rowspan="2">Contract and procedures that guide relationship with call centre</td><td rowspan="2">NABS significant disease investigation procedure guidelines</td><td rowspan="2">Agreements between PIRSA and private vets (every two years)</td><td>DPIRD annual letter requesting continued support for SWASP</td><td>Handbook for the Weed Spotters Network Qld</td><td rowspan="2">Best Practice Management Guide for State Prohibited Weeds</td></tr>
<tr><td>Fishcare volunteer guidelines</td><td>MPG Guidelines for responding to reports</td><td>SWASP participation framework</td><td>Terms of Use for the Weed Spotters Application</td></tr>
<tr><td rowspan="2">Species and their environment</td><td>Main scope</td><td>24 exotic, noxious, declared & established species</td><td>Khapra beetle</td><td>Weed & plant disease</td><td>Exotic & emerging livestock disease</td><td>Exotic & emerging livestock disease</td><td>Scope target species</td><td>240 restricted & prohibited species</td><td>8-12 State Prohibited Weeds</td></tr>
<tr><td>Environment</td><td></td><td></td><td></td><td>Remote environment</td><td>Remote environment</td><td>Climate, tidal and shipping variation between ports</td><td></td><td>Target notifier recruitment to fill geographical gaps</td></tr>
</table>

[1] Institutions outside of the program. DES, Department of Environment & Science; QLD, Queensland; MPG, My Pest Guide; NABS, Northern Australia Biosecurity Surveillance; PIRSA, Primary Industries and Regions South Australia; WA, Western Australia.

diagrams were developed for each case study (Supplementary Material 3). Many program coordinators used these diagrams to communicate about their programs.

3.3 Leverage points

Many leverage points were identified across the case study programs. They cover all four groups according to Angheloiu and Tennant (2020) (i.e. parameters, feedback loops, systems structures and mental models), and 7 of the 12 intervention points according to Meadows (1999) were clearly identified. They are:

- Intervention 1. The power to transcend paradigms,
- Intervention 3. The goals of the system,
- Intervention 4. The power to add, change, evolve or self-organise system structure,
- Intervention 6. The structure of information flow (who does and does not have access to information,
- Intervention 7. The gain around driving positive feedbacks),
- Intervention 10 Stocks & flows, and
- Intervention 12 Subsidies.

Case study examples are discussed below.

3.3.1 Parameters

Constants, parameters, numbers (No. 12). The RPEDSP and NABSnet programs both offer subsidies to private vets to help cover the costs of significant disease investigations. The subsidy allows the vets to provide a better service to livestock producers. By doing a more detailed investigation, private vets are more likely to get a diagnosis and offer better targeted treatment, which encourages producers to

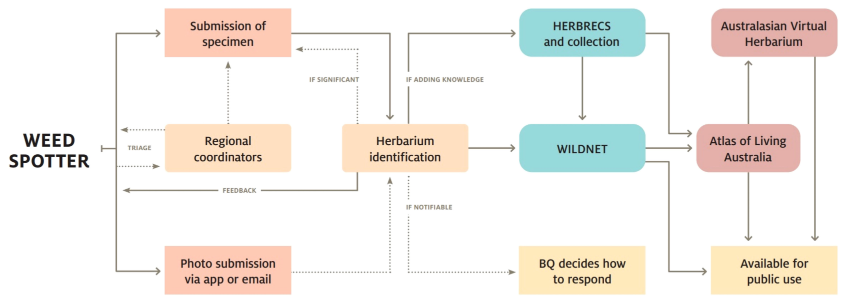

FIGURE 3
Data flow through WSNQ. BQ, Biosecurity Queensland; WILDNET, database HERBRECS, Internal BQ database; Atlas of living Australia, Database. The notifier (Weed Spotter) can contact their regional coordinator and ask advice about reporting a potential weed species (ie. triaging the report). If appropriate the Weed Spotter can either make a submission with photos via the app or email, or provide a specimen sample to the Herbarium. Samples are identified by staff at the Herbarium, who then provide feedback to the Weed Spotter about what their submission was. The herbarium staff enter data into relevant internal and external databases and collections (i.e. internal HERBRECS, WILDNET; external Atlas of Living Australia, Australasian Virtual Herbarium). The public can access the external data sets.

participate. The RPEDSP disease surveillance manager and NABSnet advisor are responsible for approving program subsidies.

The structure of material, stocks & flows (No. 10). Another parameter intervention point identified in the case studies was to buffer any influx in reports (i.e. a stock) and manage an efficient flow through to identification/diagnosis. This enabled efficient program operations and quick responses to detections. Many case studies had triage processes to manage the flow of reports to identification experts. For example, in the quotes below one interviewee pointed to advertising campaigns causing notifications to surge. Another spoke of a Facebook campaign that boosted member numbers (another stock). The respective program coordinators monitored these flows.

> *"Some of the campaigns …, as soon as we started pumping out the media, the social stuff, and if any of the news networks or papers pick it up, we get an influx of reports." [Program management]*

> [After a targeted Facebook campaign] *"… we gained 3 years' worth of membership in a month. It was used as a bit of a case study as to what Facebook can achieve." [Program management]*

The importance of triaging reports is shown in the quote below. The Pantry Blitz program coordinator appointed a dedicated triage person so that only potential detections were passed onto identification experts.

> *"The other bit that didn't work super well, the level of time we set aside to triage. Not having enough skilled individuals in a role like that and not having a committed individual in that role,… well … that changed, which is why we recommended having permanent triage staff to consistently review all our reports." [Laura Fagan, MyPestGuide®]*

3.3.2 Feedback loops

The gain around driving positive feedback loops (No. 7). An example of driving a positive feedback loop, evident in many programs, was providing notifiers with a positive participation experience to encourage their continued monitoring and reporting. A positive participation experience included an easy sign-up process to use tools like apps, minimal administrative requirements, readily accessible program information, quick and easy monitoring and reporting requirements and having positive interactions with people from throughout the program. For example, the NZGS call centre answers 95% of calls within 20 seconds. There are strict protocols to ensure the report reaches the appropriate people in NZ MPI promptly. Callers with a potentially significant detection often hear back from a NZ MPI expert within an hour after making the call. This example is shown in Figure 4. In several case study programs, laboratory or herbarium staff provide notifiers with interesting information about the species they reported, even if out-of-scope.

Another example of driving positive feedback was to provide benefits for all actors in the program, rather than only focusing on the programs' surveillance goal. This win-win approach helped to sustain engagement from actors throughout the whole program. For example, offering direct benefits to notifiers made it easier to attract and maintain their involvement. Knowing the notifiers motivations and barriers to participation informed this process. This information was sought formally via surveys and workshops, or less formally during *ad hoc* interactions. The program coordinator for the case studies usually gathered this information. For example, the research survey with Weed Spotters and Pantry Blitz participants revealed that concern for the environment was a key motivating driver for over 90% of respondents (Kruger et al., 2022). Other motivating factors included being able to deliver a better service to their clients for private veterinarians participating in RPEDSP, learning new skills for early retirees who are FishCare volunteers supporting SA FishWatch, and parents who would like their children to get involved in hands-on science activities for Pantry Blitz participants. The quote below shows that NABSnet

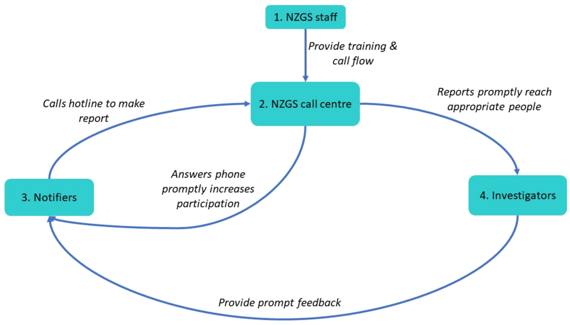

FIGURE 4
Feedback loop for NZGS caller engagement. The NZGS staff provide training, a call flow and protocols to the call centre (1 to 2). For example, the NZGS call centre answer 95% of calls within 20 seconds. Making the process easy helps to keep notifiers engaged (loop between 2 and 3). Protocols ensure the report reaches the appropriate people in NZ MPI promptly (2 to 4). Callers with a potentially significant detection often hear back from a NZ MPI expert within an hour after making the call, which again contributes to a positive participation experience (4 to 3).

private vets were motivated to participate in the program for the networking opportunities.

> "Probably the biggest driver of all, or interest from the vets, was actually connectedness. It was actually the network and the ability to get together and talk about things and to … feel[ing] … part of something. … cross-connecting was a more important driver … than the funds [from] … a subsidy" [NABSNet interviewee]

The NABSnet advisor played a proactive role in enabling this connection by keeping in touch with the private vets if they have not heard from them in a while. Keeping the private vets engaged provides a broader surveillance network than relying on government vets alone.

The Queensland Herbarium is part of the Queensland Department of Environment and Sciences. One of the reasons why Queensland Herbarium supported WSNQ was the program's contribution to achieving this department's strategic goal of maximising community engagement in science, including citizen science. This department valued being able to show how their expertise in species identification supports citizen science efforts.

Another example of a driving positive feedback loop was the SWASP, where eDNA was introduced to test for target species in the settlement array samples. This enabled port authorities' access to biodiversity information in addition to biosecurity data, which helped them meet environmental stewardship requirements set out in the WA Ports Authority ACT 1999. Also, as explained in the quote below, port staff could demonstrate the level of biodiversity that still existed in their ports, which support their social license with the community around their environmental impact.

> *"We've transitioned to the eDNA approach, … originally … [it was] pest, no pest, … don't care about anything else.… That was easier to do but somewhat limited in terms of … [the] ports. …. So the approach to the eDNA was get a diversity measure out of it. Now the ports actually love that probably more than the pest part, because it's added to [the] whole social license to operate, and to show that … [the ports] were maintaining relatively healthy environments, and they had good diversity." [SWASP interviewee]*

Due to the benefits, the ports stayed engaged, and consequently DPIRD got a state-wide marine surveillance network. Curtin University also benefited, having access to a stream of samples and data for analysis, and applied research ideas which assisted in securing funding.

3.3.3 System structures

The structure of information flow (who does and does not have access to information) (No. 6). Information flow was an important component of general surveillance programs. All case studies resourced communication throughout the program and facilitated information flow between actors, usually via the program coordinator(s). The case studies used newsletters, websites, calendars, and other printed material to provide notifiers background information about species of interest, detections, and generally to remind them about the program, keep them informed and motivate continued participation (Table 2).

However, the way information is exchanged was important. For example, many programs (WSNQ, WSV, SWASP, NABSnet, RPEDSP) trained notifiers to increase the accuracy and completeness of reports. Although some training was available online (WSV and WSNQ), several programs provided in-person training (e.g. WSNQ, WSV, NABSnet, RPEDSP). Direct interaction facilitated less formal exchange of experiences rather than a one-way dissemination of information from the coordinator. In the quote below, the SWASP management reflected on the importance of face-to-face interactions with port staff to support their involvement. Site visits allowed for two-way interaction between the SWASP and port staff, which improved scientific consistency in the samples the ports were taking, and enabled the SWASP staff to hear the port staff's perspectives.

> *"So one of … [the] team would go out, walk on the shoreline and point things out to the [port] staff. It's getting them actively engaged and knowing what to look for. Resourcing cuts essentially meant that we couldn't travel as much, so we collaborated with the ports so they started retrieving the arrays and sending them back for us…*

> *So they'd get a report back, we would chat to them over the phone, explain everything, but there was very little face-to-face. We're now getting back to the face-to-face because it's … of fundamental importance…. it's been a positive, so we're getting a lot more engagement from the ports." [SWASP staff]*

Some programs shared information through organised meetings, like the NABSnet master classes and FishWatch forums. Others utilised existing meetings like discussing the SWASP at Western Australia port authority environmental working group meetings. These gatherings facilitated sharing knowledge and information, and brainstorming new ideas and solutions to challenges between people from across the program.

Sometimes knowledge dissemination failed and regulations were unknowingly broken. WSV experienced this with Culturally and Linguistically Diverse (CALD) communities who had come to Australia from countries with different legislation for specific plant species, as shown below.

> *"We are failing in our community engagement and that's why people are trading in these species. People are unaware that it is illegal. All the people we interview say it is an innocent mistake, they don't know where to find information." [WSV staff]*

The power to add, change, evolve or self-organise system structure (No. 4). In the NABSnet time-poor private vets struggled to complete background reports that provided sufficient information to laboratory staff to inform their tests and diagnosis. The challenge resulted from the many hours that private vets spent driving between jobs in remote locations. As the annual Master Classes enabled laboratory staff and private vets to connect informally, they discussed the problem, and found a solution that suited both. They also had the power to implement a suitable change. The solution was that private vets took and submitted the samples accompanied by a brief background description. Laboratory staff then phoned the private vets to discuss the case while the vets were driving the long distances, allowing the private vets to provide the detailed description that the laboratory technician required at a convenient time.

In cases where there was a real or even perceived power imbalance, negative and unintended consequences can occur. For example, one case study previously identified issues with the illegal possession and trade of a prohibited species in Culturally and Linguistically Diverse (CALD) communities. This was somewhat attributed to their different cultural backgrounds. Program staff reported (below) an anecdotal fear of reporting this prohibited species to the government authority by the CALD communities. Staff ran a targeted awareness campaign for the CALD community, in multiple languages, to improve the knowledge about what to do if they found the species, because of the risk of incursion if people panicked and tried to dispose of it themselves.

> *"We did facts sheets in different languages … and we found that there were definitely people who had it, and hadn't reported it, but they didn't report it because they were nervous of authority figures. They would prefer to dispose of it themselves." [Government staff member]*

3.3.4 Mental models

The goals of the system (No. 3). For case studies where the program contributed to securing market access, or addressed legislative requirements, aligning the goals with the strategic direction of the lead organization added legitimacy and assisted in securing ongoing funding. The program coordinator played a fundamental role in ensuring that this happened. For example, the Queensland Biosecurity Act 2014 lists the prohibited and restricted invasive plant species for the state, emphasizes that biosecurity is a shared responsibility, and clarifies reporting, record keeping and data sharing requirements for notifiable weeds. WSNQ was aligned with the Act by targeting the prohibited and restricted plants that are listed. The WSNQ reporting avenues enabled the community to contribute their part of the shared responsibility in biosecurity and provided an engaged network of people who benefited from receiving WSNQ information and data.

In Victoria it was the responsibility of Agriculture Victoria Biosecurity Officers to implement a response if there was a new or emerging weed incursion. Below, WSV noted the benefit in aligning the scale of recruitment and training of new weed spotters to that of the scale of response.

> *"With [an Agriculture Victoria staff member] training across the whole state we can notice where there are gaps and contact the target audiences and deliberately see if we can get them on-board. That seems to work a lot better at getting a more over-arching approach across the state, which works because the weeds are managed state-wide too." [WSV staff]*

In FishWatch, the marine pest were reported via the infrastructure primarily designed and implemented for compliance of commercial and recreational fishers. The quote below explains how aligning the biosecurity program so it can 'piggy-back' upon the existing and successful compliance program, has helped to secure its resourcing.

> *"I think it [the program] will get funded because … it's a compliance tool mainly for fisheries and aquaculture. … it's … important for the fisheries compliance aspect of it and … there is a benefit as a surveillance tool for Biosecurity SA." [FishWatch*

> *interviewee]*

The power to transcend paradigms (No. 1). The SWASP case study transcended paradigms. In 2010 the Australian Government implemented a detailed and involved surveillance program in 18 ports around Australia, the National System for the Prevention and Management of Marine Pest Incursions (McDonald et al., 2020). Although it provided extensive sampling and analysis of invasive marine species, it was very expensive (in excess of AU$350,000 per port), labour intensive and was only done every 2 years, thus undermining its effectiveness. It was the mindset of the SWASP manager that enabled a shift in the marine surveillance paradigm. As mentioned, the SWASP did not have the most scientifically rigorous sampling regime, but the manager was prepared to trade-off that component to keep the costs lower and enable more ports to participate. Perhaps of greater significance was the different approach to surveillance that facilitated the current SWASP. That is, the change in approach from one of enforcement, to one of collaboration and codesign which benefited the overall effectiveness of the program. DPIRD staff had relinquished their position of power, 'taken the regulatory hat off', and become members of a collaborative management team with the ports.

> *"… the ports are essentially stakeholders, clients. But it's those face-to-face meetings initially and breaking down the barriers between the regulator and the clients…, and letting them know we want to work together." [SWASP staff]*

4 Discussion

The research framework, based on innovation systems thinking, supports structured analysis around different components of a general surveillance program and the interactions between them. The complexity of general surveillance programs is evident by the number and types of components (Tables 2–4) and the number and types of interactions between them (Section 3.2). Program coordinators reported that the flow diagrams we developed (e.g Figure 3) were useful to represent the components and interactions of a program and communicate these complex systems to others. Literature also reports that developing these types of diagrams in a stakeholder workshop helps facilitate discussion and a shared understanding (Chen and Pollino, 2012).

Section 3.3 presents many examples where leverage points were evident in the case studies. Some interventions produced incremental change, such as subsidies offered to private vets for disease investigation. Vets reported that although the subsidies supported their investigation, it was not key to driving their motivation to participate because the subsidy often did not completely cover the cost. Instead, other benefits such as the connection with others was a stronger motivation to participate in the program. Therefore investing in the driving motivations by providing opportunities for vets to connects with others, such as in the NABSnet Master Classes, will provide greater impact on program performance and more likely to achieve long-term engagement from the vets, as explained in Section 3.3.2.

Other interventions produced more transformational change, such as the structure of information flow. The key influence here is not just the sharing of information, but the mechanisms for sharing. The benefits that come from face-to-face sharing of information and experience include building relationships, trust and ownership of the program as evident in the SWASP. With information integration comes self-organisation, such as between private vets and laboratory staff in NABSnet. Innovation is also enabled, such as the introduction of eDNA identification in the SWASP. This leads to program improvement, and in time, programs that are fit for purpose for all actors involved. This finding agrees with Nettle et al. (2013) that truly collaborative efforts require trust, Ernst et al. (2018) that information flow enables different options to be explored, and Van Bueren Ellen et al. (2003) that interactions between stakeholders help to manage uncertainty (i.e. collaboration, innovation and adaptation). The quote below demonstrates how the trusted relationships between the SWASP and port staff made port staff willing to accept the risks of participating in the new program, and enabled them to adapt and improve the program together. However, achieving this level of transformational change required a balanced power distribution between collaborating actors and the overall power to act.

> *"I think you can't say enough about, … work with those who want to work with you to start with. Don't give yourselves early roadblocks … get it up and working, because that allows you to iron out the creases with people that you trust, with that mutual trust… … because when things go wrong, instead of having people going, I just spent … [money] on that, that's your fault, you've got people going, hey, … we knew that we were in for a bit of a rocky road to start with." [Port authority interviewee]*

Monitoring and evaluation identifies barriers and opportunities to adapt the program and increase its effectiveness. It presents an important process throughout the project cycle which helps to inform about the current context of the program, set desired goals, identify required inputs and suitable processes for implementation, and determining the outputs and outcomes achieved (Hockings et al., 2006). In response to monitoring and evaluation each case study program evolved over time, summarised in the timelines given in the case study infographics (Kruger et al., 2022). Mechanisms that identified potential points for interventions included notifier surveys, stakeholder meetings, formal program reviews and program team reflections. Adaptations to improve program management included changes in constants (i.e. No. 12) such as WSV reducing resource waste by only providing notifiers who requested a calendar with one. Other examples drove positive feedback loops that supported notifiers' engagement. These included developing the reporting app for WSNQ to reduce the time and effort for notifiers and herbarium staff. The introduction of eDNA identification for the SWASP array samples increased the efficiency in identification and provided more useful data for the ports. The Pantry Blitz team broadened the lure on the traps to more common species other than Khapra beetle, as notifiers were more engaged when they trapped something rather than nothing. NABSnet administrators stopped requiring private vets to sign an annual Memorandum of Understanding (MOU) which lessened the load on both private vets and program administrators without impacting surveillance outcomes. With these adaptations notifiers remained engaged, and the programs stayed relevant, effective and efficient, making them more sustainable. The innovation systems framework provides guidance on which components and interactions to look for in a program and which adaptations are more likely to provide great benefit (i.e. transformational leverage points). Mapping feedback loops allows the immediate and future impacts of actual and potential changes to be considered, which can help to target resources to improve program effectiveness in the long-term. For example, Figure 5 shows the impact of implementing their strategic plan on WSV. Detailed in the figure footnote, the plan provides focus which frees up the capacity of the program coordinator, enables WSV to better service weed spotters, and helps the program achieve its surveillance goals.

Program coordinators played an extensive role in the implementation of the case study programs. They completed simple tasks like approving subsidies (i.e. RPEDSP and NABSnet) and triaging reports (e.g. WSV and WSNQ). They gathered feedback from notifiers to improve the program, such as to redesign the settlement arrays in the SWASP. More complex coordination activity included managing stakeholder engagement and the flow of reports so laboratory staff were not overwhelmed, and making sure the program met everyone's needs, such as trading-off scientific integrity to enable notifier participation (SWASP). More nuanced activities included ensuring face-to-face contact with others in the program to build connections. This far exceeds the role of awareness raising and presents a similarly complex list of functions as presented by others in the innovation literature (Klerkx and Leeuwis, 2008; Klerkx et al., 2010; Kilelu et al., 2011; Klerkx et al., 2012; Nettle et al., 2013).

However, the coordination role needs to be sufficiently resourced (Kruger et al. under review). Many program coordinators' activities are intangible, thus difficult to measure and demonstrate, complicating securing funds for their work (Klerkx et al., 2012) despite calls for discrete investment in innovation capacity (Nettle et al., 2013). This research agrees with Angheloiu and Tennant (2020) that tangible adaptations, like administering subsidies (Figure 2 No. 12), are much easier to measure and to justify to funders and policy makers, compared to transcending paradigms, such as changing mindsets. The quote below shows the challenge over the last 30 years in getting people to appreciate the value of early detection.

> "Early detection is hard to sell when it's competing against other forms of management. If you are preventing things coming in it's hard to see, and therefore it's hard to sell. It's also hard … to prove what you have kept out. … I've been nagging people for 30 years and I can definitely see the message is slowly getting through. Prevention is a good idea. We're not going to spend all resources on prevention but it is going up from 10 to 20 years ago when it was only about 1%." [Case study interviewee]

Problems with resourcing program coordination can impede program performance. For example, the Tasmanian Weed Alert Network was first established in 1996 to enable the general public

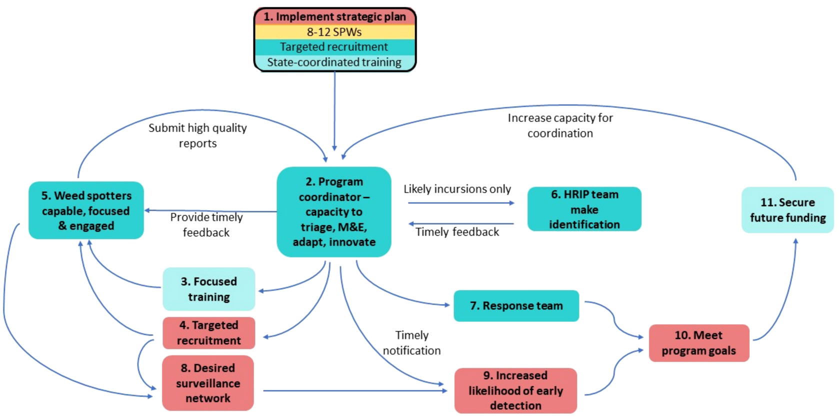

FIGURE 5
Two connected feedback loops following the implementation of the strategic plan into the WSV program and the impact on the program coordinator. WSV developed and implemented a new strategic plan (1) which reduced the target species to between 8 to 12 State Prohibited Weeds (SPWs). It also meant that recruitment of notifiers was targeted to fill gaps in the surveillance network, and training was coordinated at a state level so it was consistent across the state. This meant that the program coordinator could focus their training material on the target species (3) and recruitment on targeted notifiers (4), which means that the notifiers/Weed Spotters were trained focused and engaged and able to submit high quality reports (5). With only high quality reports the program coordinator could provide timely feedback to the Weed Spotters contributing to their continued participation. As the program coordinator is only receiving high quality reports they have time to triage any submissions and only send likely incursion to the High Risk Invasive Plant team (HRIP) for identification (6). With fewer out-of-scope reports the HRIP can also provide timely feedback to the coordinator who can pass on a timely notification to the biosecurity response team if necessary (7). Engaged and informed Weed Spotters (5) who have been recruited to fill surveillance gaps (i.e. 4. targeted recruitment) give WSV their desired surveillance network (8) and increase the likelihood of the early detection of the targets SPWs (9). An increased likelihood of detection (9) and a timely response (7) means the program is more likely to meet its goals (10), and therefore secure future funding (11). Funding will support the program coordinator to continue fulfilling their varied role.

to report suspect weeds (Morton, 2007). Initially Tasmanian government weed officers engaged potential notifiers in the network to report new and emerging weeds. Additional funding for a dedicated 'weed education position' was provided to train notifiers, publish a newsletter three times a year, and develop a reporting tool (Hanson, 2003 in Morton, 2007). When the funding ended, some staff within the Tasmanian government undertook the weed education role only as part of their role, suggesting a lack of ownership. This "reduced the effectiveness of the role", until the network ceased altogether in 2003 (Morton, 2007:15). The network was re-established in 2009 and funded for another two years. From 2011 funding was reduced again to support the weed education position for only half a day a week (Gouldthorpe, 2011). Despite many important detections over time the program was discontinued.

5 Conclusions

General surveillance programs are complex systems with many interacting components. In this research, systems thinking was used to explore general surveillance programs using a literature review and nine case studies from across Australia and New Zealand. The case study programs are diverse in structure across four main components and their interactions (i.e. actors and their relationships; infrastructure, including physical tools, knowledge and resources; formal and informal institutions; and invasive species and their environment) (Figure 1). However, there are many common findings informing the aims of this paper.

Using systems thinking helped to understand general surveillance programs from a broader perspective, and demonstrates that a sustainable program requires more than raising awareness of a target species and ways to report it. Flow diagrams are a useful approach to consider the general surveillance process itself, and changes through time. For example, weaknesses in one part of the system, such as a poor reporting experience for notifiers, can undermine program performance, by deterring people from reporting again. The case studies contain many examples of systems thinking concepts such as leverage points, including feedback loops and the structure of information flow. Developing timelines guides reflection on past innovations, adaptations and program evolution.

Program coordinators play a crucial role in enabling general surveillance programs to adapt to remain effective and relevant. Program adaptation is underpinned by program coordinators' facilitation of the flow and sharing of information in-person between actors, which builds trust. The resultant connections and networks promote self-regulation, innovation and improves program effectiveness, allowing for more transformational change.

Program coordinators need to be adequately resourced with the power to act. This means having enough time and funding to carry out the necessary engagement with actors from across the program, monitoring and evaluation, reflection on program performance and program adaptation including negotiations with funding and policy bodies. This can be difficult to substantiate to funders due to the many intangible outcomes. To help demonstrate worth, program coordinators could consciously monitor these less tangible outcomes, based upon the innovation framework presented here (Figure 1). For example, they could undertake surveys and evaluations with people on how they have used knowledge and information following a workshop to change their practices, including anecdotal evidence of the impact of sharing information and creating larger networks.

Data availability statement

The datasets presented in this article are not readily available because the data collected is confidential and not available for distribution. Requests to access the datasets should be directed to jen.ticehurst@aff.gov.au.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. However, the participants provided their written informed consent to participate in this study.

Author contributions

The underlying research forming the basis of this paper was completed jointly by HK and JT, with a small contribution from Alex van der Meer Simo, HK was the lead researcher. JT led the drafting and refinement of this research paper and HK provided critical feedback, revision and input several times throughout that process. All authors contributed to the article and approved the submitted version.

Funding

This research was funded by the Australian Department of Agriculture, Water and Environment now the Australian Department of Agriculture, Fisheries and Forestry, through the Australian Bureau of Agricultural and Resource Economic and Sciences (ABARES). We acknowledge financial support from the Centre of Excellence in Biosecurity Risk Analysis (CEBRA), University of Melbourne, in publishing this work.

Acknowledgments

The authors thank all case study programs for their involvement in this research, as well as all participants in the interviews, focus groups and surveys for their time and input. We are grateful to the ABARES Biosecurity and Social Sciences program team for all their input, support and encouragement for this project.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1106750/full#supplementary-material

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