frontiers | Frontiers in Ecology and Evolution

TYPE Original Research
PUBLISHED 09 August 2023
DOI 10.3389/fevo.2023.1106751

OPEN ACCESS

EDITED BY
Rebecca Epanchin-Niell,
University of Maryland, College Park,
United States

REVIEWED BY
Frank H. Koch,
United States Department of Agriculture
(USDA), United States
Denys Yemshanov,
Natural Resources Canada, Canada

*CORRESPONDENCE
Heleen Kruger
heleen.kruger@aff.gov.au

RECEIVED 24 November 2022
ACCEPTED 13 July 2023
PUBLISHED 09 August 2023

CITATION
Kruger H, Ticehurst JL and Hester SM (2023) Systems thinking for general surveillance programs – practical insights and limiting factors to guide resourcing decisions.
Front. Ecol. Evol. 11:1106751.
doi: 10.3389/fevo.2023.1106751

Systems thinking for general surveillance programs – practical insights and limiting factors to guide resourcing decisions

Heleen Kruger[1]*, Jenifer L. Ticehurst[1] and Susan M. Hester[2,3]

[1]Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), Department of Agriculture, Fisheries and Forestry, Canberra, ACT, Australia, [2]Centre of Excellence for Biosecurity Risk Analysis, The University of Melbourne, Parkville, VIC, Australia, [3]University of New England Business School, University of New England, Armidale, NSW, Australia

General surveillance programs promise cost-effective ways to contribute to various biosecurity outcomes, including early detection, understanding the spread of invasive species, and evidence of pest and disease freedom to support trade. These programs encourage people from all walks of life to monitor, detect, and report biosecurity threats. Because general surveillance programs make use of the general public and other people already operating in environments where pests may be present, it is often assumed that programs can occur at very low or even no cost. This article discusses lessons learnt about resourcing general surveillance programs from nine in-depth case studies in Australia and New Zealand across a range of biosecurity sectors. Lessons learnt are derived from qualitative analysis using systems thinking, in particular via the concept of limiting factors. It shows that funding is required for program establishment and coordination, adaptive management, and a range of other activities, and there are various sources of transaction cost. It outlines the strategies used to attract and maintain funding and in-kind contributions over time, including how programs navigated various funding challenges. It highlights the importance of using efficient tools and processes for reporting, species identification/disease diagnosis, and data management. The article provides insights that should prove useful for improving return on investment for general surveillance programs.

KEYWORDS

citizen science, biosecurity, community engagement, transaction cost, resource allocation, limiting factors, systems thinking, general surveillance

1 Introduction

Surveillance is a pivotal component of a robust biosecurity system, supporting detection and response activities related to biosecurity threats. Surveillance provides information about the presence (or absence) and distribution of pests, weeds and diseases, and delivers evidence of freedom from certain pests and diseases to support

trade. The effectiveness of surveillance systems in delivering timely detections has a direct impact on the feasibility, cost, and probability of achieving eradication (Carnegie and Nahrung, 2019). Resource allocation for surveillance activities requires careful consideration given finite budgets, competing priorities and the desire to achieve the greatest return on investment. Optimal resource allocation for surveillance and other biosecurity activities is often plagued with uncertainty (Barnes et al., 2019; Kompas et al., 2019).

Traditional forms of surveillance—namely active surveillance that typically involves a rigorously designed sampling strategy and trained biosecurity agency staff to carry out search activities—are expensive. With expanding trade volumes and passenger numbers, climate change and other pressures on the biosecurity system, applying active surveillance for all biosecurity threats in all locations is impossible (Caley et al., 2020). Hence, many biosecurity agencies are turning to general surveillance, including by involving the community and industry, to boost capacity to monitor and detect invasive species threats to overcome the high cost associated with active surveillance (e.g. Gardiner et al., 2012; Lawson et al., 2015; Anderson et al., 2017). Indeed, there are many recorded instances of first detections of invasive species being made by members of the public, industry and scientific community (Wilson et al., 2004; Carnegie and Nahrung, 2019; Carvajal-Yepes et al., 2019; Epanchin-Niell et al., 2021).

General surveillance programs for the purpose of this article are defined as those which engage people from all walks of life in the monitoring and reporting of pests, weeds and diseases. Such people include: professionals such as agronomists and veterinarians; businesses; members of food and fibre supply chains; not-for-profit organisations; recreational, environmental or community groups; and the general public. Note that general surveillance is defined somewhat differently in the plant and animal biosecurity sectors. In animal biosecurity general surveillance sometimes refers to generalised, broader surveillance, in contrast to targeted pathogen-specific surveillance. For example, Hoinville (2013, p8) defines general surveillance as "surveillance that is not focused on specific hazards and uses general tests (e.g. clinical examination or gross pathology)". In plant biosecurity, general surveillance encompasses "…a process whereby information on pests of concern in an area is gathered from various sources" (FAO, 2018), including data mining and analysis of data collected for other purposes (Anderson et al., 2017).

General surveillance has already made considerable contributions to early detections. For example, general surveillance delivered 71% of exotic forest pest detections in Australia since 1996 (Carnegie and Nahrung, 2019). However, general surveillance programs have been reported as challenging to develop and maintain (Oidtmann et al., 2011; Crall et al., 2012).

There are increasing calls for biosecurity to be underpinned by partnership approaches involving various biosecurity stakeholders (Enticott and Franklin, 2009; Donaldson, 2013; OIE, 2019). Indeed, countries such as Australia and New Zealand view biosecurity as a shared responsibility between government, industry and the community (NZ Ministry of Primary Industries, 2016; Craik et al., 2017). In these countries, most high-level biosecurity strategies across sectors (animal, environment, marine, plant and weeds) now include calls for general surveillance programs (e.g. NZ Ministry of Primary Industries, 2016; Invasive Plants and Animals Committee, 2017a; Invasive Plants and Animals Committee, 2017b; Marine Pest Sectoral Committee, 2019; PHA, 2021). This is consistent with standards set by international bodies such as the International Plant Protection Convention, who view general surveillance as an integral part of countries' national surveillance systems (FAO, 2018).

While hugely diverse, most general surveillance programs cover the functions of program administration, community engagement, monitoring, reporting, species identification or disease diagnosis, data management and analysis, and data use. Most programs focus on a defined set of species/diseases within a defined region (Figure 1). Programs vary from being very unstructured to highly structured, based on how well defined the program attributes are, including for data collectors, species of concern, timing of surveillance, geographic scope and the way surveillance is being carried out and findings reported (Kruger et al., 2020). Program reports might arise from unstructured *ad hoc* fortuitous detections (Hester and Cacho, 2017) or from relatively structured activities in programs that are designed to be fit for purpose by engaging skilled

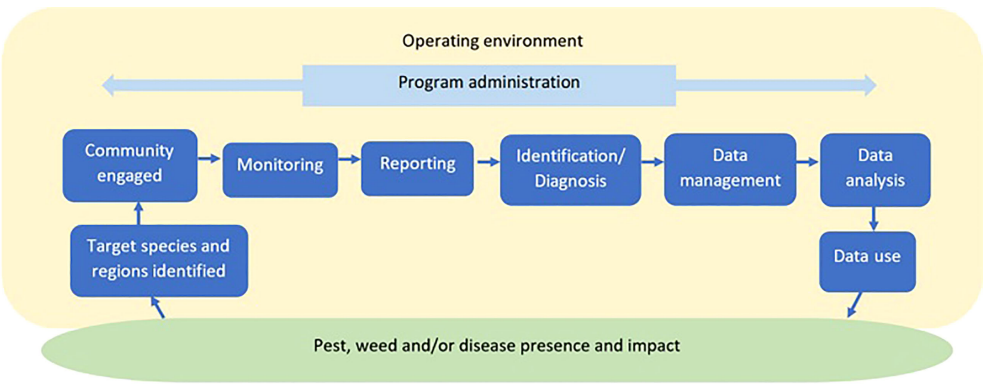

FIGURE 1
Functions of general surveillance programs.

people (Hester and Cacho, 2017; Kruger et al., 2020) who are ideally located, and/or motivated (Kruger et al., 2020).

Individuals who collect data and lodge reports—*notifiers*—are typically members of the general public, citizen scientists, or interested parties, often providing their support to general surveillance programs in a voluntary capacity (Sinden et al., 2004; Thomas et al., 2017). Perhaps because of this there is a pervasive expectation that these programs can exist with limited public investment (Conrad and Hilchey, 2011), based on information provision, the delivery of reporting tools (Poland and Rassati, 2018) and training; sometimes in the hope that they would become self-sustaining (e.g. PHA, 2021).

However, some cost-benefit analyses of existing programs have been done and suggest that successful programs involved significant investment. The public engagement activities of the Red Imported Fire Ant Eradication Program in Queensland included an intense public awareness program with various activities, including tailored approaches to multiple community groups and zones and working through networks and partnerships. Despite the cost of the activities to the Queensland government of around AUS$860,000 between 2006 and 2010, every AUS$1m invested in public engagement activities delivered an estimated AUS$60m saved in active surveillance costs, delivering significant benefits to society (Cacho et al., 2012). Program design and the awareness campaigns and associated engagement activities that activate and maintain general surveillance require careful consideration because they impact the cost-effectiveness of initiatives (Aceves-Bueno et al., 2015)

Achieving cost-effective surveillance has been the focus of academic research, including for general surveillance. Yet, evidence-based guidance for biosecurity agencies on cost-effective ways to achieve monitoring and reporting from the community remains scant (Hester and Cacho, 2017). Some of the literature focuses on modelling, such as spatially explicit simulation models to inform minimum expenditure required to contain an invasion (Cacho et al., 2010). Epanchin-Niell et al. (2012) developed a modeling framework that accounts for various features involved in the decision and invasion environment, to optimise surveillance systems under budgetary constraints. Rich et al. (2013) developed a conceptual framework for the allocation and composition of surveillance resources. They combined the socio-economic drivers, such as farmer behaviour, of risk and disease response with the spatial and biological aspects of disease. Others focus on technical aspects, such as the trade-off between using newer diagnostic tests that are more accurate but more expensive to deploy than visual inspections (Mastin et al., 2019). Others compare the cost of a general surveillance program with the cost of a surveillance program undertaken by professionals. For example, Sousa et al. (2020) explored citizen-science mosquito surveillance using smart phone technology versus similar programs involving professionals. Some explore the influence of in-field practicalities, such as daily logistical constraints (Koch et al., 2020) or the spatial arrangement of sample points to increase cost-efficiency (Berec et al., 2015).

This article explores how nine general surveillance programs across a range of biosecurity sectors achieve and maintain resourcing, including practical lessons learnt from program participants' experience. The investigation is mainly qualitative, and is undertaken to capture detail that is not found elsewhere in the literature. It draws on systems thinking, in particular the concept of limiting factors, to identify how the cost-effectiveness and sustainability of general surveillance programs can be maintained and improved, based on understanding how the supporting system should be configured to enable these programs. This article complements Ticehurst and Kruger (2023) which explores the implications of systems thinking for program management based on the same set of surveillance programs.

This article is also a source of information to support calculations of the cost-effectiveness of programs. It provides an understanding of the type of investment required to make general surveillance programs work sustainably and sheds light on the transaction costs involved in establishing and maintaining general surveillance programs as observed from case study programs; areas of resourcing that could be easily overlooked. Conversely, we identify broader benefits that these programs deliver, benefits that may not always be included in traditional benefit cost analyses (McCann et al., 2005) and other valuation approaches (Stoeckl et al., 2018).

2 Materials and methods

Six overarching questions motivated the analysis about general surveillance program resourcing:

- How are current programs resourced?
- Which activities, processes and equipment require resourcing?
- How do current programs improve cost-effectiveness?
- How do programs deal with resourcing pressures?
- What are key sources of transaction cost?
- What are the limiting factors that can have implications for resource allocation?

The study used a mixed method approach—collection and analysis of quantitative survey and published data and qualitative analysis of interview transcripts. Qualitative research allows the in-depth study of complex phenomena, including case study context and different stakeholder perspectives. The rigour of the research was maintained through triangulation and verification steps (Denscombe, 2009) as outlined in Section 2.3.

2.1 Systems thinking and most limiting factors

We conceptualise a system as various elements that are interconnected and organised to deliver certain desired outcomes, namely delivery on the system's objective(s). Stocks are the elements that can build up or be depleted in the system. Key stocks in general surveillance programs include notifiers, notifications, data and information. Flows are the elements that cause stocks to increase

or decrease. The dynamics of stocks and flows represent much of the dynamics within a system. Stocks can increase by building up their inflows or decreasing their outflows (Meadows, 2008; Richardson, 2011).

The interconnections between elements can be sources of unintended inefficiencies (Meadows, 2008). These interactions have implications for resourcing, either as sources of cost or potential areas for cost savings. Ticehurst and Kruger (2023) focus on leverage points, feedback loops and information flow. This article considers *limiting factors* in a system—variables in a system that restrict the system's ability to achieve desired outcomes (Senge, 2006).

Meadows (2008) suggested there are multiple and layered causes that may limit a system's performance. The *most limiting factor* is the component (or small number of components) that imposes the greatest restriction on the system's performance, discussed in Section 3.6. The most limiting factor(s) act as bottlenecks that prevent the system from achieving its full potential (Sterman, 2002; Senge, 2006). Identifying and addressing the most limiting factor is key to improving the performance of the system (Senge, 2006) or preventing the system from sliding backwards in achieving its goal. Spending resources and effort elsewhere will have lesser overall effect (Meadows, 2008).

2.2 Research approach

This article presents findings that are part of a four-year research project called 'Making General Surveillance Work' that used systems thinking to explore general surveillance programs (Kruger et al., 2022b).

Phase 1 of the project (2018-2019) involved a literature review and a survey to identify and collate a list of existing general surveillance programs in Australia and New Zealand. The survey questions are contained in the Supplementary Material. The survey was sent to individuals and organisations identified by the research team and through departmental networks as having oversight of, or management responsibilities in, general surveillance initiatives. Survey participants were asked to forward the survey to others in their networks who also manage general surveillance programs. The survey asked participants about general surveillance initiative(s) that they are familiar with, including how these programs are resourced.

In phase 2 (2020-2021), nine diverse case studies of general surveillance programs across sectors were selected and analysed to develop General Surveillance Guidelines (hereafter Guidelines) to support the planning, implementation and monitoring of such programs. More information about the case study approach and analysis method is provided below.

Phase 3 (2021-2022) involved verification and refining of the Guidelines including a multi-stakeholder workshop with selected experts, who were identified with the support of Australia's biosecurity sectoral committees. The workshop included a resourcing session with people who were knowledgeable about resourcing general surveillance and other biosecurity programs. Their feedback was incorporated in the final version of the Guidelines. The final Guidelines were released in February 2022 (Kruger et al., 2022a), followed by the full research report in April 2022 (Kruger et al., 2022b).

2.2.1 The case study approach and analysis

A multiple case study approach was chosen because it provides a strong base for understanding a phenomenon, resulting in propositions grounded in empirical evidence from across various contexts. Effectively, each case study presents a trial of a general surveillance program under different conditions (Eisenhardt and Graebner, 2007).

Case studies were selected to incorporate a range of: sectors (plant, animal, marine, weed, environment); stakeholders involved (e.g. government, industry, private businesses, community); target species; geographic scope; sampling methodology; and technologies used to detect and report. The selected case studies are given in Table 1 and Box 1, with more detail provided in the full research report (Kruger et al., 2022). A flowchart for each case study's data flow is contained in the Supplementary Material. The Indigenous case study was not a specific program, but explored how to best undertake Indigenous community engagement about general surveillance, and was based on a series of interviews with people experienced in this area.

A desktop analysis of any available written materials was carried out for each case study. We conducted 93 interviews and eight focus groups with stakeholders involved in case studies (Table 1). The full range of stakeholders from general surveillance programs were interviewed, including program staff, notifiers, people responsible for the identification of species or diagnosis of disease, data managers and analysts, data users, volunteer regional coordinators, hotline staff, communication staff, and reporting app developers. 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).

Representatives of other general surveillance programs and other experts were also interviewed to fill gaps and contribute to verification of emerging themes. This included people with insight in programs that had ceased prematurely, and some who were responsible for the legal aspects of a general surveillance program.

A generic set of basic interview questions were developed and adjusted according to the interviewee's role (see Supplementary Material). All interviewees were asked about program characteristics that, from their perspective, worked well and those that did not work well. Questions about resourcing were also adjusted according to each interviewee's role. For example, program staff were asked 'What are your reflections about sustaining resourcing for the program?', while funders were asked questions such as:

- as resources are always limited, what are the key pressures that may affect the level of resourcing you give to the program?

TABLE 1 Case studies and research effort (undertaken between July 2020 and May 2021).

Case study	Acronym	Sector	Objective	Total interviews	Interviews referring to resourcing	Focus groups (No. of participants)
Fishwatch, South Australia	Fishwatch	Marine	Early detection	7	4	1 (4)
NZ General Surveillance (plant health)	NZGS	Plant	Early detection Supports trade	10	7	1 (5)
Northern Australia Biosecurity Surveillance Net	NABSnet	Livestock	Early detection Supports trade	9	9	1 (7)
Pantry Blitz, using MypestGuide® Reporter App, Western Australia	Pantry Blitz	Plant	Early detection Supports trade	8	6	1 (6)
Rural Practitioner Enhanced Disease Surveillance Program, South Australia	RPEDSP	Livestock	Early detection Supports trade	11	9	1 (5)
State-Wide Array Surveillance program, Western Australia	SWASP	Marine	Early detection	10	5	1 (6)
Weed Spotters Network Queensland	WSNQ	Weeds	Early detection	11	5	1 (8)
Weed Spotters Victoria	WSV	Weeds	Early detection	10	8	1 (9)
Indigenous engagement for general surveillance	Not applicable	Not applicable	Not applicable	8	6	NA
Other interviews for verification and filling gaps	Not applicable	Not applicable	Not applicable	9	5	NA
Total				93	64	8 (50)

- from your perspective, how can general surveillance programs maximise their chances to sustain resourcing?
- what are the key conditions that you place on the resources you provide to the program?
- what else should we be aware of in relation to funding general surveillance programs?

Verbatim interview transcripts were analysed using Nvivo 11. Key themes were identified based on the structural components of innovation systems (Kruger et al., 2020). The information was summarised and presented to a focus group to verify the findings and fill gaps. Each focus group involved people from across the case study's different functions and who were not interviewed. Focus group findings were used to update the case study summaries. The case study summaries formed the basis for drafting the Guidelines for review in Phase 3.

Almost two-thirds (62%) of the interviewees commented on resourcing, and resourcing was discussed in all focus groups (see Table 1). All interview comments related to cost, money or funding were extracted and reviewed based on the research questions. Focusing on resourcing in this way helps situate resourcing-related comments in a broader understanding of what good practice involves.

For discussion of the qualitative findings from interviewees, we used 'some' when we refer to 1 or 2 interviewees who made the point; 'several' or 'various' when 3 to 5 interviewees were involved, and 'many' in the case of 5 or more interviewees who raised the idea.

3 Results and discussion

The Phase 1 survey results were used to help understand how general surveillance programs are being resourced, while the rest of the results are based primarily on the Phase 2 interview and focus group findings. Results are presented for each research question.

3.1 How are the general surveillance case study programs resourced?

Phase 1 of the project identified 110 general surveillance programs, with 98 from Australia and 12 from New Zealand. As

BOX 1 Overview of the case studies.

FishWatch South Australia

FishWatch provides an 'one-stop-shop' for the general public, commercial fishers and others to access information and report potential marine pest sightings or suspect fishing activities to the Department of Primary Industries and Regions, South Australia (PIRSA) experts via the Fishwatch SA hotline. Fishcare volunteers provide face-to-face support to fishers and the general public at key fishing locations across the state.

Indigenous community engagement about surveillance

This case study differs from the others in that it does not relate to a specific program. People who have engaged with Indigenous communities about general surveillance were interviewed. Most had a connection with the Northern Australia Quarantine Strategy and/or the Indigenous Ranger Program of the National Indigenous Australian Agency.

MyPestGuide® – Pantry Blitz

In this case study, members of the public place sticky traps, including a Khapra beetle lure, in their pantries. Participants report weekly for one month by submitting photos through the MyPestGuide® Reporter app. The Department of Primary Industries and Regional Development, Western Australia (DPIRD) developed the app. The data collected can provide supporting evidence of pest freedom if trading partners enquire about the status of Khapra beetle in Western Australia.

Northern Australia Biosecurity Surveillance Network (NABSnet)

The NABSnet program engages with private veterinarians in northern Australia to improve animal pest and disease surveillance. Private veterinarians are trained, resourced and subsidised to do high quality significant disease investigations. The program enables networking between private veterinarians and government biosecurity staff, including laboratory staff. The Australian Government administers the program.

New Zealand General Surveillance Program – Plant health component

This hotline-based program allows all New Zealanders to report suspected new or emerging pests, weeds and diseases. It includes targeted engagement of groups that have the motivation, capability, and access to do surveillance. The New Zealand Ministry for Primary Industries (MPI) funds it. Plant Health Incursion Investigators follow-up on potential high-risk notifications. The Plant Health and Environment lab in Biosecurity NZ undertakes species identification or disease diagnoses.

Rural Practitioner Enhanced Disease Surveillance Program (RPEDSP), South Australia

PIRSA provides subsidies for private veterinary investigations into livestock diseases in the RPEDS program. Investigations involve laboratory tests to rule out notifiable diseases and whether an infectious agent is a potential cause. Five government veterinarians oversee certain livestock species and certain regions. They build trusted relationships with private veterinarians to encourage and support their participation. A private lab undertakes the disease identification. The RPEDS program contributes to detecting new and emerging diseases early and providing proof of freedom from certain diseases to markets.

State Wide Array Surveillance Program (SWASP)

Under SWASP, most Port Authorities and Industry Ports (referred to as ports) in Western Australia deploy and retrieve settlement arrays—sets of plates submerged in the marine environment on which the larvae of marine organisms and marine algae can settle. eDNA technology is used to identify potential invasive species incursions. Arrays are placed in optimal locations around the ports in summer and winter. DPIRD administers the program and supports the ports, through equipment, technical knowledge and sample analysis and interpretation.

Weed Spotters Network Queensland

The Weed Spotters Network Queensland is a citizen science program that aims to detect and identify new incidents of state restricted and prohibited weeds early, so that preventative measures can be taken. The Queensland Herbarium and Biosecurity Queensland support the program in various ways. To make notifications, weed spotters submit a specimen to the Herbarium or send in photos via email or the Weed Spotter App. In addition, volunteer regional coordinators support weed spotters and promote the program in their regions.

Weed Spotters Victoria

Agriculture Victoria coordinates the targeted recruitment of weed spotters in that state. It trains volunteers to ensure they have the necessary skills, opportunity and motivation to report any of 8 to 12 state prohibited weeds. Monitoring and evaluation ensure a desirable state-wide coverage of weed spotters. Agriculture Victoria administers the program and undertakes most of the species identification through photo submissions, species descriptions and field visits.

the project was based in Australia, the relatively low number of cases in New Zealand likely reflects that the survey had lesser reach in New Zealand. The results (Figure 2) suggest that for most Australian general surveillance programs state or territory governments are key resource contributors. For 10 of the 12 New Zealand general surveillance programs governments (local or national) are major resource contributors.

All case study programs are managed largely from within government departments, mainly state/territory, but also national government agencies. Two programs that were not run from within government were invited to participate as case studies in the project. Both faced significant resourcing challenges at the time with uncertain futures and declined to participate.

The nine case studies chosen for further analysis represent a range of funding models. The funding models are detailed in Box 2. It was not possible to obtain financial details for all case studies, however budgetary information for three case studies is outlined in Box 3.

Sustained funding—where funding became part of business as usual—was easier to attract for those case studies that addressed requirements under legislation, such as detection and removal of a target species. For example, Weed Spotters Victoria is a key mechanism to detect state prohibited weeds; in New Zealand, government investment in general surveillance is justified because it is embedded in both the NZ *Biosecurity Act 1993* and the *Biosecurity 2025 Direction Statement* for New Zealand's biosecurity system.

Some general surveillance programs assisted organisations to demonstrate progress against strategic plans, which helped to sustain funding. For example, the Queensland Department for the Environment and Science has a focus on citizen science that enables support of the Department's Herbarium for the Weed Spotters Network Queensland.

In Fishwatch SA, the promotion of general surveillance activities was integrated with an existing compliance program targeted at commercial and recreational fishers around fishing rules and regulations. Those interviewed about Fishwatch viewed the program as valuable and cost-effective, given its ability to simultaneously deal with systemic non-compliance and give information to the public, without employing additional fishery officers.

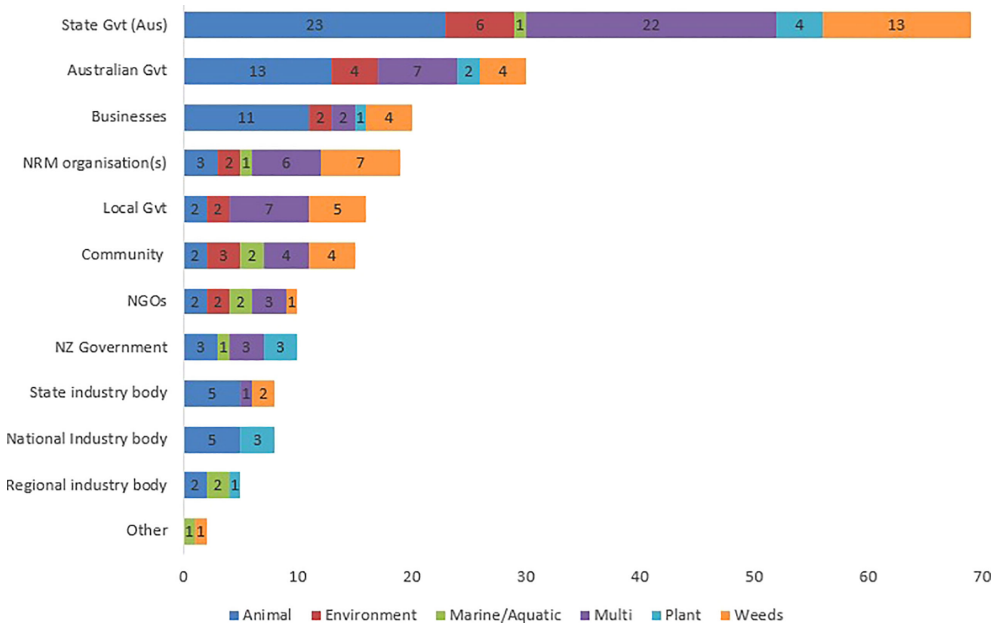

FIGURE 2
Financial and in-kind resource contributors to general surveillance programs.

3.1.1 Start-up resourcing

Some case study programs commenced on a relatively modest scale, either with external or internal funding, and after demonstrating their worth became part of "business as usual" for government departments. For example:

- Weed Spotters Network Queensland started in 2006 as a pilot that was co-designed by the Queensland government (mainly the Herbarium within the then Queensland Department of Environment and Resource Management) and interested community groups. The Natural Heritage Trust and Cooperative Research Centre for Australian Weed Management resourced the pilot.
- SWASP was co-designed and implemented by the Western Australia government (the then WA Fisheries) and three ports who were willing to participate in a small-scale program, initially called the Early Warning System.

The benefits of starting small-scale include less up-front initial investment, which may present a more attractive proposition to funding bodies. With fewer notifiers, it is also easier to undertake in-depth engagement, such as for co-design, to work through "teething problems" and to be flexible with approach taken. For example, in SWASP some ports did not have the resourcing to actively deploy and retrieve arrays so the SWASP staff would go in the field and do it for them. The ports that did have the resources and the inclination to deploy and retrieve the arrays were trained to do it themselves.

BOX 2 Overview of the case study program funding models.

One government funder
Programs involving a single government organisation as funder include the NZ General Surveillance program and Weed Spotters Victoria.

Co-resourcing by governments
Co-resourcing by different level of government occurs with NABSnet and the RPEDSP. The Australian Government funds the private veterinarian subsidies and external contractors for communication and liaison in NABSnet, and state governments provide in-kind support through lab services and government vets. The Australian Government contributes funding to the significant disease investigations in the RPEDSP, which the South Australian government supplements.

Co-resourcing by several state government departments within one state
The Weed Spotters Network Queensland is co-funded by the Queensland Herbarium (Queensland Department of Environment and Science) and Biosecurity Queensland (Queensland Department of Agriculture and Fisheries). Local governments contribute to Biosecurity Queensland's contribution through a precept system.

Co-resourcing by public and private entities
The SWASP program involves co-resourcing by a state government department (DPIRD) and private businesses (ports); some ports share costs with private partners.

Grant funding
The 2016 and 2017 Pantry Blitz were funded directly by the National Science Week and Western Australia's Royalties for Regions Boosting Biosecurity Defences project.

Leveraging
General surveillance program activities might 'piggy-back' on existing initiatives. This is the case for Fishwatch SA, where general surveillance reporting was added to the original compliance hotline, including receiving support from the Fishcare volunteers. Funding is provided through compliance and regulatory service agreements with fisheries and aquaculture licensees, and the Australian Government.

BOX 3 Examples of general surveillance program financial budgets (excl. in-kind contributions).

The Weed Spotters Network Queensland

The Weed Spotters Network Queensland costs about AUS$120,000 per year, with Biosecurity Queensland and the Queensland Department of Environment and Science (QDES) each contributing AUS$60,000. In 2019 the program delivered 107 notifications of 33 prohibited or restricted species. Between 2013 and 2015 the program submitted 3000 weed specimens to the Queensland Herbarium, resulting in 383 detections (about 12.8% of total submissions) of incursions of 88 priority weed species (Laidlaw et al., 2016).

SWASP

Ports contribute about $35,000 per year to the program. The eDNA analysis provides ports with biosecurity and biodiversity data for two sampling periods, summer and winter (McDonald et al., 2020). This compares to the National System that 'often requires in excess of AUD$350,000 per port surveillance event' (McDonald et al., 2020:79). Port representatives mentioned that they make financial contributions due to the direct benefit they receive from the program, including that early detection can help avoid potential large costs related to prolonged closures of wharfs during responses. In addition, access to biodiversity data assists them to maintain a social licence to operate as it helps demonstrate stewardship of the environment.

New Zealand's (entire) general surveillance system

The 2019–2020 budget for New Zealand provided an injection to further strengthen the general surveillance system, including additional funding for new Incursion Investigators and diagnostics capacity (NZ$6.75 million over 4 years) and for strengthened community engagement (NZ$1.77 million over 4 years) (Gould, 2019).

The Pantry Blitz was initially funded by an external grant, and while the funding was tight, it provided flexibility that would have been difficult to attain if it was internally resourced. For example, government managers may not have allowed much time spent talking to the public, given competing demands on government staff's time.

In some case studies, interviewees spoke about the initial difficulties conveying program ideas to colleagues and managers. There was concern that new general surveillance initiatives would waste or reallocate resources away from existing initiatives. Justifying programs became easier once they demonstrated worth, including showing significant detections or attracting significant external resources. For example, ports now routinely contribute financially to SWASP.

3.1.2 Maintaining resourcing

Numerous interviewees mentioned the importance of demonstrating worth to maintain or attract resources, typically through detections of invasive species of concern. For "unstructured" programs such as the NZ General Surveillance program, the great majority of notifications involve organisms of no biosecurity concern. However, the program has delivered significant finds, such as the detection of pea weevil in the north island of New Zealand, which resulted in a successful eradication program. The early notification made eradication feasible and prevented significant losses to the New Zealand pea industry, currently worth around NZ$120 million to the country's economy (Voice et al., 2022).

Various interviewees pointed out that demonstrating impact can be difficult, particularly in relation to early detection of exotic and other species and diseases that are yet to spread widely. Interviewees spoke about the importance of proactive and continual communication with managers, current and potential funders and other stakeholders contributing financial and in-kind resources to ensure they value a program:

- Several program managers used examples of detections that led to successful eradications. For example, in Weed Spotters Network Queensland a local government officer who was trained through the Weed Spotters Network Queensland recognised Karroo-thorn (*Vachellia karroo*) in pots in a residential backyard. This exotic species has the potential to do more damage than the similar species, prickly acacia (*Vachellia nilotica*), one of Queensland's worst weeds (Queensland Government, 2016).
- Some put the cost of the program in perspective by comparing it with the cost related to eradication or management over time. For example, Morfe (2014) undertook an economic evaluation of Weed Spotters Victoria, focusing on *Salvinia molesta*, by comparing the impact on the Victorian economy with and without the Weed Spotters program, at the average cost (undiscounted) of AUD$ 157,500 per year. The study concluded that the Victorian government would have spent approximately AUD$ 2,2 million in incursion-response costs in the absence of the Weed Spotters program.
- Several programs highlighted the monetary worth of the trade or the agriculture industry(ies) that the general surveillance programs help protect.
- Some programs were initially outliers in their Departments and it required a "hard-sell" to gain internal support. Some promoted a program to key decision-makers in government by highlighting what the key decision-maker has personally to benefit from the program. Others found emphasising the risks and benefits, and third-party verification of the program's success helpful to gain internal support.

> *"We had this meeting with him [senior decision-maker], he says his biggest nightmare was waking up one day, coming to work and he's told that there was [priority pest] … So when you can develop something and say … it won't cost you a fortune, it's innovative and it's going to protect your butt. Then you'll get buy in."* [Interviewee]

> *"They would occasionally question the justification for resourcing … [we] could say, look, we have stakeholder engagement from high-risk sites, and we're not paying for it. So I did initially have to battle. … And I had to do the whole presentation on likelihood of risk, …We got good stakeholder reports, which I believe helped. So the [notifier] bosses would contact my bosses and say, this is working really well."* [Program Manager]

Some maintain the visibility of a program and its achievements with key stakeholders. Programs like Weed Spotters Network Queensland set program milestones and communicate success with them.

> *"We can demonstrate outcomes with annual statistics on notifications, growth in membership, training numbers, number of reads and hits on websites. This means we can also easily demonstrate cost-effectiveness, which is attractive."* [Weed Spotter Network Queensland interviewee]

In terms of demonstrating worth, various interviewees said that general surveillance programs often deliver additional benefits beyond producing surveillance data. For example, they:

- *build networks* that can be engaged for subsequent surveillance and other biosecurity activities (e.g. Pantry Blitz, livestock case studies, weed spotter programs). Weed Spotters Network Queensland has a close connection with local government councils whose staff receive direct benefits as a result, such as easier access to the Queensland Herbarium for weed identifications, weed training workshops, and networking opportunities with peers in other local governments councils. The network is likely to be invaluable if subsequent on-ground surveillance is required.
- *strengthen peer support networks*, such as NABSnet which provides private vets, who spend long hours on their own in remote areas, with a valuable network. Contact with other veterinarians working in similar circumstances helps mitigate mental health risks, including depression and suicide (Moir and van den Brink, 2020).
- *improve capacity and capability* by delivering more educated and engaged people from all walks of life supporting biosecurity system objectives (e.g. NZ General Surveillance program). These trust-based relationships, such as with private veterinarians or with ports, could be harnessed during emergency responses, and in some cases they have enabled further collaborations (e.g. SWASP has built relationships between ports and the Western Australia Government).
- *provide an income source*, such as the fee-for-service for Indigenous Rangers program which delivers an important source of income for related communities and the rangers reportedly represent positive role models for youth and others (Ayer et al., 2021).
- *deliver extended community engagement* about biosecurity, such as various WA ports that engage with the community about the marine environment and include conversations about biosecurity thereby increasing the community's awareness of marine related biosecurity issues.

3.2 Which activities, processes and equipment require resourcing?

Resourcing requirements for case studies are summarised in Table 2. For several case studies, the staffing requirements for lab/herbarium services, data management, in-field and other investigations, delimitation or response activities, and support from communication teams were absorbed within the routine business of government. Some encountered fee-for-service models and had to pay for services such as database management or communication support in large government organisations. Several interviewees pointed out that they have encountered considerable need for specialised skills, such as expert taxonomists and entomologists, or managers of complex databases.

Some programs' resourcing requirements varied during the year, such as for Pantry Blitz where more staff are needed during the months leading up to and during the intense surveillance event. Some programs experience seasonal surges in notifications, such as during spring when more people spend time outdoors and some species are more visible, such as weeds flowering. Several case studies outsource certain functions to allow for this surge capacity, such as using private call centres for hotlines, or managing mail-outs during a blitz. SWASP removed some of the reliance upon the in-kind identification service from DPIRD by contracting specialised eDNA analysis through eDNA Frontiers (Curtin University). The New Zealand Ministry of Primary Industries outsources advertising relating to pest campaigns as the external companies involved have strong networks with the media and valuable creative thinking skills. In NABSnet, consultants with extensive relevant experience are contracted to fulfil the engagement role.

A key theme was the importance of a paid coordinator to undertake vital tasks such as program administration and liaising with internal and external stakeholders to ensure functions are delivered on time (Ticehurst and Kruger, 2023). There is often a need for liaison between different program functions, e.g. communication staff liaising with lab staff before launching a campaign to ensure the call centre and lab can deal with a surge in notifications.

Some programs use volunteers for various purposes, for example to promote the program, create awareness and support notifiers (e.g. Fishcare volunteers supporting Fishwatch SA) or data entry (e.g. Weed Spotters Network Queensland). Fishcare volunteers receive reimbursements to cover costs, such as travel and other out-of-pocket expenses.

Several interviewees across case studies lamented a lack of capacity (time) and sometimes capability (skill) for additional data analysis. They felt more value could be derived from the data, other than achieving the primary purpose of early detection, e.g. about species/disease distribution.

3.2.1 Resource considerations for monitoring and reporting

Notifiers are at the heart of monitoring and reporting and in most case studies, notifiers offer their support free of charge. Many

TABLE 2 Common expenditures for general surveillance programs.

Function	Examples of related expenditure
Program coordination	• Internal engagement across program and related functions (e.g. notifiers, lab/herbarium staff, data managers, analysts & users, funders, field staff, scientists, etc.) • External stakeholder engagement to build support networks e.g. for program promotion, collection of samples/specimens, triage support, etc. • Continual improvement, including monitoring and evaluation
Monitoring and reporting	• Understanding the motivations, barriers and other needs and expectation of notifiers, e.g. through social research activities • Notifier training, e.g. venue hire and catering for workshops, or development of online training packages • On-going engagement and support, e.g. venue hire and catering for meetings; stalls at events, regular newsletters, meetings, field visits, maintaining websites, radio, media, etc. • Engagement materials, e.g. promotional and instructional materials • Subsidies and reimbursements • Equipment, e.g. settlement arrays for ports, post-mortem kits for livestock producers and vets, insect traps for households. If produced as part of a program, development and fine-tuning may require considerable investment
Identification/ Diagnostics	• Qualified staff, incl. capacity and capability to follow up with notifiers • Field equipment, e.g. post-mortem kits • Labs and lab equipment, e.g. eDNA, PCRs, serological tests, etc. (Considerable trade-off exist between accuracy, efficiency and cost of different identification and diagnostic methods)
Data collection, management & analysis	• Qualified staff to design IT systems, maintain databases, interrogate and analyse data • Database updates, such reconfiguration required to allow for better data sharing • Software packages to support data management and analysis • Fit for purpose databases (e.g. to deal with high number of photos) and back-up systems • Development, fine-tuning and updating of reporting tools and tools to support data collection, transfer, storage, and analyses • Where community groups or others are expected to collect and analyse their own data, capacity building or support for sounds data analysis may be needed
Data use	• Field visits, and response measures related to delimitation, management or eradication • Combining data with other data, e.g. climate, soil type, etc. to deliver greater insights • Communicating information derived from data
Other	• Legal advice so the program is not at risk of liability or to establish trademarks • Public liability insurance funding, if an organisation doesn't already have it, such as some community groups • Engaging scientific and other technical expertise • Setting up and implementing triage systems • Reimbursement of volunteer expenditures, such as travel • Capacity building at different points in system • Courier fees, postage and delivery fees, e.g. courier cost for sample/specimen submissions to ensure they reach the lab/herbarium in good quality and on time.

case study programs are designed to minimise the burden on notifiers. For example, ports participating in SWASP accept two to five days' staff time per year as an acceptable investment of their time in return for the data generated. NABSnet administrators assume private veterinarians have an estimated 5% of their time available for general surveillance. Indigenous rangers receive a fee for service. This assists program administrators and service providers to negotiate and agree on requirements such as when surveillance activities will occur, what they entail, or the payment conditions.

The livestock case studies offer subsidies for significant disease investigations, plus compensation for travel and accommodation, where private veterinarians may need to travel long distances to collect samples. The RPEDSP involved three levels of subsidised investigations: (i) base level herd/flock disease investigation; (ii) significant disease investigation (low suspicion of exotic disease), which includes funding for all lab testing and limited private veterinary payment; and (iii) exotic or "new" disease investigation (high suspicion of exotic disease), which includes full lab and private veterinary funding. NABSnet provides private veterinarians with a subsidy of up to AUD$2000 to conduct a full disease investigation for an eligible case and to write a report, that is, one involving high numbers of sick or dead animals and/or symptoms consistent with an exotic or emerging disease. While the subsidies seem generous, some NABSnet veterinarians said they do not always cover all costs, especially if there is a need for more than one visit relating to a disease investigation, but they "just wear it" or pass the cost on to the producer.

Sometimes these programs provide additional funding when exceptionally long travel distances are involved. NABSnet covers private veterinarians' travel and accommodation to attend master classes, a popular training event that brings together a range of stakeholders supporting NABSnet. Some emphasised the importance of reimbursing veterinarians without delays to avoid dissatisfaction with the program. Some spoke about the importance of program resourcing to be well tailored to needs. For example, in the livestock industry some cases require more time or are remotely located. This requires testing equipment to be readily available in remote areas to get results in a timely manner.

Most programs produce web-based information or print material to support notifiers to carry out their monitoring activities. Weed Spotters Network Queensland provides a handbook to assist with identifying target species. Weed Spotters Victoria offers weed spotters annual calendars to help keep target

species for particular seasons front-of-mind. In the Pantry Blitz, participants received a kit containing the trap and instructions.

3.2.2 Operating environment

General surveillance programs are effectively systems within systems—a general surveillance sub-system supported by a larger biosecurity system. If supporting systems are under-resourced, there will be flow-on effects for general surveillance programs. For example, biosecurity agencies need to be adequately resourced to respond to reports from general surveillance (Carnegie and Nahrung, 2019). Interviewees mentioned other examples of potential funding deficits in supporting systems that could negatively impact on outcomes of their general surveillance programs. These include: the availability of taxonomists, entomologists and other experts; the maintenance of specimen backed systems such as used in herbariums and museums; automated systems to support data storage and management and administrative tasks; and access to capabilities such as data analysis to make sound inferences from data collected. For programs that act as an early warning system, resources are required for additional investigations to confirm the identity of a suspect sighting or detection. Sometimes there was a need to determine whether the organism is likely to cause significant impacts and therefore warrant a response.

3.3 How do case study programs improve cost-effectiveness?

Adopting a cost-effective approach from a systems thinking perspective refers to considering how the interconnectedness and interdependencies of various elements of the system enable value to be maximised while minimising costs, including to the broader system. In this respect, the key cost-effective elements identified in the analysis of case studies relate to notifier engagement, tools and equipment, risk-based approaches and prioritisation, and monitoring and evaluation.

3.3.1 Effective notifier engagement by delivering a positive participation experience

Various interviewees mentioned the importance of achieving *quality* notifications, rather than simply increasing the *quantity* of notifications. Quality notifications refer to those that are accurate, timely and complete. Inaccurate notifications (including false positives) tend to be costly elsewhere in the system. For example, they increase the workload on herbarium or lab staff, or challenge the capacity of the data management system when large numbers of images are involved. False positives may also waste resources by leading to unnecessary active surveillance (Spring and Cacho, 2015). Public reports of pests and diseases are known to increase false positives (Hester and Cacho, 2017). Timely reporting is particularly important for early detection, as eradication is most feasible when very few cases of a pest, weed or disease are present. Complete notifications minimise the need for program, lab, herbarium, and/or data management staff to spend resources on follow-up with notifiers to chase-up missing information.

While various case study programs welcome reports from the whole community, they target engagement efforts at people who have the motivation, capability and/or who are located in key areas. The weed spotter programs and the NZ General Surveillance Program are examples of where targeting is used. Program managers found that this targeting can significantly increase the quality of notifications. For example, while Weed Spotters Victoria initially trained anyone who showed interest, over time it became apparent that it was more cost-effective to strategically target people who were likely to encounter weeds of concern, such as those working in the field, who identify weeds correctly, and who deliver timely reporting of target weeds (Munakamwe et al., 2018).

Deeper engagement processes, such as face-to-face workshops and meetings were often mentioned as a highly effective way to achieve and maintain engagement, support and improve the quality of notifications.

> *"So we're doing two [personal visits] a year now. It's expensive, so you could argue to cut it from a purely expense perspective … But I believe the benefits far outweigh the cost … we get a lot more engagement."* [Program manager]

Up-front investment in understanding notifiers helps with offering them a value proposition that resonates, which could be biosecurity related or not. Many notifiers participate because of their concern about the impact of pests, weeds and diseases on the environment and industry. For example, a survey of 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). Notably, however, in several cases the value proposition had nothing to do with biosecurity. In these cases, the value proposition included access to biodiversity data for ports participating in SWASP, opportunities for private veterinarians to network with peers (NABSnet) and deliver a better service to their clients (RPEDSP), and learning new skills or gaining work experience (some Fishcare volunteers supporting Fishwatch SA). This is further explored in Ticehurst and Kruger (2023).

To ensure notifier support, some case study programs invest in activities beyond those contributing to the main purpose of the programs. For example, where possible, the livestock programs also gave farmers information about why their animals had died or were sick. Some interviewees mentioned that livestock producers are unlikely to pay just to have a notifiable disease ruled-out as the cause of death or sickness. However, some RPEDSP interviewees mentioned that there is a need to continually justify with funding managers why the program is funding disease investigations beyond emergency diseases and diseases that affect trade.

Many interviewees emphasised the importance of giving notifiers a positive participation experience to maintain their involvement. Several highlighted the costliness of having to re-invest in training new notifiers when people withdraw from the program. Notifiers tend to become more skilled in delivering quality notifications the longer they participate. Others pointed out that disgruntled notifiers can damage the reputation of the program and willingness of others to participate. More detail about what a

positive participation experience involves is provided in Ticehurst and Kruger (2023).

3.3.2 Well-considered tools and equipment

Several programs found that investing in well-considered and tested tools and equipment tailored to user needs (users of the app interface and the "back-end" data) paid dividends over time, even if higher upfront investment in consultation may be needed. For example, apps that dovetail with existing data systems and contain well-considered data fields will prevent wasting resources on data cleaning and reformatting, and following-up with notifiers. Apps that are user-friendly for on-ground users are likely to better sustain notifier support and usage over time. This has been the experience of the MyPestGuide® Reporter App and the Indigenous Ranger app.

> *"… if the initial product [such as an app] that hits the market isn't quite user friendly, or fit for purpose, people may have a negative experience with that and then never come back. … If you're not actively asking people about what they're after in a resource, you can't assume that they will come to you and tell you. "* [Program coordinator]

SWASP uses an eDNA-based approach as a more cost-effective way to detect invasive species rather than relying on detailed invasive marine species surveys. The Pantry Blitz team opted for cheap sticky traps in combination with the Khapra Beetle Lure rather than more expensive professional beetle traps. Weed Spotters Network Queensland used a masters student to develop a reporting app for Android smartphones.

3.3.3 Risk-based approaches and prioritisation

Most case studies identified target species/diseases and considered where and when monitoring and reporting occurs. Several case studies focused on key species or diseases (e.g. Weed spotter programs; campaigns in NZ on species such as Brown Marmorated Stink Bug) and/or high-risk areas (e.g. SWASP, NABSnet, Pantry Blitz) to optimise the use of scarce resources.

Some programs make financial support or response decisions on a case-by-case basis, depending on how much funding is available, particularly in the livestock case studies. This is possible in NABSnet where the reporting veterinarian represents one point of call to make decisions about whether a requested significant disease investigation is justifiable. When something outside of the ordinary is reported via Fishwatch SA the program team makes an assessment to determine how to deal with it operationally and resource it appropriately.

Triaging of notifications was undertaken in many case study programs to prioritise detections and ensure resources were spent following up higher-risk detections. In several case studies lab/herbarium capacity was a scarce resource (e.g. Weed Spotter Network Queensland, NZ General Surveillance Program, Pantry Blitz) so it was important to minimise the number of out-of-scope species that lab/herbarium staff had to deal with, and to minimise follow-up with notifiers. Triaging processes assisted with this process. Examples of how this occurred include:

- *Call centres* — such as in NZ General Surveillance and Fishwatch SA. To be effective, this requires investment in training call centre staff and developing support systems, such as intuitive software, that can guide call centre staff about what to prioiritise and who to contact within the related government department.
- *Volunteers* — such as regional coordinators in Weed Spotters Network Queensland who support weed spotters uncertain about whether something is worth reporting.
- *Appointed staff* — such as private veterinarians who are required to seek permission from appointed staff to continue with a subsidised significant disease investigation. In the Pantry Blitz program, a triage officer ensured only suspect cases of Khapra Beetle were sent to the senior entomologist. In NZ, industry representatives triage submissions to the Find-a-Pest app: photos of possible high-risk species are sent via the MPI hotline for identification; photos of low-risk species, such as established pests and weeds, are passed onto iNaturalist NZ, a web-based citizen science platform, where skilled volunteers undertake the identification.
- *Internal lab triage and prioritisation processes* — for example, less samples may be requested of lower risk species, such as insects detected in households' stored grain.
- *Technology* — for example, images received via the Weed Spotters Network Queensland App help herbarium staff triage which reports require specimens rather than receiving all reports as specimen submissions.

3.3.4 Monitoring and evaluation

Monitoring and evaluation activities are essential to ensure optimal resource allocation (Drewe et al., 2012). Undertaken regularly, these activities support adaptive management where responses to issues and opportunities occur as they arise. None of the case studies started with a perfect design; all adjusted over time to respond to issues and become more cost-efficient. Most programs undertook monitoring, ranging from informal team reflections through to contracting experts to undertake formal reviews to strengthen and streamline program processes, communications and tools to avoid wasting resources. Several programs have used surveys with key stakeholders such as notifiers to gather their input to continually refine the initiative. Examples include the NZ General surveillance program, Weed Spotters Victoria and Weed Spotters Network Queensland. Staff working on campaigns in NZ said that research-based marketing campaigns are important to ensure the campaigns deliver value for money and to continually improve them over time to ensure best return on investment. These investments also build the skills of communication staff so they are better placed to undertake cost-effective engagement activities.

A Weed Spotters Network Queensland survey with weed spotters identified that the main barrier to reporting is a lack of time. This finding instigated the development of a reporting app.

Some interviewees noted that it is important to ensure resources are available to maintain tools such as apps to ensure they continue to meet users' needs.

> *"… we've found there to be a lot of benefits for continuously and regularly asking people if it's doing what they require. Also recognising that what people need changes over time."* [Program coordinator]

3.4 How do case studies deal with resourcing pressures?

Several interviewees referred to pressure from stakeholders and managers who expect general surveillance programs to run on very limited resourcing.

> *"…but departmental managers expect us to deliver surveillance data with little or no funding because they have been incorrectly advised citizen science can provide quality data for peanuts … I think managers think they're just getting free labour."* [Program coordinator]

Many interviewees also emphasised the importance of on-going funding. Uninterrupted financial support is particularly important to maintain momentum with notifier engagement. At times, various case studies had been able to adjust to decreased funding. For example, in SWASP, government staff ceased port visits when resources were cut and relied on port staff doing some surveillance tasks themselves. This was possible because SWASP team members had already spent the time with the port staff implementing and explaining the surveillance process. When funding increased again, government staff returned to field visits to ensure monitoring was being undertaken correctly, particularly when new staff started at the ports. The personal connection also makes it easier for port staff to contact the SWASP team if they have questions.

Some programs found alternative sources of funding through their networks. This funding helped programs "tick over" until more secure funding could be found. For example, when the initial funding for NABSnet ended, the program team was able to use some funding from the Australian Government's Northern Australia Quarantine Strategy to keep the bare minimum of the program functioning until new funding was secured. However it meant that the program coordinator had to check in with the program administrators on each significant disease investigation requested from private veterinarians to ensure sufficient subsidy funding was available, thus adding to the administrative burden. Weed Spotters Victoria cut back on face-to-face engagement (via stalls at agricultural shows and field days) following a change of government which resulted in a funding cut. It also moved some of its training from face-to-face forums to online training. Some interviewees expressed disappointment with the subsequent lack of interaction between weed spotters and staff, and among weed spotters.

3.4.1 Consequences of sustained under-resourcing

Communication and engagement functions are often first to be cut when resources become limited. In addition, programs tend to become reactionary and less proactive. In these circumstances programs easily start to focus on solely achieving funder objectives, at the expense of the notifier value proposition. When this occurs, careful consideration is required to maintain notifier engagement. For an animal disease program, some interviewees spoke about the fine line they need to tread with their messaging to private veterinarians when funding becomes limited.

> *"From time to time, our funding tightens up and we then have to give a kind of a mixed message to [private] veterinarians that you have to cut down on your testing a little bit. And then you've got to be very careful with that because they'll stop all together, and then you won't know what's going on."* [Government vet]

A RPEDSP interviewee noted the possible consequences of declining producers' requests for disease investigations—it risks farmers stopping their interaction with the program and reverting to shooting and burying sick animals, thus undermining the early detection objectives of the program.

Some interviewees mentioned that resourcing uncertainty is very tiring. A significant administrative burden (a transaction cost) was often involved in working out how programs would proceed on less funding. Solutions included asking stakeholders to contribute more, perhaps by taking on more tasks. Often it meant departure of program staff who had built up trusted relationships with a range of key stakeholders, with valuable corporate knowledge lost.

Funding of monitoring and evaluation is also typically a casualty of under-resourcing. Ironically, for various programs it was the monitoring activities that informed the adaptive management that in turn brought about greater efficiencies and cost-effectiveness.

3.5 What are key sources of transaction cost?

Marshall (2013) (p188) defines transaction costs as *the costs of the resources used to: define, establish, maintain, use and change institutions [rules] and organisations; and define the problems that these institutions [rules] and organisations are intended to solve.* Transaction costs can be a considerable part of the total policy cost due to their influence on activities such as information collection, information integration from different sources, negotiations, administration, contracting, monitoring and enforcement. Actions by one party, such as collating information and making it readily available, can greatly lower the transaction costs for others (Coggan et al., 2010).

Examples of common areas of transaction cost in the case study programs are listed below:

- Getting to know key stakeholders, including their needs, motivations, barriers and expectations. It could include the resources spent on meetings, workshops, social research activities and other interactions. For example, a consultancy was funded for NABSnet to undertake a needs analysis of all the key groups involved in the program, including producers, private veterinarians, state government veterinarians, state veterinarian laboratories and more (Brightling and Hope, 2017).
- The time and effort needed to refine new, or update, existing tools such as reporting tools or instructions to suit the needs of users, but that will deliver considerable cost-efficiencies in the future. For example, MyPestGuide® Reporter App required the development of prototypes and extensive consultation with app users to ensure it meets their needs and functions well with different smart phones and in different locations. The app developers also liaised extensively with data users to ensure the format of the data that is generated matches the department's data systems and that there is minimal need for data cleaning and reformatting.
- Gaining and maintaining the trust of stakeholders, including notifiers and others throughout the system. For example, PIRSA veterinarians involved in the RPEDSP are required to visit participating private veterinarians twice a year, which helps sustain their continued support for the program.
- Identifying program rules that take the needs of the program and different people across the system into consideration and setting up systems accordingly, such as in the co-designed processes of SWASP and Weed Spotter Network Queensland.
- Context alignment, i.e. to ensure a general surveillance program fits well within existing arrangements for functions such as species identification/disease diagnosis, data management, and public communication. For example, the MyPestGuide® team had to work with various groups in DPIRD to ensure the department supports the reporting tool and the Pantry Blitz activities, such as the department's species identification and data management teams. At the time DPIRD did not have processes and policy guidance in place to support the health and safety or privacy of notifiers. Setting up such processed and policies required considerable investment to be able to implement the Pantry Blitz. In addition, it is not unusual for existing teams or organisations to have to invest in adjustments to accommodate a general surveillance program. For example, the Queensland herbarium had to invest in developing and implementing new hygiene and notification protocols.
- The administrative burden resulting from allocating budgets and refining these allocations, particularly following funding cuts.

Some forms of transaction cost may involve increased upfront cost, e.g. to develop a reporting app, others may increase over time such as when a program grows.

> *"So, as the program's gotten bigger and we've got more stakeholders, it does get a little bit more challenging to implement changes that work for everyone…"* [Program coordinator]

3.6 Limiting factors

Limiting factors represent areas that, if not addressed and resourced well, can significantly impact on a program's ability to deliver intended outcomes in a cost-effective way. This section outlines the limiting factors encountered in two or more case studies (summarised in Table 3, most have been discussed earlier) as well as understanding key limiting factors as they relate to the main stocks of general surveillance programs, i.e. notifiers and notifications; data; and information.

Table 3 outlines the limiting factors and their potential impact (s). It provides examples of direct and indirect causes to illustrate how issues could ripple through the system. For example, the first limiting factor listed is program coordination effort. People in the operating environment can easily underestimate the skill set and effort needed from, and therefore the investment required for, an effective program coordinator (indirect cause). This results in the appointment of a person/team who lacks the needed capabilities and capacity (direct cause) resulting in poor program coordination that causes the underperformance of multiple other limiting factors.

Figure 3 is related to Table 3 (as indicated by the alphabetic numbering) and provides an overview of how the most common limiting factors and program functions interact with each other throughout the program.

Table 3 and Figure 3 show that limiting factors can be located across all functions of general surveillance programs. We will now consider the limiting factors related to the stocks of notifiers and notifications (discussed together as they are intricately linked), data, and information, including highlighting possible most limiting factors.

3.6.1 Notifiers and notifications

Access to notifiers (or engaged community) is where much of the opportunity for more cost-effective surveillance come from in general versus active surveillance programs. They present an opportunity to tap into people's motivation, skill and location as opposed to paying for trained staff's time and travel. The importance of effective community engagement has been outlined above, including the importance of retaining notifiers to prevent losing the investment in their engagement and training, and to capitalise on their learning to date that leads to better quality reporting. This optimises the use of lab/herbarium capacity, a scarce resource in general surveillance programs, as it prevents

needing to deal with out-of-scope species or following up with notifiers on missing information.

Given the voluntary (or limited renumeration) nature of notifiers' participation, delivering a positive participation experience is essential to maintain their involvement, which depends on various functions within the program, including engagement, reporting and data management processes.

It could be easy to think that increasing notifications require campaigns or programs to engage more people. However, the most limiting factor might not be the inflow of notifiers, but rather the outflow that result from arduous processes or other negative experiences that make people lose interest in actively participating in a program.

> *"If you know you're going to have to sit down, go through a real bureaucratic process, filling out endless forms … in a busy vet's life it can be hard to find that time. Therefore, you can think, "Oh, I'll just manage this disease by myself, I won't even mention it [the subsidy] to the farmer""* [Private vet]

3.6.2 Data

Data is a key stock in general surveillance programs and tend to undertake a significant journey from where it is collected, often through several databases, to where it is used. Key themes from the case studies relate to maximising data value and minimising

TABLE 3 Overview of the key limiting factors reported in the case studies.

Limiting factor	Figure 3.	Potential impact if limiting	Example of direct cause(s)	Example of indirect cause(s)
PROGRAM ADMINISTRATION				
Program coordination effort		Underperformance of multiple other limiting factors	Project coordinator/team lacks skill/ commitment and time (Program admin)	Skill set and effort required misjudged (Operating environment)
Responsiveness, incl. continual improvement		Failure to capitalise on opportunities, learn from mistakes and address issues in a timely way (Various, incl. program admin)	Project coordinator/team lacks capacity or capability (Program admin)	Need for M&E under-appreciated (Operating environment)
Support from higher management in host organisation		Reduced support, e.g. resourcing if program is not prioritised (Various, incl. program admin)	Poor communication between project coordinator/team and senior management (Program admin/Operating environment)	Need for higher level connectivity underestimated (Operating environment)
Stakeholder understanding of program benefits to maintain coalition of support		Weakened support from various fronts (Various, incl. program admin)	Poor communication between project coordinator/team and stakeholders (Program admin/Operating environment)	Need for communication with stakeholders underestimated (Operating environment)
Different parts of program adjust to each other's needs and the operating environment		Inefficiencies at various points in the program. For example, much time spent on following-up with notifiers about missing information (Various, incl. program admin)	Lack of coordination between different parts of program and/or with operating environment. E.g. reporting tool poorly designed, not meeting staff needs. (Program admin/Operating environment)	The need for coordination between different parts overlooked. E.g. funding allowed for development of reporting tool only, not for testing it with staff. (Operating environment)
Legislative and other duty of care requirements integrated		Unforeseen consequences e.g. litigation, damaged reputation (Various, incl. program admin)	Need for duty of care overlooked (Program admin)	Need for duty of care overlooked (Operating environment)
Sustained resourcing		Risk disengaging community, sub-optimal program management (Various, incl. engaged community, program admin)	Extent of resourcing needed underestimated; too many demands on limited resources (Operating environment)	
ENGAGED COMMUNITY				
Targeted engagement to people best placed to do monitoring and reporting	a.	Resources wasted on people who lack interest, skill or right location. etc. (Program admin); sub-optimal reporting (Reporting)	Need for targeted engagement overlooked or not prioritised (Program admin)	Need for investment in understanding target groups underestimated (Operating environment)
Tailored engagement	b.	Sub-optimal engagement, e.g. failure to secure support where needed (Engaged community); sub-optimal reporting (Reporting)	Need for tailored engagement overlooked or not prioritised (Program admin)	Need for investment to tailor engagement to target groups underestimated (Operating environment)

(Continued)

TABLE 3 Continued

Limiting factor	Figure 3.	Potential impact if limiting	Example of direct cause(s)	Example of indirect cause(s)
Community participation experience	c.	Notifier drop out, loss of investment in their training and communication; need to train new notifiers (Engaged community & Reporting)	Sign-up and training cumbersome (Program admin); reporting is arduous (Reporting), slow/no reporting feedback (Species ID/ disease diagnosis); data not ethically used (Data management)	Lack of investment in system coordination (Operating environment)
Level of guidance to support quality reporting	d.	Time and effort wasted on following-up on notifiers who submitted incomplete/poor reports (Species ID/ disease diagnosis); data not useable (Data use)	Too much focus on increasing quantity rather than quality of reporting (Program admin)	Too much focus on increasing any reporting (Operating environment)
MONITORING				
Level of guidance to support where and what to look for	d.	Lack of reporting (Reporting) and/or lack of quality reporting (Species ID/ disease diagnosis)	Need for community support underestimated (Program admin)	Extent of community engagement needed underestimated (Operating environment)
REPORTING				
Support with achieving and maintaining specimen/sample quality	d. & e.	Labs receive low quality specimens and samples (Species ID/disease diagnosis)	Lack of training and/or equipment (e.g. sampling kit) in place (Program admin)	Lack of investment in system coordination (Operating environment)
Reporting tool design to meet host organisation needs	f.	Data integration into existing systems is difficult, wasted time on data cleaning & reformatting (Data management, analysis & use)	Reporting tools developed without consideration for existing system (Program admin)	Lack of investment in system coordination (Operating environment)
SPECIES IDENTIFICATION/DISEASE DIAGNOSIS				
Lab/Herbarium capacity & capability	h.	Lab struggles to cope with influx (Species ID/disease diagnosis); Notifiers do not receive timely feedback to maintain positive participation experience (Community engaged)	Need for coordination with lab/herbarium overlooked (Program admin)	Lack of skilled lab/herbarium staff (Species ID/disease diagnosis) Lack of supply of skilled lab/herbarium staff (Operating environment)
Triage processes in place	i.	Lab struggle to cope and/or resources not targeted at highest risk detection (Species ID/disease diagnosis)	Need for triaging processes overlooked or underestimated (Program admin)	Lack of investment in system coordination (Operating environment)
Need to follow up on missing information in notifications	h.	Time wasted on follow-up with notifiers (Species ID/disease diagnosis)	Lack of community training (Program admin)	Extent of investment needed for community training under-estimated (Operating environment)
DATA MANAGEMENT				
Multiple points of data handling, incl. data transfer between different data systems	j.	Can cause vulnerabilities to errors, effort wasted on data cleaning and reformatting (Data analysis and use)	Lack of evaluation of data's journey through system to end users to address vulnerabilities (Program admin)	Lack of data system integration (Operating environment)
DATA ANALYSIS				
Ease of data interrogation	k.	Sub-optimal value derived from data (Data use)	Lack of data analysis capacity and capability (Data analysis); lack of user-friendly databases (Data management)	Lack of investment in well-designed databases or data interrogation software (Operating environment)
DATA USE				
Trust in data	l.	Data users do not use general surveillance data (Data use)	Lack of species verification (Species ID/ disease diagnosis); lack of appropriate community training (Program admin)	Lack of consultation about data users' expectations to inform reporting and species ID/disease diagnosis processes (Program admin)

(Continued)

TABLE 3 Continued

Limiting factor	Figure 3.	Potential impact if limiting	Example of direct cause(s)	Example of indirect cause(s)
PEST, WEED AND/OR DISEASE PRESENCE AND IMPACT				
Prioritisation of key species based on risk and data collection requirements	m.	Community overwhelmed with too many spp. and/or not able to monitor certain species. (Engaged community)	Species selection not aligned with community expectations and needs (Program admin)	Potential of general surveillance programs overestimated (Operating environment)
OPERATING ENVIRONMENT				
Supply of ID/ diagnostic skilled staff		Limited capability and capacity to maintain spp. ID or diagnosis (Species ID/disease diagnosis)	Lack of investment in skilled lab/herbarium staff (Species ID/disease diagnosis)	
Legislation support		Program lacks legitimacy at various fronts (Program administration)	Program lacks supportive institutional environment (Operating environment)	

potential inefficiencies, such as the need for data cleaning and reformatting; or challenges related to storage. Limiting factors relate to data quality, value and efficiencies and these may happen throughout the system, from the point of collection through to where it is used.

Maximising data value begins with knowing key end-users' expectations, including how they use data, and what format best suits their needs. The value is further defined by the purpose of the program, for example, surveillance programs aimed at early detection require quick data flow to support rapid responses. In various case studies, maximising data value was hampered by a lack of capability (staff skill and/or data interrogation software) and capacity (staff time).

As before, effective community engagement and training maximise the quality of incoming data. Triaging can help with sifting out lower priority data. Inefficiencies may result from poor alignment between reporting tools and databases, or between the different databases that the data flow through.

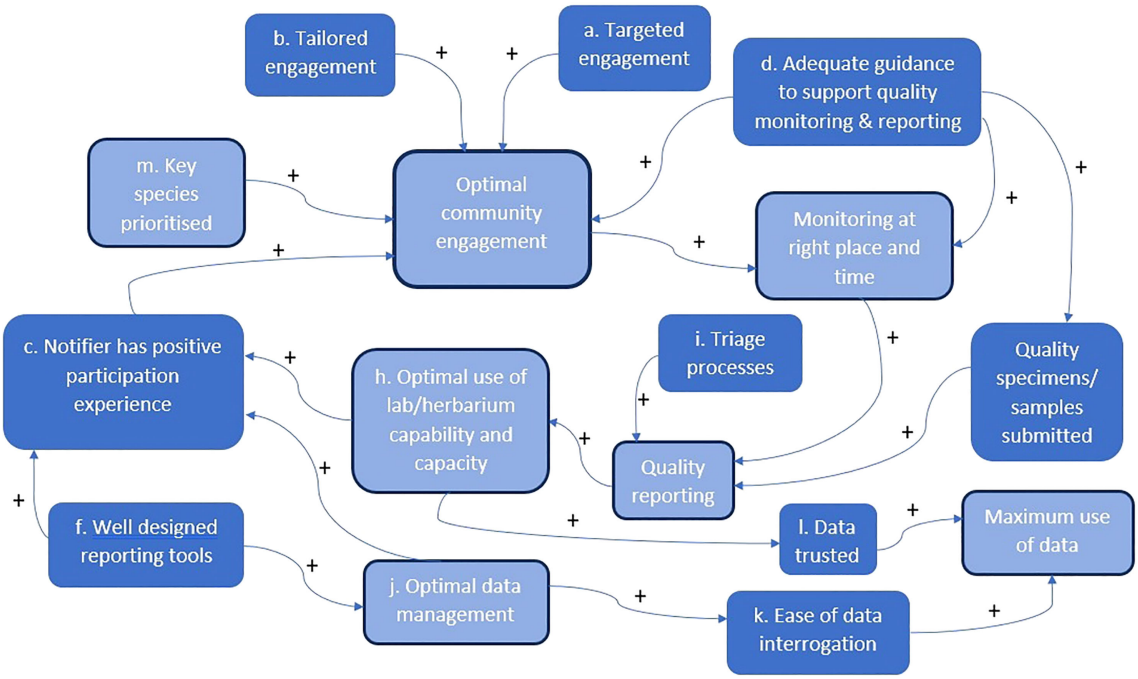

FIGURE 3
Causal loop diagram of the most common limiting factors in general surveillance programs. Various factors could limit key functions (framed boxes, see also Figure 1) in general surveillance programs. Optimal community engagement is dependent on several factors, including tailored and targeted engagement, adequate notifier guidance and support and a manageable number of target species identified. A positive participation experience for notifiers flows from various part in the program, including community engagement, feedback from the lab/herbarium and data management (e.g. privacy considerations). The quality of community engagement through adequate guidance to support quality monitoring and reporting determines whether monitoring occurs at the right time and place, which contributes to the quality of reporting, including the quality of the specimens/ samples submitted. Lab/herbarium capability and capacity is supported by triage processes as well as the quality of the reports coming in.

This suggests that the ability to answer certain surveillance related questions may not be hampered only by a lack of data, but the most limiting factor may relate to making better use of existing data which could be impeded by a lack of capability, capacity and inefficiencies. Investment in further data collection would be unwise until these challenges have been addressed.

3.6.3 Information

Information flow involving multi-directional communication about various aspects of a general surveillance program and its context is an important stock that needs to be actively managed by the program coordinator/team and can be easily underestimated. It relates to both (i) ensuring alignment within the program and with the operating environment, including information flow about limiting and most limiting factors in the system; and (ii) sustaining support from key actors.

There are seldom people who have intimate knowledge of all aspects of a general surveillance program. It can be easy to incorrectly assume things, such as capability and capacity of people and systems related to certain functions. For example, one could easily assume a program's notifications will go through a government department's usual reporting pathway with little consideration given to whether the lab/herbarium involved could deal with the increased workload. Or that the data will be stored in existing databases without considering their capacity to store additional large amounts of data, e.g. when photos are involved. Effective information flow is therefore vital to ensure information about limiting, and most, limiting factors reach decision-makers in a timely fashion to ensure that they can be addressed appropriately.

Maintaining the interest of notifiers, senior management and stakeholders is required to ensure their on-going support. This requires continuing engagement and demonstrating worth. A lack of support from any of these key groups have the potential to be the key limiting factor to a program that is functioning well and/or well resourced.

4 Conclusion

The results illustrate the diversity and commonalities of many general surveillance programs and how programs make valuable contributions to biosecurity. Contributions include fulfilling their primary purpose, such as supporting early detection; and by delivering other benefits such as building valuable networks and educating people about biosecurity that are beneficial for other biosecurity purposes, such as during emergency responses.

General surveillance programs require resourcing for a range of purposes beyond the initial and direct need for early detection of species or disease. These include intangible needs, such as building trust, undertaking liaisons and negotiations, regular engagement with stakeholders throughout the system, and being responsive to their needs. Some of these represent costs that could be easily overlooked as they are difficult to measure, yet they are essential for programs to adjust to be fit for purpose. This includes tools and processes being practical to, and well-accepted by, a range of people throughout the system. In addition, resources need to be available for adaptive management, as none of the case studies were designed perfectly from the start, but most have evolved to be more cost-effective over time.

Understanding the limiting factors, and particularly the most limiting factor, helps direct resources where they will deliver the greatest return on investment to ensure a general surveillance program achieves its goals cost-effectively. While various general surveillance programs have many limiting factors in common, there are no universal most limiting factors in general surveillance programs. The most limiting factor varies between programs and between stages of a program. For example, at some point in time for a given program it could be a lack of notifiers actively looking for certain species. Once that has been resolved, e.g. through recruitment and training, it could be that the capacity of the lab/herbarium to deal efficiently with large amounts of notifications is being challenged.

Understanding the most limiting factor requires in-depth understanding of a program and open communication between people representing different functions of the program. Well-resourced program coordinators who are well connected with people throughout the program are best placed to identify most limiting factors in a timely manner. It requires consideration of the stated goals of the program and the different stocks involved, i.e. notifiers and notifications, data and information. Regular monitoring and evaluation activities can ensure most limiting factors are identified in a timely manner to ensure apt interventions.

The survey of general surveillance programs and the case studies revealed that for most programs governments are major financial contributors. Other parties are more likely to contribute resources if they receive direct benefit from a program, including for purposes that are not directly related to biosecurity. It suggests an opportunity for attracting investment provided programs can be designed to deliver a win-win situation for different funding contributors, such as the ports participating in SWASP. This typically requires investment in co-design processes with prospective partners.

This work illustrates that it is important to understand the complexity of general surveillance programs to design programs that are cost-effective and sustainable. This understanding usually develops over time, but can be facilitated by investing in understanding the perspectives of people throughout the system. It is evident from the case study programs that it is unlikely that general surveillance programs can be developed based on a high reliance on the provision of information, resources and tools to notifiers alone that are tagged onto existing services such as species identification and data management. It seems that for general surveillance programs it is a matter of "needing to spend money to save money" as under-resourcing can seriously undermine the cost-effectiveness and sustainability of these programs.

Similarly to Pages et al. (2019), this study found that several case studies experience a tension between many funders' rationalised approaches to resourcing, e.g. to invest only in shallower engagement processes mainly based on information provision and/or to fund only surveillance of exotic species or diseases. This may fail to connect with motivations of notifiers to participate in or

support general surveillance programs. In addition to potential disengagement of notifiers, focusing on funder priorities only is likely to reenforce the divide between the community and biosecurity professionals, which counters the push for shared responsibility and partnerships in biosecurity.

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 heleen.kruger@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. The patients/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 another person, HK was the led researcher. HK lead the analysis, drafting and refinement of this research paper and JT and SH provided critical feedback, revision and input several times. All authors contributed to the article and approved the submitted version.

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. This work would not have been possible without the financial support from ABARES through the project Making General Surveillance Work (AB071M06-PZ05). Thank you to the two reviewers for valuable input to improve earlier drafts of this article.

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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1106751/full#supplementary-material

References

Aceves-Bueno, E., Adeleye, A. S., Bradley, D., Tyler Brandt, W., Callery, P., Feraud, M., et al. (2015). Citizen Science as an approach for overcoming insufficient monitoring and inadequate stakeholder buy-in in adaptive management: criteria and evidence. *Ecosystems* 18, 493–506. doi: 10.1007/s10021-015-9842-4

Anderson, C., Low-Choy, S., Whittle, P., Taylor, S., Gambley, C., Smith, L., et al. (2017). Australian plant biosecurity surveillance systems. *Crop Prot.* 100, 8–20. doi: 10.1016/j.cropro.2017.05.023

Ayer, M., Yunupingu, D., Wearne, J., Cheryl, O. D., Vernes, T., and Marika, M. (2021). Accounting for Yolŋu ranger work in the Dhimurru Indigenous Protected Area, Australia. *Ecol. Soc.* 26(1):24.

Barnes, B., Giannini, F., Arthur, A., and Walker, J. (2019). Optimal allocation of limited resources to biosecurity surveillance using a portfolio theory methodology. *Ecol. Economics* 161, 153–162. doi: 10.1016/j.ecolecon.2019.03.012

Berec, L., Kean, J. M., Epanchin-Niell, R., Liebhold, A. M., and Haight, R. G. (2015). Designing efficient surveys: spatial arrangement of sample points for detection of invasive species. *Biol. Invasions* 17, 445–459. doi: 10.1007/s10530-014-0742-x

Brightling, P., and Hope, A. (2017). *NABS Stakeholder Needs Analysis - Laying the foundation for stakeholder participation in the disease surveillance system in Northern Australia* (Harris Park Group report for the NABS Working Group), 46pp

Cacho, O., Reeve, I., Trammell, J., and Hester, S. (2012). Valuing community engagement in biosecurity surveillance. Australian Centre of Excellence for Risk Analysis, 90pp. cebra.unimelb.edu.au/__data/assets/pdf_file/0005/2068736/1004B_OID7_Report.pdf

Cacho, O. J., Spring, D., Hester, S., and Mac Nally, R. (2010). Allocating surveillance effort in the management of invasive species: A spatially-explicit model. *Environ. Model. Software* 25, 444–454. doi: 10.1016/j.envsoft.2009.10.014

Caley, P., Welvaert, M., and Barry, S. C. (2020). Crowd surveillance: estimating citizen science reporting probabilities for insects of biosecurity concern. *J. Pest Sci.* 93, 543–550. doi: 10.1007/s10340-019-01115-7

Carnegie, A. J., and Nahrung, H. F. (2019). Post-border forest biosecurity in Australia: response to recent exotic detections, current surveillance and ongoing needs. *Forests* 10, 336. doi: 10.3390/f10040336

Carvajal-Yepes, M., Cardwell, K., Nelson, A., Garrett, K. A., Giovani, B., Saunders, D. G., et al. (2019). A global surveillance system for crop diseases. *Science* 364, 1237–1239. doi: 10.1126/science.aaw1572

Coggan, A., Whitten, S. M., and Bennett, J. (2010). Influences of transaction costs in environmental policy. *Ecol. economics* 69, 1777–1784. doi: 10.1016/j.ecolecon.2010.04.015

Conrad, C. C., and Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environ. Monit. Assess.* 176, 273–291. doi: 10.1007/s10661-010-1582-5

Craik, W., Palmer, D., and Sheldrake, R. (2017). *Priorities for Australia's biosecurity system: An independent review of the Capacity of the National Biosecurity System and its Underpinning Intergovernmental Agreement* (Canberra: Commonwealth of Australia).

Crall, A. W., Renz, M., Panke, B. J., Newman, G. J., Chapin, C., Graham, J., et al. (2012). Developing cost-effective early detection networks for regional invasions. *Biol. Invasions* 14, 2461–2469. doi: 10.1007/s10530-012-0256-3

Denscombe, M. (2009). *Ground Rules for Social Research: Guidelines for Good Practice* (McGraw Hill Open University Press, UK).

Donaldson, A. (2013). "Governing biosecurity," in *Biosecurity: the socio-politics of invasive species and infectious diseases*. Eds. A. DOBSON, K. BARKER and S. L. TAYLOR (Routledge). doi: 10.4324/9780203113110

Drewe, J. A., Hoinville, L., Cook, A., Floyd, T., and Stärk, K. D. (2012). Evaluation of animal and public health surveillance systems: a systematic review. *Epidemiol. Infection* 140, 575–590. doi: 10.1017/S0950268811002160

Eisenhardt, K. M., and Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of management journal* 50, 25–32.

Enticott, G., and Franklin, A. (2009). Biosecurity, expertise and the institutional void: the case of bovine tuberculosis. *Sociologia Ruralis* 49, 375–393. doi: 10.1111/j.1467-9523.2009.00496.x

Epanchin-Niell, R. S., Haight, R. G., Berec, L., Kean, J. M., and Liebhold, A. M. (2012). Optimal surveillance and eradication of invasive species in heterogeneous landscapes. *Ecol. Lett.* 15, 803–812. doi: 10.1111/j.1461-0248.2012.01800.x

Epanchin-Niell, R., Thompson, A. L., and Treakle, T. (2021). Public contributions to early detection of new invasive pests. *Conserv. Sci. Pract.* 3, e422. doi: 10.1111/csp2.422

FAO (2018). *IPSM 6 - Surveillance. International Standards for Phytosanitary Measures* (Food and Agriculture Organisation).

Gardiner, M. M., Allee, L. L., Brown, P. M. J., Losey, J. E., Roy, H. E., and Smyth, R. R. (2012). Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. *Front. Ecol. Environ.* 10, 471–476. doi: 10.1890/110185

Gould, B. (2019). *Biosecurity surveillance continuing to play a critical role in New Zealand's biosecurity system. Surveillance - Ministry for Primary Industries Reporting on New Zealand's Biosecurity Health Status. Annual Report ed* (NZ: Wellington).

Hester, S. M., and Cacho, O. J. (2017). The contribution of passive surveillance to invasive species management. *Biol. Invasions* 19, 737–748. doi: 10.1007/s10530-016-1362-4

Hoinville, L. (2013). Animal Health Surveillance Terminology Final Report from Pre-ICAHS Workshop,version 1.2, 1–27. Available at: www.fp7-risksur.eu/sites/default/files/partner_logos/icahs-workshop-2011_surveillance_tewrminology_report_V1.2.pdf.

Invasive Plants and Animals Committee (2017a). *Australian Pest Animal Strategy 2017 to 2027* (Canberra: Department of Agriculture and Water Resources).

Invasive Plants and Animals Committee (2017b). *Australian Weeds Strategy 2017 to 2027* (Department of Agriculture and Water Resources).

Koch, F. H., Yemshanov, D., Haight, R. G., Macquarrie, C. J., Liu, N., Venette, R., et al. (2020). Optimal invasive species surveillance in the real world: practical advances from research. *Emerging Topics Life Sci.* 4, 513–520. doi: 10.1042/ETLS20200305

Kompas, T., Chu, L., Van Ha, P., and Spring, D. (2019). Budgeting and portfolio allocation for biosecurity measures. *Aust. J. Agric. Resource Economics* 63, 412–438. doi: 10.1111/1467-8489.12305

Kruger, H., El Hassan, M., Stenekes, N., and Kancans, R. (2020). *Understanding general surveillance for biosecurity as a system* (Canberra: Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES).

Kruger, H., Ticehurst, J., and Van Der Meer Simo, A. (2022a). *Guidelines for general surveillance programs – Insights and considerations from systems thinking and nine case studies. Canberra: ABARES*, 81pp. Available at: https://daff.ent.sirsidynix.net.au/client/en_AU/search/asset/1033161/0.

Kruger, H., Ticehurst, J., and van der Meer Simo, A. (2022b). *Making general surveillance programs work - Lessons from nine case studies* (Australian Bureau of Agricultural and Resource Economics and Sciences).

Laidlaw, M. J., Holland, A., and Guymer, G. (2016). Many eyes on the prize: the role of citizen scientists in active weed surveillance. In Proceedings of the 20th Australasian Weeds Conference, Perth, Australia (pp. 11–15).

Lawson, B., Petrovan, S. O., and Cunningham, A. A. (2015). Citizen science and wildlife disease surveillance. *EcoHealth* 12, 693–702. doi: 10.1007/s10393-015-1054-z

Marine Pest Sectoral Committee (2019). *National Marine Pest Surveillance Strategy* (Canberram: Department of Agriculture).

Marshall, G. R. (2013). Transaction costs, collective action and adaptation in managing complex social–ecological systems. *Ecol. Economics* 88, 185–194. doi: 10.1016/j.ecolecon.2012.12.030

Mastin, A. J., Van Den Bosch, F., Van Den Berg, F., and Parnell, S. R. (2019). Quantifying the hidden costs of imperfect detection for early detection surveillance. *Philos. Trans. R. Soc. B* 374, 20180261. doi: 10.1098/rstb.2018.0261

McCann, L., Colby, B., Easter, K. W., Kasterine, A., and Kuperan, K. V. (2005). Transaction cost measurement for evaluating environmental policies. *Ecol. economics* 52, 527–542. doi: 10.1016/j.ecolecon.2004.08.002

Mcdonald, J. I., Wellington, C. M., Coupland, G. T., Pedersen, D., Kitchen, B., Bridgwood, et al (2020). A united front against marine invaders: Developing a cost-effective marine biosecurity surveillance partnership between government and industry. *Journal of Applied Ecology* 57, 77–84.

Meadows, D. H. (2008). *Thinking in systems: A primer* (White River Junction, USA: Chelsea Green Publishing).

Moir, F., and van den Brink, A. (2020). Current insights in veterinarians' psychological wellbeing. *New Z. veterinary J.* 68, 3–12. doi: 10.1080/00480169.2019.1669504

Morfe, T. (2014). *An Economic Evaluation of Enhanced Passive Surveillance Design: The Difference 'Weed Spotters Project'Make in Early Detection (The Discovery of Salvinia molesta incursion in 2010 in West Gippsland, Victoria)* (Melbourne: Department of Environment and Primary Industries (DEPI).

Munakamwe, Z., Constantine, A., and Mcinerney, C. (2018). "The Victorian Weed Spotters: recruitment and training of citizen scientists," in *21st Australasian Weeds Conference," Weed Biosecurity-Protecting our Future*, Sydney, New South Wales, Australia, 9-13 September 2018. 193–196.

NHMRC (2007). *National Statement on Ethical Conduct in Human Research* (Canberra: National Health and Medical Research Council, Australian Government).

NHMRC (2018). *Australian Code for the Responsible Conduct of Research* (Canberra: National Health and Medical Research Council, Australian Government).

NZ Ministry of Primary Industries (2016). *Biosecurity 2025 - Direction statement of New Zealand's Biosecurity System* (Wellington: Ministry of Primary Industries).

Oidtmann, B. C., Thrush, M. A., Denham, K. L., and Peeler, E. J. (2011). International and national biosecurity strategies in aquatic animal health. *Aquaculture* 320, 22–33. doi: 10.1016/j.aquaculture.2011.07.032

OIE (2019). *The OIE PPP Handbook: Guidelines for Public-Private Partnerships in the Veterinary Domain* (OIE Paris).

Pages, M., Fischer, A., van der Wal, R., and Lambin, X. (2019). Empowered communities or "cheap labour"? Engaging volunteers in the rationalised management of invasive alien species in Great Britain. *J. Environ. Manage.* 229, 102–111. doi: 10.1016/j.jenvman.2018.06.053

PHA (2021). *National Plant Biosecurity Surveillance Strategy 2021-2031* (Canberra, ACT, Australia: Plant Health Australia).

Poland, T. M., and Rassati, D. (2018). Improved biosecurity surveillance of non-native forest insects: a review of current methods. *J. Pest Sci.* 92, 37–49. doi: 10.1007/s10340-018-1004-y

Queensland Government (2016). *Invasive Plant Risk Assessment - Karroo thorn (Acacia karroo)* (DEPARTMENT OF AGRICULTURE AND FISHERIES).

Rich, K. M., Denwood, M. J., Stott, A. W., Mellor, D. J., Reid, S. W., and Gunn, G. J. (2013). Systems approaches to animal disease surveillance and resource allocation: methodological frameworks for behavioral analysis. *PloS One* 8, e82019. doi: 10.1371/journal.pone.0082019

Richardson, G. P. (2011). Reflections on the foundations of system dynamics. *System Dynamics Rev.* 27, 219–243. doi: 10.1002/sdr.462

Senge, P. M. (2006). *The Fifth Discipline - The Art & Practice of the Learning Organisation* (New York: Doubleday/Currency).

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R., et al. (2004). The economic impact of weeds in Australia. *CRC for Australian Weed Management Technical Series* no.8, 65pp. Available at: https://weeds.org.au/wp-content/uploads/2020/02/tech_series_8.pdf.

Sousa, L. B., Fricker, S. R., Doherty, S. S., Webb, C. E., Baldock, K. L., and Williams, C. R. (2020). Citizen science and smartphone e-entomology enables low-cost upscaling of mosquito surveillance. *Sci. Total Environ.* 704, 135349. doi: 10.1016/j.scitotenv.2019.135349

Spring, D., and Cacho, O. J. (2015). Estimating eradication probabilities and trade-offs for decision analysis in invasive species eradication programs. *Biol. invasions* 17, 191–204. doi: 10.1007/s10530-014-0719-9

Sterman, J. (2002). System Dynamics: systems thinking and modeling for a complex world. *Massachusetts Institute of Technology, Engineering Systems Division, Working Paper Series*, ESD-WP-2003-01.13. Available at: https://dspace.mit.edu/bitstream/handle/1721.1/102741/esd-wp-2003-01.13.pdf?sequence=1&isAllowed=y.

Stoeckl, N., Hicks, C., Farr, M., Grainger, D., Esparon, M., Thomas, J., et al. (2018). The crowding out of complex social goods. *Ecol. Economics* 144, 65–72. doi: 10.1016/j.ecolecon.2017.07.021

Thomas, M. L., Gunawardene, N., Horton, K., Williams, A., O'connor, S., Mckirdy, S., et al. (2017). Many eyes on the ground: citizen science is an effective early detection tool for biosecurity. *Biol. Invasions* 19, 2751–2765. doi: 10.1007/s10530-017-1481-6

Ticehurst, J. L., 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

Voice, D. G., Maclellan, R., Russell, A., Goulden, D., Lawrie, I., Baker, G., et al. (2022). The eradication of pea weevil Bruchus pisorum (L.)(Coleoptera: Chrysomelidae) from New Zealand. *CABI Agric. Bioscience* 3, 1–13. doi: 10.1186/s43170-022-00093-8

Wilson, J., Stephenson, B., Gill, G., Randall, J., and Vieglais, C. (2004). Principles of response to detections of new plant pest species and the effectiveness of surveillance. *New Z. Plant Prot.* 57, 156–160. doi: 10.30843/nzpp.2004.57.6896