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Toward biodefence: a framework for the mitigation of malicious threats to livestock production enterprises in Australia

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Abstract Biosecurity underpins the Australian agricultural sector, estimated to be worth $51 billion in exports and trade, $50 billion in tourism, $5.7 trillion in environmental assets, and more than 1.6 million jobs. Given the value to the Australian economy and the potential consequences of a deliberately introduced biological agent, measures to prevent malicious biosecurity threats are critical for national security. Using the framework of Situational Crime Prevention (SCP), the study examined recommended biosecurity practices for cattle production enterprises in Australia and explored the extent to which the Australian biosecurity framework is underpinned by preventative security. The study found the existing biosecurity framework has limited theoretical security underpinning and is constituted by practices primarily aimed at preventing naturally occurring and accidental threats, rather than an active preventative security approach at the farming level to mitigate threats of a malicious or deliberate nature. These findings identify a deficit in Australia's national security approach to biosecurity in cattle production enterprises, establishing a need for biosecurity recommendations at an industry and primary production level to embed security theory and principles to account for malicious actors in alignment with international biodefence strategy. Subsequently, the study demonstrated how security theory can be applied to biosecurity and the agricultural sector more broadly and developed an SCP framework toward biodefence of agriculture, converging biosecurity and security as a bilateral approach to mitigating naturally occurring, accidental, and deliberate biosecurity threats.

1 Introduction

Agricultural systems around the world, including Australia, may be highly vulnerable to malicious attack from international and domestic terrorists, militant animal rights activists, economic opportunists, biocriminals, and motivated individuals [1–3]. A deliberately introduced pathogen has the potential to disable an entire agricultural industry and national economy, food production, and supply chains and could further impact human health in the event of a deliberately introduced zoonotic disease affecting both animals and humans. Modern agricultural production, distribution, and trade is a global endeavor, and as such, the implications of a malicious attack on agriculture could be catastrophic [4–7].

In recent years, biosecurity risks resulting from unlawful access to Australian agriculture have been demonstrated through several deliberate incidents on farming properties, including trespassing and theft of livestock by animal activists, and the deliberate contamination of farm produce [8–12]. However, the risk of more serious incidents such as terrorism, agro-terrorism, and biocrime may increase where malicious actors are able to acquire pathogens from naturally occurring outbreaks, from microbiological facilities with inadequate security measures, or by exploiting advances in biotechnology to create or modify existing pathogens for deliberate introduction or release [13, 14].

Recently, the spread of Foot and Mouth Disease (FMD) within Indonesia has created significant concerns regarding the impact a FMD outbreak would have on the Australian agricultural industry, exports, and wider national economy if the virus were to penetrate the national border [15]. An outbreak of FMD is estimated to cost $80 billion in industry and trade and could result in the destruction of millions of animals [16, 17]. Pre-border and border-based biosecurity efforts are proactive and extensive and have thus far prevented FMD and other diseases being introduced to Australia. However, the response at the border is reliant to some extent on the cooperation of incoming travelers in complying with biosecurity control measures and therefore may not detect all potential sources of high-consequence pathogens or prevent their introduction and transmission [18–21]. Consequently, deliberate attempts to conceal such pathogens may succeed in penetrating existing border defenses and farming enterprises.

Despite the global biosecurity literature indicating that the implementation of biosecurity practices on farms can help mitigate the deliberate introduction and spread of biological organisms [2, 3, 22], there are currently no mandatory requirements for Australian

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cattle production enterprises to implement preventative security measures or biosecurity practices at the farming level. This limitation suggests a disconnect between the Australian biosecurity framework and the best practice in international biodefence strategy, where biosecurity measures are used in conjunction with frameworks, systems, policies, and practices to mitigate biological threats across the risk continuum [3, 23–25]. Unlike Australia, the international biodefence approach is holistic and explicitly recognizes threats of a malicious nature, incorporating security theory into biosecurity definitions and approaches with a strong emphasis on preventative strategies [3, 26–28].

The disconnect between the Australian biosecurity framework and international biodefence strategy raised questions as to the prevalence and nature of preventative security measures incorporated into biosecurity practices at the farming level and the potential vulnerability of livestock production enterprises to malicious biological threats. Subsequently, the study examined published recommendations of biosecurity practices for Australian cattle production enterprises to explore the extent to which the current biosecurity framework can account for and reduce opportunities for malicious biosecurity threats at the farming level.

2 Study aim

The study examined the extent to which underlying security theory and principles are incorporated into the current biosecurity framework using Situational Crime Prevention (SCP), as both a foundational and criminological approach to mitigating threats within the spectrum of security [29–35]. Subsequently, the study reviewed published recommendations of biosecurity practices for cattle production enterprises in Australia to evaluate the presence of SCP categories and techniques and further developed an architecture of practices to account for malicious biosecurity threats in alignment with international biodefence strategy [25, 26, 28]. The SCP framework toward biodefence converges biosecurity and security as a bilateral approach to mitigating naturally occurring, accidental, and deliberate biosecurity threats and demonstrates how cattle production enterprises and the broader agricultural sector can be included within a wider national biodefence strategy.

3 Theoretical framework

Situational Crime Prevention (SCP) [29] was used as the study's underlying theory to explore the extent to which the current biosecurity framework incorporates preventative security measures within biosecurity publications at the farming level. The work of Lab [34] noted that SCP embodies rational choice theory in that offenders have control over their actions and that there is a clear belief that offenders make rational choices to offend based on a personal cost-benefit analysis [34]. Therefore, SCP premises that manipulations to the immediate environment in a manner that will increase the effort involved, increase the risks, decrease the rewards, reduce provocations, and remove excuses will drive offenders to seek out situations where there is less effort and risk required [34]. The development of SCP over time has seen the application of techniques expanded to emerging and contemporary situations including organized crime, identity theft, and terrorism [36]. The contemporary SCP typology (Table 1) consists of a rubric of five overarching crime prevention categories embodying situational-focused techniques that can be used individually or collectively to deter and prevent an offender targeting specific types of crimes at specific locations [31–34].

The appropriateness of SCP to mitigate deliberate and malicious acts such as terrorism or bioterrorism has been supported across the broader crime prevention literature [36–39]. Freilich and Newman [36] assert that although terrorism is often seen as a political problem, responses which are anchored outside of political theory may, in fact, offer a more holistic solution. They explicitly affirm the use of SCP to mitigate opportunity for the expression of discontent through harmful actions, by limiting the opportunities through target hardening and access control measures, increasing the risks through increased surveillance and detection measures, and reducing the rewards through harm reduction techniques. Clare and Morgan [37] affirm SCP as a proactive approach to mitigate

Table 1 Twenty-five techniques of situational crime prevention

Increase the Effort	Increase the Risk	Reduce the Reward	Reduce Provocations	Remove Excuses
1. Target Harden	6. Extend Guardianship	11. Conceal Targets	16. Reduce Frustrations and Stress	21. Set Rules
2. Control Access to Facilities	7. Assist Natural Surveillance	12. Remove Targets	17. Avoid Disputes	22. Post-Instructions
3. Screen Exits	8. Reduce Anonymity	13. Identify Property	18. Reduce Arousal and Temptation	23. Alert Conscience
4. Deflect Offenders	9. Use Place Managers	14. Disrupt Markets	19. Neutralize Peer Pressure	24. Assist Compliance
5. Control Tools/Weapons	10. Strengthen Formal Surveillance	15. Deny Benefits	20. Discourage Imitation	25. Control Drugs and Alcohol

Adapted from 'Crime Analysis for Problem Solvers in 60 Small Steps' by R.V. Clarke and J.E. Eck, 2016, Center for Problem-Oriented Policing. Copyright 2016 by U.S. Department of Justice

against deviance, referring to Clarke and Newman's [38] Situational Prevention of Terrorism (SPT) in conjunction with additional opportunity reducing techniques including political, social, and economic policy, diplomacy, harm minimization, and improvements to increase the impact of legal, judicial, and law enforcement mechanisms.

4 Methodology

The study applied a mixed-methods approach across two research stages [40]. Stage One of the study undertook a systematic review to develop biosecurity sub-themes from publications of biosecurity practices recommended for livestock (cattle) production enterprises. Stage One further aligned the biosecurity sub-themes with Situational Crime Prevention (SCP) techniques, by placing the developed themes within a SCP Biosecurity Rubric for validation in Stage Two of the study. Stage Two used a Multidimensional Statistical Scaling (MDS) survey instrument to validate the placement of biosecurity sub-themes within the biosecurity Situational Crime Prevention (SCP) Rubric, by measuring comparisons of 'pairs of objects,' consisting of both biosecurity sub-themes and SCP techniques. Subsequently, by spatially conveying the relationship between concepts, MDS expresses how well the placement of biosecurity sub-themes is within the Biosecurity SCP Rubric, with clustered object points indicating similarity and subsequently correct placement [41–44]. The outcome of Stage Two was to validate the degree to which the populated Biosecurity SCP Rubric was underpinned by security theory, thereby facilitating the development of an SCP framework toward biodefence of agriculture in alignment with international biodefence strategy.

4.1 Stage One—systematic review

Stage One undertook a systematic review of published guides and manuals for recommended on-farm biosecurity practices in livestock (cattle) production. The systematic review used a purposive dataset of publications of biosecurity practices recommended for livestock producers (dairy and beef production). The review was conducted using formulated review questions, with inclusion and exclusion criteria being developed in accordance with the systematic review process [45, 46]. The literature search was conducted across 34 online sources and located more than 400 documents for evaluation. A total of 45 publications were identified for critical appraisal, and 14 publications were included for extraction and theme development [45–47].

A Thematic Analysis was undertaken to generate descriptive biosecurity sub-themes from extracted data. A total of 2074 biosecurity practices contained in the 14 selected publications were extracted for Thematic Analysis. An inductive approach to data analysis was used, where the extracted biosecurity practices were grouped by thematic category ('Initial Themes'), and dual-purpose biosecurity practices were identified. Initial Themes were further analysed to develop overarching biosecurity sub-themes which were then aligned with Situational Crime Prevention (SCP) techniques and categories (see Table 2) [34, 40, 48–51].

Following alignment with SCP categories and techniques, the developed biosecurity sub-themes were then embedded into a Biosecurity SCP Rubric to reflect the security categories included in publications of recommended on-farm biosecurity practices for WA Cattle Production Enterprises. The Biosecurity SCP Rubric was then taken into Stage Two of the study to verify the positional aligning of biosecurity practices with SCP techniques using MDS. Expert verification of the positional alignment of biosecurity sub-themes with SCP techniques subsequently validated the population of the Biosecurity SCP Rubric and, therefore, the degree to which SCP theory is embedded in published recommendations of biosecurity practices.

4.2 Stage Two—Multidimensional Statistical Scaling (MDS) evaluation

Stage Two of the study validated the alignment of the Stage One biosecurity sub-themes with Situational Crime Prevention (SCP) techniques and categories. This stage used Multidimensional Statistical Scaling (MDS) analysis, in which security and biosecurity experts and competent professionals rated the dissimilarity of biosecurity sub-themes and SCP techniques to visually depict the strength of the object relatedness. The MDS analysis was used to verify the positional aligning of biosecurity practices with SCP

Table 2 Alignment of biosecurity practices and themes with SCP categories and techniques

Recommended biosecurity practice from publication	Pub. no.	Dual-purpose Practice	Initial Themes	Biosecurity Sub-theme	SCP Category	SCP Technique
Check animals for health status before purchasing	8	x	Pre-purchase Inspections	Entry Screening	Increase the Risk	Assist Natural Surveillance
		x	Stock/Health Declarations		Remove Excuses	Assist Compliance

techniques. As MDS uncovers underlying structure of associated concepts, this technique was used to verify or refute the alignment of security and/or biosecurity themes extracted within the Stage One Biosecurity SCP Rubric [41–44].

Themes and categories from Stage One data analysis were inserted into an online survey instrument designed to allow participants to rate the dissimilarity of the themes and categories tested [41, 42]. A dataset of 'pairs of objects' for testing was generated through the random selection of biosecurity themes within three SCP Rubric squares (SCP Technique #2: *Control Access to Facilities*; SCP Technique#22: *Post-Instructions*; and SCP Technique #24: *Assist Compliance*). To reduce ambiguity of survey terms, biosecurity sub-themes and SCP terms were adjusted to include 'practical' language, introducing more tangible terms for presentation to participants [50, 52]. The practical biosecurity themes and modified SCP terms, together with the central term 'Biosecurity,' produced 45 pairs of objects for testing in the MDS Survey Instrument [41]. Participants rated the dissimilarity of two items at a time using a sliding scale [41, 42]. The MDS survey was distributed electronically with a survey link to participants who met the developed criteria for selection or those referred by snowballing technique (see Population and Sample).

Data analysis was conducted with Qualtrics and SPSS using descriptive statistics and Multidimensional Statistical Scaling (MDS). Survey responses were exported from Qualtrics to SPSS, and descriptive statistics were generated from the survey responses. The MDS analysis was conducted with SPSS software using the PROXSCAL algorithm. Mean scores were used to construct a half-matrix in SPSS to enable a Scree Plot and Common Space map to be generated for analysis of participant responses [42, 44, 52]. The Scree Plot is typically used to determine the number of dimensions suitable for the Common Space map by generating the highest interpretability in conjunction with the lowest Stress value [42, 53].

A Scree Plot with a minimum of one-dimension and a maximum of nine-dimensions was generated to identify the number of dimensions which should be used to minimize Stress when locating data objects as points in space [42, 44, 52]. A Scree Plot with a minimum of one- and a maximum of three-dimensions produced a distinct 'elbow' at the second dimension, indicating two-dimensions as being optimal for Stress [42, 44, 52]. Interpretation of the relatedness of data (object points) was facilitated through generation of an MDS Common Space map [42, 44, 53]. Common Space maps were generated for all nine-dimensions, and plots at three-dimensions and higher were found to have significantly reduced interpretability, again indicating two-dimensions as being optimal for interpretability. The Common Space map generated for interpretation (see Analysis and results) therefore used a minimum and maximum of two-dimensions [42, 44, 53].

4.3 Population and sample

The study used a nonprobability purposive sample of local, national, and international security and biosecurity experts and competent professionals [52]. Development of the inclusion criteria for survey participation considered qualitative and quantitative elements of both 'expertise' and 'professional competence.' The criteria for participation included security and biosecurity experts and professionals within multiple industries, activities, and with varying degrees of training and qualifications including professional security and biosecurity practitioners, qualified security or biosecurity professionals, and individuals with extensive industry, government, academic, or research experience in security or biosecurity.

The study used an acclamation approach and snowballing technique [52, 54]. Daniel [55] suggests a sample size of 30 participants for nonprobability samples requiring analysis of minor sub-groups. Subsequently, the initial sample size for this study was 30 participants; however, the survey instrument was divided into two conditions to reduce the number of judgments required and subsequently reduce the potential for participant fatigue [56]. Division of the survey into two conditions resulted in the sample size increasing from 30 to 60 participants [56]. A total of 259 experts and competent professionals were contacted for participation (including 27 participants referred via a snowballing technique) [52], with 66 participants from 18 countries and across six continents responding to the survey (Survey One, $n = 34$; Survey Two, $n = 32$), giving an overall response rate of 25.48%. Of the 248 participants initially identified, 10% ($n = 25$) were biosecurity experts or competent professionals, while 88% ($n = 218$) were security experts or competent professionals, and 2% ($n = 5$) belonged to both populations.

4.4 Validity and reliability

In Stage One of the study, publications included in the systematic review were assessed by independent reviewers to ensure selected publications met the inclusion criteria and satisfied the research objectives, thereby establishing face and content validity [48]. Independent reviewers were also used to ensure the coding and interpretation of themes were appropriate [57]. Validity for Stage One was further achieved as a result of the Stage Two MDS analysis supporting the placement of Stage One themes within the Biosecurity SCP Rubric. Validity of Stage Two results was supported through the MDS 'Goodness-of-Fit' by achieving a Stress value of 0.00119 indicating the approximate Goodness-of-Fit of the data was 'Excellent' based on Kruskal's Stress formula [42, 43]. Reliability of Stage Two was also evaluated through the MDS 'Goodness-of-Fit,' where the instrument was considered reliable if the Stress value was less than 0.1 [42, 43, 58]. To further increase reliability, a test–retest method correlated the results of the pilot study with the results of the main study using Cronbach's alpha [58, 59]. The test–retest reliability coefficient was calculated at 0.84 indicating good reliability in accordance with correlational scores in the range of ≥ 0.8 and ≤ 0.9 [60].

Increase the Effort	Increase the Risks	Reduce the Rewards	Reduce Provocation	Remove Excuses
1. Target Harden	**6. Extend Guardianship**	**11. Conceal Targets**	**16. Reduce Frustrations**	**21. Set Rules**
Emergency Preparedness; Infection Prevention & Control; Create Biosecurity Awareness	Community Engagement; Promote Biosecurity Knowledge and Awareness; Collaborate with Industry & Professionals			Detect Contamination; Livestock & Product Entry Screening; Livestock Health Exit Screening; Outbreak Detection; Prevent Contamination; Restrict Movement
2. Control Access to Facilities	**7. Assist Natural Surveillance**	**12. Remove Targets**	**17. Avoid Disputes**	**22. Post Instructions**
Access Control; Detect Biosecurity Breaches; Prevent Access from unknown or Wild Animals	Disease, Pest & Weed Surveillance; High Risk Environmental Surveillance		Maintain Asset & Valuation Evidence	Display Biosecurity Signs & Visual Aids
3. Screen Exits	**8. Reduce Anonymity**	**13. Identify Property**	**18. Reduce Emotional Arousal**	**23. Alert Conscience**
	Identify Livestock with Tags & Records; Record Keeping to Increase Traceability			Accurate & Honest Record Keeping; Encourage Adoption of Biosecurity Practices
4. Deflect Offenders	**9. Utilise Place Managers**	**14. Disrupt Markets**	**19. Neutralise Peer Pressure**	**24. Assist Compliance**
				Administration & Management; Promote & Comply with Regulations & Standards; Develop & Implement Policy & Procedure
5. Control Tools/ Weapons	**10. Strengthen Formal Surveillance**	**15. Deny Benefits**	**20. Discourage Imitation**	**25. Control Drugs & Alcohol**

Fig. 1 SCP categories and techniques represented in publications of biosecurity practices. *Note*: Adapted from 'Crime Analysis for Problem Solvers in 60 Small Steps' by R.V. Clarke and J.E. Eck, 2016, Center for Problem-Oriented Policing. Copyright 2016 by U.S. Department of Justice; adapted from 'Crime prevention: Approaches, practices and evaluations' by S. Lab, 2013. Copyright 2013 by Routledge

5 Analysis and results

5.1 Stage One—systematic review and SCP Biosecurity Rubric

The systematic review and Thematic Analysis resulted in the extraction of 842 unique biosecurity practices from publications of recommended biosecurity practices. There were a total of 2074 biosecurity practices analysed, including dual-purpose practices ($n = 706$) and duplicates ($n = 1232$). The Thematic Analysis produced 164 initial themes resulting in the development of 26 biosecurity sub-themes [32, 34]. Biosecurity sub-themes generated from the Thematic Analysis aligned with 10 of 25 possible SCP techniques, resulting in the Biosecurity SCP Rubric being partially (40%) populated. The study found that biosecurity sub-themes aligned across the SCP techniques of Target Harden, Control Access to Facilities, Extend Guardianship, Assist Natural Surveillance, Reduce Anonymity, Avoid Disputes, Set Rules, Post-Instructions, Alert Conscience, and Assist Compliance. Subsequently, the Biosecurity SCP Rubric (Fig. 1) was found to be constituted by 10 SCP techniques (shown in green), revealing the SCP categories and techniques which are absent (shown in red) from publications of recommended biosecurity practices.

However, determining the extent of security underpinning within the biosecurity sub-themes aligned with SCP categories was challenging. Although the biosecurity sub-themes were aligned with 10 SCP categories, this was not indicative that biosecurity sub-themes included conventional security measures designed to mitigate malicious threats. For instance, while biosecurity sub-themes were aligned with SCP Technique #1 Target Harden, the majority (76%) of recommended biosecurity practices within this group

related to the biosecurity sub-theme Infection Prevention and Control, that is, the sub-themes did not account for malicious actors. Biosecurity practices included measures such as vaccination and treatments, disinfectants, Personal Protective Equipment (PPE), and hygienic practices such as washing, cleaning, etc. 'Target Hardening' in this case did not include physical security measures to secure the physical environment [35, 38].

In contrast to the broader security theories and principles, which include 'Target Hardening' assets through the application of conventional security measures, the recommended biosecurity practices were predominantly intended to reduce pathogenic opportunity by obstructing the entry, establishment, and spread of pathogens among livestock, essentially 'Target Hardening' the livestock. Consequently, the Biosecurity SCP Rubric was found to be constituted by practices which are primarily aimed at preventing the 'pathogenic offender' (naturally occurring and accidental threats), rather than measures to prevent and detect the 'human offender' with malicious intent (deliberate threats) [36, 39, 61]. Therefore, despite some alignment of biosecurity sub-themes with SCP categories in the Biosecurity SCP Rubric, the degree of security theories and principles underpinning biosecurity practices was exceptionally limited, indicating the capacity for recommended biosecurity practices to mitigate malicious human actions is also likely to be limited [31, 34, 35, 38].

Furthermore, the study found evidence of a deficit in security measures across all publications of recommended biosecurity practices. For instance, the systematic review of biosecurity publications uncovered a complete absence of recommendations for physical and procedural security measures such as the installation of CCTV, security lighting, vehicle exit barriers, farm-based monitoring and intrusion detection systems, security/background screening for employees, and IT/cybersecurity (such as computer and information security). Subsequently, the low density of biosecurity sub-themes within the Biosecurity SCP Rubric combined with the absence of physical and procedural security measures provided substantive evidence that the current recommendations of biosecurity practices are not adequately underpinned by preventative security theory and practice. This lack of security underpinning within the current framework signifies that recommended biosecurity practices may have a limited efficacy in reducing opportunities for malicious centered threats (see [32, 34]).

5.2 Stage Two—MDS evaluation

The Multidimensional Statistical Scaling (MDS) analysis presented a visual representation of the proximity distances of biosecurity themes in multidimensional space, to validate the structure and placement of sub-themes within the biosecurity Situational Crime Prevention (SCP) Rubric [42, 44]. Validation of sub-themes within the Biosecurity SCP Rubric was achieved through identification and interpretation generated proximities (clustering) within the two-dimensional MDS Common Space map. Interpretability of the Common Space map at two-dimensions was high (Shinkareva et al., 2013, p.4). The Normalized Raw Stress value at two-dimensions was 0.00119, and the corresponding Stress-1 value was 0.03453a, supporting the Goodness-of-Fit of the data as 'Excellent' based on Kruskal's Stress formula [42, 43, 62].

Clustering of object points within the MDS Common Space map supported the placement of biosecurity sub-themes within the SCP Rubric due to the close proximity of object points [42, 53]. In total, three out of 10 SCP techniques were tested with MDS. All SCP categories and biosecurity sub-themes were clustered consistently within the Common Space map (Fig. 2), with the exception of *Display Emergency Contact Lists*. Figure 2 explicitly identifies clustering of items tested from SCP Rubric Square #2; SCP category (*Control Access to Farm*), and biosecurity sub-themes (*Reduce Number of Entry Points to Property; Secure Fences*). Clustering of items tested from SCP Rubric Square #24 is also clearly identifiable: SCP category (*Support Biosecurity Compliance*) and biosecurity sub-themes (*Comply with Biosecurity Legislation; Implement a Biosecurity Policy*).

Testing of SCP Rubric Square #22 (*Display Instructions*) was not as strongly clustered; although the SCP category *Display Instructions* and biosecurity sub-theme *Display Biosecurity Signs* were closely located, the biosecurity sub-theme *Display Emergency Contact Lists* was distinguishable as an outlier [52]. Ambiguity of terms may have influenced the isolated placement of this sub-theme rather than incorrect alignment within the SCP Rubric. Subsequently, the position of *Display Emergency Contact Lists* as an outlier may be attributable to variation in participant interpretation. The clustering of all other object points within the MDS Common Space map was consistent with the structure and placement of biosecurity sub-themes within the SCP Rubric [42]. The MDS analysis therefore validated the placement of biosecurity themes within the SCP Rubric.

5.3 Situational Crime Prevention (SCP) framework toward biodefence

As a result of identified theoretical security deficits, the study found that the current recommendations of biosecurity practices may address naturally occurring and accidental biosecurity threats but may not adequately mitigate malicious threats to cattle production enterprises. Subsequently, Australian cattle production enterprises, and potentially other primary production enterprises both nationally and internationally, may have a high level of vulnerability to malicious biosecurity threats, requiring the application of security measures underpinned by security theory for malicious threat mitigation.

To mitigate naturally occurring, accidental, and malicious biosecurity threats in alignment with international biodefecse strategy, recommended biosecurity practices must be underpinned by established security theory. Subsequently, the SCP Rubric for biodefence (Fig. 3) was developed in response to the primary research question as a consolidated SCP framework, addressing malicious biosecurity threats through the application of combined security and biosecurity measures within each of the 25 SCP techniques.

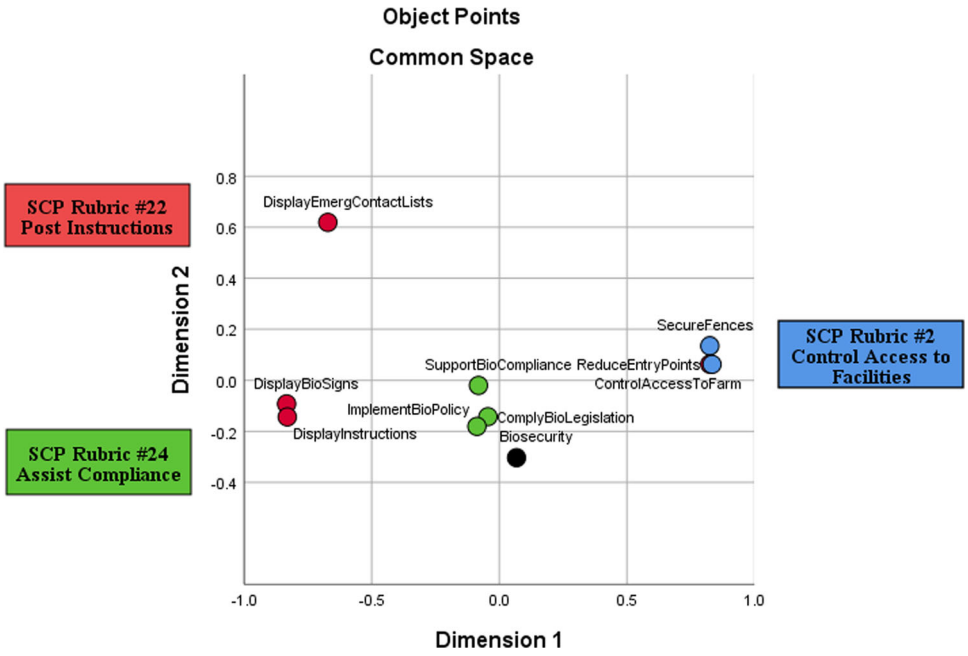

Fig. 2 MDS spatial representation of SCP categories and biosecurity sub-themes

This SCP framework toward biodefence converges biosecurity and security as a bilateral approach to mitigating naturally occurring, accidental, and deliberate biosecurity threats, demonstrating how the agricultural sector can be included within a wider national biodefence strategy.

6 Discussion

While the SCP Rubric for biodefence proposes several preventative practices, the specific implementation measures required to contextually address and reduce human opportunities should ultimately be developed with the involvement of industry. Consultation with owners and operators of cattle production enterprises is imperative to assess the potential costs and impacts of recommended techniques and measures on operations, production, animal welfare, organizational culture, or other environmental and contextual considerations. Consultation may also facilitate the development, implementation, and standardisation of SCP techniques for biodefence across production enterprises and wider industry sectors [1, 2, 25, 63–66].

The study explored the degree to which recommended biosecurity practices incorporate preventative security measures for the mitigation of malicious threats at the farming level and, specifically, in cattle production enterprises. The study identified deficits in the theoretical security underpinning of the Australian biosecurity framework at the farming level. Subsequently, the research engages in national security discourse, establishing that the current biosecurity recommendations at a primary production and industry level do not account for malicious actors. Of significance is that the study identified key vulnerabilities for national security strategies, highlighting that the intent and capabilities of threat actors may exceed the current levels of situational preventative and defensive measures applied to cattle production enterprises. Therefore, the study not only provides insight as to the likely efficacy of the existing biosecurity framework to reduce opportunities for malicious biosecurity threats but also signals the potential physical vulnerability of primary production enterprises and the agricultural sector more broadly. Consequently, without change, security vulnerabilities within cattle production enterprises at the farming level could be exploited by malicious actors, with profound social and economic consequences.

While the SCP framework toward biodefence demonstrates an approach in alignment with international biodefence strategy, there are several limitations and considerations. Firstly, the study acknowledges that SCP techniques do not constitute a Physical Protection System (PPS), and therefore, mitigation of malicious threats may require preventative techniques in addition to targeted security practices, drawing from theory and principles across the 'spectrum of security' [67, 68]. Furthermore, there are limited empirical data on the efficacy of SCP to mitigate malicious threat actions in an agricultural context. This aspect is likely due to the limited data concerning malicious biosecurity threats and activity in agriculture, in addition to the difficulty in accessing and obtaining data from other environments, contexts, and events such as terrorist attacks [69].

Secondly, the SCP Rubric for biodefence presents a preventative methodology for opportunity reduction only. While there is little criticism for SCP as the theoretical basis for implementation of techniques in the pursuit of biodefence, SCP must be encapsulated as a foundational pillar within a wider security theory and applied as a process for malicious threat mitigation in agriculture. The SCP Rubric for biodefence may therefore require extension beyond preventative methods to include preparedness, risk assessment

SCP Rubric for Biodefence

Reducing Human Opportunities **Reducing Pathogen Opportunities**

Increase the Effort	Increase the Risks	Reduce the Rewards	Reduce Provocation	Remove Excuses
1. Target Harden	**6. Extend Guardianship**	**11. Conceal Targets**	**16. Reduce Frustrations**	**21. Set Rules**
Emergency Preparedness; Infection Prevention & Control; Create Biosecurity Awareness; Lock Feed/ Storage Sheds; Secure Medicine/ Treatments; Develop Vaccines; Tamper Seals for Vaccines/ Medicines	Community Engagement; Promote Biosecurity Knowledge & Awareness; Collaborate with Industry & Professionals; Neighbourhood Watch; Community Security & Police Patrols	Conceal Livestock from Main Roads; Conceal Feed and Equipment from View; Screen Production Areas with Natural Screening (trees, hedges etc.)	Ensure Professional Conduct; Maintain Ethical Practices; Provide Adequate Remuneration and Conditions for Staff	Detect Contamination; Livestock & Product Entry Screening; Livestock Health Exit Screening; Outbreak Detection; Prevent Contamination; Restrict Movement; Code of Conduct; Report Security Breaches
2. Control Access to Facilities	**7. Assist Natural Surveillance**	**12. Remove Targets**	**17. Avoid Disputes**	**22. Post Instructions**
Access Control; Install Electronic/ Physical Access Control Systems Detect Biosecurity Breaches; Prevent Access from Unknown or Wild Animals	Disease, Pest & Weed Surveillance; High Risk Environmental Surveillance; Use CPTED Principles Where Practical; Install Lighting around sheds and buildings	Destroy (Burn/Shred) Discarded Confidential Information; Reduce or Avoid Taking Animals to Agricultural Shows	Maintain Asset & Valuation Evidence; Resolve Workplace Grievances; Ensure Financial Obligations to Suppliers are met	Display Biosecurity Signs & Visual Aids; Post Security Messages ("No Trespassing" etc.)
3. Screen Exits	**8. Reduce Anonymity**	**13. Identify Property**	**18. Reduce Emotional Arousal**	**23. Alert Conscience**
Single Exit Point; Exit Barriers/ Gates	Identify Livestock with Tags & Records; Record Keeping to Increase Traceability; Employee/ Staff Uniforms; Visitor ID Tags	Cattle Branding; Label (Engrave) Farm Equipment	Prevent Discrimination; Promote Workplace Equality & Cultural Diversity; Reduce Intersectionality; Ensure Ethical & Humane Treatment of Animals	Accurate & Honest Record Keeping; Encourage Adoption of Biosecurity Practices; Develop & Promote a Culture of Security
4. Deflect Offenders	**9. Utilise Place Managers**	**14. Disrupt Markets**	**19. Neutralise Peer Pressure**	**24. Assist Compliance**
Background Screening for Employees and Casual Staff; Deny Access without ID and Signature; Cease use of Fresh Produce Stalls at Farm Entrance	Security Training for Farm Manager and Staff; Reward Vigilant Staff	Use Licensed Vendors; Implement Controls on Livestock Sales; Establish Hotline to Report Unlicensed Livestock Sales	Rewards for Security Vigilance & Reporting; Discourage Lackadaisical Attitudes to Security and Biosecurity	Administration & Management; Promote & Comply with Regulations & Standards; Develop & Implement Policy & Procedure; Implement Security Policy & Procedures
5. Control Tools/Weapons	**10. Strengthen Formal Surveillance**	**15. Deny Benefits**	**20. Discourage Imitation**	**25. Control Drugs & Alcohol**
Prohibit Contractor Equipment from Farm; Prohibit Farm Equipment from Being Taken Off-farm	Alarm Systems; Guard Dogs; CCTV Surveillance; Request Local Police Patrols; Use Security Guards if Required	Livestock Insurance (Death, Illness, Injury & Malicious Damage); Disaster Recovery Planning; Income Protection; Diversify Income Stream (e.g., sheep); Offsite Backup Data Storage; Develop Treatments	Report Suspected Malicious Biosecurity Incidents to Police; Prosecute Trespassers; Rapid Outbreak Response	Employee Drug Testing; Alcohol Free Site

Fig. 3 SCP Rubric for biodefence. *Note*: Adapted from 'Crime Analysis for Problem Solvers in 60 Small Steps' by R.V. Clarke and J.E. Eck, 2016, Center for Problem-Oriented Policing. Copyright 2016 by U.S. Department of Justice; adapted from 'Crime prevention: Approaches, practices and evaluations' by S. Lab, 2013. Copyright 2013 by Routledge

(including threat, vulnerability, and criticality), security risk treatment, and protection methods such as Defense in Depth (DiD) and Protection-in-Depth (PID), as well as recovery planning and strategy [68, 70, 71].

Thirdly—and while acknowledging the role of SCP as a theoretical and foundational pillar—the SCP Rubric for biodefence provides an architecture of techniques to reduce opportunities for malicious action. However, a broader approach to biosecurity requires a deeper framework with the strategies and techniques derived from a risk-based approach. As there is no set prescription for the application of SCP techniques, this means that the framework of SCP techniques requires specific contextualisation and development for agriculture. Subsequently, an SCP Rubric for biodefence with embedded bilateral SCP techniques must be transformed into an overarching model with an actionable methodology or process which can be implemented, monitored, reviewed, and managed by cattle production enterprises.

Consideration of the SCP Rubric for biodefence suitability must also acknowledge that malicious threats will not be prevented exclusively by the introduction of bilateral SCP techniques in cattle production enterprises. Malicious threat mitigation requires the application of a Biological Protection-in-depth methodology, building on existing multidimensional, multisectoral, and multi-jurisdictional structures and mechanisms. For instance, governance and risk frameworks which introduce policies, procedures, and mechanisms at the international and national levels support threat mitigation at the community and enterprise level. These mechanisms, together with intelligence, law enforcement, and other agencies and structures may determine how threats are informed and assessed and facilitate the provision for additional measures at national, state, and territory levels [1, 2, 26, 65]. Consequently, the implementation of SCP Techniques for biodefence is something that may be achieved at an enterprise and community level with the explicit support of state, territory, and federal agencies.

A collaborative approach with the involvement of community will assist in determining the appropriateness, practicalities, and limitations of implementing such measures. Such an approach may adequately inform policy, particularly in terms of which measures may be feasible, enforceable, and scalable in the event of a biological event or incident, as well as providing some indication of which measures can or should be mandated as part of a national Agricultural Biodefecse Strategy. Taking into account these considerations, preventative measures contained in the SCP Rubric for biodefence must be encapsulated as a foundational pillar within a wider security framework and applied in a systematic manner consistent with security theory. Subsequently, practices developed from the SCP Rubric for biodefence may provide a foundation for further research and development of an overarching biodefence methodology for agricultural enterprises.

7 Conclusion

The study explored the extent to which the Australian biosecurity framework is underpinned by preventative security measures by applying Situational Crime Prevention (SCP) theory to biosecurity practices recommended for cattle production enterprises. The study established that the current recommendations of biosecurity practices at the farming level are not adequately underpinned by security theory. The biosecurity Situational Crime Prevention (SCP) Rubric was constituted by practices which are primarily aimed at preventing the 'pathogenic offender' (naturally occurring and accidental threats), rather than measures to prevent and detect the 'human offender' with malicious intent (deliberate threats) from a situational perspective at the farming level. Such an absence of broad SCP representation may impact on the degree to which biosecurity practices are able to prevent malicious threats; therefore, the results of the study indicate Australian cattle production enterprises may currently have a high level of vulnerability to malicious biosecurity threats [1–3, 36, 39]. While the likelihood of Australian cattle production enterprises being the target of a deliberate biological attack is unknown, the potential capabilities of malicious actors—and potential consequences should such an attack be perpetrated—warrant explicit preventative action for biological preparedness in agriculture.

The study signifies a key vulnerability for the Australian agricultural sector and for national security, as the intent and capabilities of threat actors may exceed the current level of preventative and defensive measures applied to cattle production enterprises—sustained global terrorism, the recent targeting of Australian farms by animal activists, and the pace and magnitude of progress in biotechnology suggests the potential threat to cattle production enterprises should not be overlooked or dismissed by policymakers.

The SCP Rubric for biodefence demonstrates how security theory can be embedded within biosecurity frameworks and may therefore be appropriate as a bilateral architecture of preventative practices for cattle production enterprises. The SCP Rubric for biodefence converges biosecurity and security measures to reduce opportunities for biosecurity threats to cattle production enterprises, but may also inform and support biosecurity efforts across agricultural sub-sectors in Australia. In alignment with biodefence strategy, this architecture has been developed as an evidence-based and holistic approach to mitigating naturally occurring, accidental, and malicious biological threats and may therefore guide the consolidation of biosecurity and biodefence strategy in the Australian and international agricultural sectors more broadly. The research provides a significant and timely reference point for policy makers in redefining biological preparedness in Australian agriculture and may assist the wider agricultural sector, both nationally and internationally, to mitigate and address threats across the biological risk continuum.

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References

1. R. Byrne, Agro-terrorism and bio-security, threat, response and industry communication. Nuffield Farming Conference, 30–31 October (2009). http://www.nuffieldinternational.org/rep_pdf/12565895572007_Richard_Byrne_Nuffield_Report.pdf
2. J. Monke, Agroterrorism: Threats and Preparedness, in *Agroterrorism*. ed. by J.T. Ollington (Nova Science Publishers Inc, New York, 2008), pp.1–78
3. J.R. Ryan, *Biosecurity and Bioterrorism: Containing and Preventing Biological Threats*, 2nd edn. (Elsevier Inc., Cambridge, 2016)
4. P. Chalk, Hitting America's Soft Underbelly: The Potential Threat of Deliberate Biological Attacks Against the US Agricultural and Food Industry. California, Rand Corporation (2004). https://www.rand.org/content/dam/rand/pubs/monographs/2004/RAND_MG135.pdf
5. M. Haley, Fields of danger: the looming threat of agroterrorism on the United States' agriculture. J. Biosecurity, Biosaf. Biodefense Law (2019). https://doi.org/10.1515/jbbbl-2019-0010
6. T.R. Patel, M.H. D'Souza, Coronavirus is not a bioweapon—but bioterrorism is a real future threat. The Conversation (2020, May 18). https://theconversation.com/coronavirus-is-not-a-bioweapon-but-bioterrorism-is-a-real-future-threat-135984
7. C. Ungerer, D. Rodgers, The Threat of agroterrorism to Australia: a preliminary assessment. Stud. Confl. Terror. **29**(2), 147–163 (2006). https://doi.org/10.1080/10576100500497012
8. Australian Associated Press, Queensland farm worker accused of putting needles in strawberries has charges dropped. The Guardian (2021, July 14). https://www.theguardian.com/australia-news/2021/jul/14/queensland-farm-worker-accused-of-putting-needles-in-strawberries-has-charges-dropped
9. G. Moret, A. Verley, Ag Minister labels national farm map an 'attack list' for animal activists, but not illegal. ABC News (2019, January 22). https://www.abc.net.au/news/2019-01-22/aussie-farms-map-sparks-outrage-from-farmers-and-ag-minister/10736006
10. Parliament of Victoria, Economy and Infrastructure Committee, Inquiry into the impact of animal rights activism on Victorian agriculture. Victorian Government Printer, Melbourne (2020)
11. K. Silva, E. Sibson, Strawberry needle contamination: Accused woman motivated by spite, court hears. ABC News (2018). https://www.abc.net.au/news/2018-11-12/strawberry-needle-contamination-woman-to-face-court/10486770.
12. Special Broadcasting Service, Activists storm Melbourne Myer cosmetics department to protest animal testing. SBS News (2018, April 29). https://www.sbs.com.au/news/activists-storm-melbourne-myer-cosmetics-department-to-protest-animal-testing
13. H.J. Jansen, F.J. Breeveld, C. Stijnis, M.P. Grobusch, Biological warfare, bioterrorism and biocrime. Clin. Microbiol. Infect. **20**(6), 488–496 (2014). https://doi.org/10.1111/1469-0691.12699
14. S.E. Schutzer, B. Budowle, R.M. Atlas, Biocrimes, microbial forensics, and the physician. PLoS Med. **2**(12), 1242–1247 (2005). https://doi.org/10.1371/journal.pmed.0020337
15. L., Smith, What is foot-and-mouth disease? Why farmers fear 'apocalyptic bonfires of burning carcasses'. The University of Sydney (2022, July 12). https://www.sydney.edu.au/news-opinion/news/2022/07/12/what-is-foot-and-mouth-disease-.html
16. J.S. Carter, L. Barbour, Foot-and-mouth disease is on Australia's doorstep. What will it look like if it spreads? ABC News (2022, July 22). https://www.abc.net.au/news/rural/2022-07-22/foot-and-mouth-disease-would-look-like-if-it-got-to-australia/101254814
17. W. Jones, 'Catastrophic': Everything you should know about foot and mouth disease. The New Daily (2022, July 22). https://thenewdaily.com.au/finance/consumer/2022/07/22/foot-and-mouth-explainer/
18. Beef Central, FMD: Airport biosecurity strengthened, Victorian farmer rally to demand further steps. Beef Central (2022, July 25). https://www.beefcentral.com/news/fmd-more-airport-compliance-but-victorian-farmers-will-march/
19. Department of Agriculture, Fisheries and Forestry, Travellers from Indonesia can help keep foot-and-mouth disease out. Australian Government (2022, July 19). https://www.agriculture.gov.au/about/news/travellers-from-indonesia-can-help-keeping-fmd-out
20. M. Rogers, Australian free from FMD outbreak… for now. Australian Rural and Regional News (2022, July 28). https://arr.news/2022/07/28/australian-free-from-fmd-outbreak-for-now/
21. A. Thorn, Airports Introduce Sanitised Foot Mats to Stop Foot-and-Mouth Disease. Australian Aviation (2022, July 23). https://australianaviation.com.au/2022/07/airports-introduce-sanitised-foot-mats-to-stop-foot-and-mouth/
22. H.S. Parker, Biosecurity in the food and agricultural industries, in *Biosecurity: Understanding, Assessing and Preventing the Threat*. ed. by R.N. Burnette (Wiley, New York, 2013), pp.129–154
23. R.N. Burnette, J.E. Hess, J.P. Kozlovac, J.Y. Richmond, *Biosecurity: Understanding, Assessing and Preventing the Threat* (Wiley, New Jersey, 2013)
24. B. Linkous, R.N. Burnette, S. Dittrich, Biodefense promotes biosecurity through threat reduction programs and global health security, in *Applied Biosecurity: Global Health, Biodefense, and Developing Technologies, Advanced Sciences and Technologies for Security Applications*. ed. by R.N. Burnette (Springer, Berlin, 2021), pp.51–71. https://doi.org/10.1007/978-3-030-69464-7_4
25. United States Departments of Defense, Health and Human Services, Homeland Security, and Agriculture. (2018). US National Biodefense Strategy. https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Biodefense-Strategy.pdf
26. C. Enemark, *Biosecurity Dilemmas: Dreaded Diseases, Ethical Responses, and the Health of Nations* (Georgetown University Press, Washington, D.C., 2017)
27. O. Grundmann, The current state of bioterrorist attack surveillance and preparedness in the US. Risk Manag. Healthc. Policy **7**, 177–187 (2014). https://doi.org/10.2147/RMHP.S56047
28. G. Koblentz, From biodefence to biosecurity: the Obama administration's strategy for countering biological threats. Int. Aff. **88**(1), 131–148 (2012). https://doi.org/10.1111/j.1468-2346.2012.01061.x
29. R.V. Clarke, Situational crime prevention: theory and practice. Br. J. Criminol. **20**, 136–147 (1980)
30. R.V. Clarke, Situational crime prevention: its theoretical basis and practical scope. Crime Justice **4**, 225–256 (1983)

31. R.V. Clarke, J.E. Eck, Crime Analysis for Problem Solvers in 60 Small Steps. Office of Community Oriented Policing Services (2005). https://portal.cops.usdoj.gov/resourcecenter/RIC/Publications/cops-w0047-pub.pdf
32. R.V. Clarke, J.E. Eck, Crime Analysis for Problem Solvers in 60 Small Steps (Rev.). Office of Community Oriented Policing Services (2016). https://ric-zai-inc.com/Publications/cops-w0047-pub.pdf
33. R.V. Clarke, R. Homel, A revised classification of situational crime prevention techniques, in *Crime Prevention at a Crossroads*. ed. by S.P. Lab (Anderson, London, 1997)
34. S. Lab, *Crime Prevention: Approaches, Practices and Evaluations*, 8th edn. (Routledge, Abingdon, 2013)
35. R.V. Clarke, Part 1: introduction, in *Situational Crime Prevention*, 2nd edn., ed. by R.V. Clarke (Lynne Rienner Publishers, Boulder, 2010), pp.1–43
36. J.D. Freilich, G.R. Newman, Introduction, in *Reducing Terrorism Through Situational Crime Prevention*. ed. by J.D. Freilich, G.R. Newman (Lynne Rienner Publishers, Boulder, 2010), pp.1–7
37. J. Clare, F. Morgan, Exploring parallels between situational crime prevention and non-criminological theories for reducing terrorist risk, in *Reducing Terrorism Through Situational Crime Prevention*. ed. by J.D. Freilich, G.R. Newman (Lynne Rienner Publishers, Boulder, 2009), pp.207–227
38. R.V. Clarke, G.R. Newman, *Outsmarting the Terrorists* (Praeger Publishers, New York, 2006)
39. M. Mair, J.S. Mair, A Complementary Approach to Bioterrorism Prevention (2003). https://www.nonproliferation.org/wp-content/uploads/npr/102mair.pdf
40. J.W. Creswell, *Research Design: Qualitative, Quantitative and Mixed Methods Approaches*, 3rd edn. (Sage Publications, Thousand Oaks, 2009)
41. D.J. Brooks, Security risk management: a psychometric map of expert knowledge structure. Risk Manage. **13**(1–2), 17–41 (2011). https://doi.org/10.1057/rm.2010.7
42. M.C. Hout, M.H. Papesh, S.D. Goldinger, Multidimensional scaling Wiley interdisciplinary reviews. Cognit. Sci. **4**(1), 93–103 (2013). https://doi.org/10.1002/wcs.1203
43. NCSS. (n.d.). Multidimensional Scaling. https://ncss-wpengine.netdna-ssl.com/wp-content/themes/ncss/pdf/Procedures/NCSS/Multidimensional_Scaling.pdf
44. Y. Takane, Z. Zhang, Statistics: multidimensional scaling, in *International Encyclopedia of Education*, 3rd edn., ed. by E. Baker, B. McGaw, P.P. Peterson (Elsevier, Oxford, 2010), pp.304–311
45. D. Denyer, D. Tranfield, Producing a systematic review, in *The Sage Handbook of Organizational Research Methods*. ed. by D.A.B.A. Brayman (Sage Publications, Thousand Oaks, 2009), pp.671–689
46. W.T. Ham-Baloyi, P. Jordan, Systematic review as a research method on post-graduate nursing education. Health SA Gesondheid **21**, 120–128 (2016). https://doi.org/10.1016/j.hsag.2015.08.002
47. J.K. Jesson, L. Matheson, F. Lacey, *Doing Your Literature Review: Traditional and Systematic Techniques* (Sage Publications, Thousand Oaks, 2011)
48. J. Bell, S. Waters, *Doing Your Research Project: A Guide for First-Time Researchers*, 6th edn. (Open University Press, Berkshire, 2014)
49. R.E. Boyatzis, *Transforming Qualitative Information: Thematic Analysis and Code Development* (Sage Publications Inc., Thousand Oaks, 1998)
50. V. Braun, V. Clarke, Using thematic analysis in psychology. Qual. Res. Psychol. **3**(2), 93 (2006). https://doi.org/10.1191/1478088706qp063oa
51. W.R. Clark, Bioterrorism: a situational crime prevention approach, in *Reducing Terrorism Through Situational Crime Prevention*. ed. by J.D. Freilich, G.R. Newman (Lynne Rienner Publishers, Boulder, 2010), pp.93–107
52. L. Cohen, L. Manion, K. Morrison, *Research Methods in Education*, 6th edn. (Routledge, Abingdon, 2007)
53. S.V. Shinkareva, J. Wang, D.H. Wedell, Examining similarity structure: multidimensional statistical scaling and related approaches in neuroimaging. Comput. Math. Methods Med. (2013). https://doi.org/10.1155/2013/796183
54. J. Shanteau, D.J. Weiss, R.P. Thomas, J.C. Pounds, Performance-based assessment of expertise: How to decide if someone is an expert or not. Eur. J. Oper. Res. **136**(2002), 253–263 (2002). https://doi.org/10.1016/S0377-2217(01)00113-8
55. J. Daniel, *Sampling Essentials: Practical Guidelines for Making Sampling Choices* (Sage Publications, Thousand Oaks, 2012)
56. P. Ben-Nun, Respondent fatigue, in *Encyclopedia of Survey Research Methods*. ed. by P.J. Lavrakas (Sage Publications, Thousand Oaks, 2008), p.743. https://doi.org/10.4135/9781412963947
57. J. Gray, *RES6101 Research Preparation: The Reading Guide* (Edith Cowan University, Perth, 2017)
58. W.M.K. Trochim, The Reliability of Concept Mapping (1993). https://socialresearchmethods.net/research/Reliable/reliable.htm
59. M. Tavakol, R. Dennick, Making sense of Cronbach's alpha. Int. J. Med. Educ. **2**, 53–55 (2011). https://doi.org/10.5116/ijme.4dfb.8dfd
60. S. Glen, Test-Retest Reliability/ Repeatability. Statistics How To (2016). https://www.statisticshowto.com/test-retest-reliability/
61. R. Wortley, A classification of techniques for controlling situational precipitators of crime. Secur. J. **14**(4), 63–82 (2001). https://doi.org/10.1057/palgrave.sj.8340098
62. S.M. Holland, Non-metric Multidimensional Scaling (MDS) (2008). https://strata.uga.edu/software/pdf/mdsTutorial.pdf
63. Blue Ribbon Study Panel on Biodefense, *Special Focus: Defense of Animal Agriculture. Blue Ribbon Study Panel on Biodefense*. (Washington, D.C., 2017)
64. H. Carter, J. Drury, R. Amlôt, Recommendations for improving public engagement with pre-incident information materials for initial response to a chemical, biological, radiological or nuclear (CBRN) incident: a systematic review. Int. J. Disaster Risk Reduct. (2020). https://doi.org/10.1016/j.ijdrr.2020.101796
65. G.D. Koblentz, *Living Weapons: Biological Warfare and International Security* (Cornell University Press, New York, 2009)
66. J.R. Revill, C. Jefferson, The Importance of engagement and education for effective biosecurity, in *Biosecurity: Understanding, Assessing and Preventing the Threat*. ed. by R.N. Burnette (Wiley, New York, 2013), pp.209–224
67. M.L. Garcia, *The Design and Evaluation of Physical Protection Systems* (Butterworth-Heinemann, Boston, 2001)
68. C.L. Smith, D.J. Brooks, *Security Science: The Theory and Practice of Security* (Butterworth-Heinemann, Boston, 2013)
69. J.D. Freilich, J. Gruenewald, M. Mandala, Situational crime prevention and terrorism: an assessment of 10 years of research. Crim. Justice Policy Rev. **30**(9), 1283–1311 (2018). https://doi.org/10.1177/0887403418805142
70. M. Coole, J. Corkhill, A. Woodward, Defence in depth, protection in depth and security in depth: a comparative analysis towards a common usage language, in *Proceedings from the 5th Australian Security and Intelligence Conference*. Perth, Western Australia (2012). https://doi.org/10.4225/75/57a034ccac5cd
71. Standards Australia & Standards New Zealand, Security Risk Management (AS/NZS HB167:2006). SAI Global (2006). https://www.saiglobal.com/