CBIS/CSP sensitivity: incorporating pre-border information analysis

Final Report for CEBRA Project 170608

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Agriculture Import Management System (AIMS): The primary software used by the Department of Agriculture, Water and the Environment (the department) to manage biosecurity and food safety risks associated with imported cargo, track and recorded imported consignments and assign fees and collect revenue on imported cargo. Entries of potential biosecurity concern are referred to AIMS from the Integrated Cargo System (ICS).

Approach rate: An estimate of the likelihood of entry of pests and diseases determined through inspection results. In the CBIS Sensitivity Module, this is based on the "failure" concept (inspection or quarantine failure) selected by the user.

Appropriate Level of Protection (ALOP): Under the *Sanitary and Phytosanitary Measures Agreement,* World Trade Organization members are entitled to maintain a level of protection they consider appropriate to protect life or health within their territory. Australia's ALOP, as defined in the *Biosecurity Act 2015*, is expressed as providing a high level of sanitary and phytosanitary protection aimed at reducing risk to a very low level, but not to zero.

Approved arrangements (AA): Voluntary arrangements, defined in Chapter 7 of the *Biosecurity Act 2015,* that allow persons to carry out activities to manage the biosecurity risks associated with specified goods, premises or other things. An AA can cover all biosecurity activities involving the physical handling of goods, such as storage, inspections and post-entry quarantine requirements, at one or more approved sites. It may also cover biosecurity activities that do not involve the physical handling of goods, such as documentary assessment for goods subject to biosecurity control by accredited persons or performing health-related measures to control or kill insect vectors of human diseases on aircraft. Physical and non-physical biosecurity activities can be grouped together under the same AA.

AQIS Commodity Code (ACC): A four-character alphanumeric code that can be entered into the Integrated Cargo System by brokers to identify a commodity to a more specific level than a tariff code.

Average outgoing quality (AOQ): The AOQ for a sampling plan describes the expected relationship between the incoming (pre-intervention) rate of non-compliance, measured by the approach rate of the relevant "failure" concept, and the outgoing (post-intervention) rate of non-compliance after completing the specified intervention protocols. Tracing out the biosecurity risk material leakage as the rate of non-compliance varies gives an **average outgoing quality curve (AOQ curve)**.

Average outgoing quality limit (AOQL): The maximum value of the average outgoing quality curve (AOQ curve). The AOQL provides a "worst case" scenario for the post-intervention rate of non-compliance; regardless of the approach rate, the post-intervention rate of non-compliance should be no higher than the AOQL over an extended period of time (i.e. the long run).

Biosecurity Import Conditions (BICON): An online database that houses the Australian Government's biosecurity import conditions database for more than 20 000 plants, animals, minerals and biological products. It is used by importers, customs brokers and overseas suppliers to determine biosecurity conditions associated with importing goods into Australia. For example, this could include whether the good requires an import permit to be granted by the department.

Biosecurity risk material: Material that has the potential to introduce a pest or disease into Australia. This could include, but is not limited to: live insects; weed seeds; soil; animal material; plant material such as straw, twigs, leaves, roots and bark; food refuse; and other debris.

Clearance number: A key parameter of the CSP-1 and CSP-3 algorithms. It represents the number of consecutive clean lines that must be reached before a target's goods can be switched to a compliance-based rate of inspection in monitoring mode.

Compliance-Based Intervention Scheme (CBIS): An intervention scheme offered by the Department of Agriculture, Water and Environment for selected plant-products which automates the application of directions under the CSP-1 or CSP-3 rules applied to biosecurity inspections. It was previously known as the Compliance-Based Inspection Scheme, the Plant Product Pathway Q-ruler and the Continuous Sampling Plan.

CBIS Sensitivity Module: A spreadsheet-based module, developed as part of this CEBRA project, that may be used to guide department officers in assessing and recommending appropriate parameters for pathways under CBIS. The approach underscoring the module does not rely on data on past interventions, enabling a broader application of this approach to risk-based interventions.

Consignment: For the purposes of this report, the term "consignment" is used in a general sense to mean "goods being delivered". Depending on the context, it could refer to the *quarantine entry* and *line* concepts described elsewhere in this section. For the avoidance of doubt, all analysis undertaken on pathways in this report refers to AIMS line-level data, rather than quarantine entry-level data.

Contaminating pest: A pest that is carried by a commodity and, in the case of plants and plant products, does not infest those plants or plant products (Food and Agriculture Organisation, 2006).

Continuous sampling plan (CSP): A technical rule for determining whether or not to inspect a consignment, based on the recent inspection history of the pathway (Dodge and Torrey, 1951). The pathway manager sets the target dimension on which the rule is applied (usually by importer) and specific rule parameters, such as the clearance number, monitoring fraction and, for the CSP-3 algorithm, the tight census number.

Documentation failure: A documentation failure occurs when there is a non-compliance detected by an assessment officer because of inadequate or missing documentation that should accompany the physical commodities according to the relevant import conditions.

Hitchhiker pest: A pest or pathogen which travels opportunistically on ships and aircraft or on the outsides and insides of sea and air containers (regardless of the goods being imported), and on general, non-containerised (break-bulk) cargo such as cars, tyres or machinery (which would not otherwise pose any biosecurity risk) (Inspector-General of Biosecurity, 2018).

Import Declaration: The declaration used for the importation of goods into Australia. It is entered into the ICS by importers or customs brokers who use information sourced from commercial invoices to create the declaration which must be supplied to the Department of Home Affairs (Australian Border Force) and, where applicable, the Department of Agriculture, Water and Environment before the goods are cleared.

Incidents database: An internal department system that is used to record additional information on AIMS entries where an inspection failure has occurred. This can include the results of further testing by the department's plant pathologists and entomologists seeking to identify plant diseases and insects.

Inspection: An examination of goods or systems for the biosecurity of animal, plant, food and human health to verify that they conform to requirements. (Beale et al., 2008)

Inspection failure: In general, an inspection failure occurs when there is a non-compliance detected at inspection. The possible types of non-compliance include the incorrect declaration of goods, packaging failures and evidence suggesting the possible presence of biosecurity risk material in consignments.

Integrated Cargo System (ICS): The ICS is the sole method of electronically reporting the legitimate movement of goods across Australia's borders. It is maintained and administered by the Department of Home Affairs (Australian Border Force). Entries of potential biosecurity concern are referred from the ICS into the Department of Agriculture, Water and Environment's AIMS.

Interception: The detection of a pest during inspection or testing of an imported consignment (Food and Agriculture Organisation, 2007). For application in this project, this definition has been modified to refer to the detection of *at least one hitchhiker pest of interest* during inspection.

Intervention: Legally enforceable obligations (through legislation or regulations) imposed by government on business and/or the community, together with government import processes that support the obligations. In the biosecurity context, this includes requirements related to:

- prescribing specific actions or requirements that must be completed before goods can be brought into the Australian territory;
- giving notice of goods to be unloaded in Australian territory;
- providing information, including documents, about the goods if requested by biosecurity officers;
- allowing for the goods to be physically inspected;
- allowing for samples of the goods to be taken; and
- prescribing treatments to reduce the biosecurity risk associated with goods or conveyances.

Leakage: Leakage occurs when a consignment containing biosecurity risk material that would or should have been detected by an intervention and treated to ameliorate biosecurity risks but was not. This results in a disease or pest entering Australia, with the possibility it becomes established and spreads post-border.

Leakage (post-intervention non-compliance) rate: An estimate of the proportion of consignments on a pathway containing biosecurity risk material that cross Australia's international borders after undergoing any required interventions.

Line: In AIMS, a line designates goods under a single Import Declaration with common characteristics (including, but not limited to, the same tariff code, goods description, supplier and exporting country) as entered by the importer or customs broker into the ICS. More than one line may be associated with a given quarantine entry reference. The CBIS Sensitivity Module uses line-level information in assessing and recommending appropriate parameters for pathways under CBIS. Any analysis undertaken on pathways refers to AIMS line-level, rather than quarantine entry-level, information.

Markov chain: In probability theory, a Markov chain is a model describing a sequence of possible events in which the probability of each event depends only on the state attained in the previous event. This means that, conditional on the present state of the system, its future and past states are independent. A Markov chain is an example of a stochastic process – a mathematical object usually defined as a family of random variables.

Menu of (regulatory) contracts: From the economic theory of contracts, a menu of regulatory contracts is approach to regulation where the regulator offers the regulated entity a suite of options (the menu) as to how it can meet requirements. A well-designed menu of regulatory contracts encourages the regulated entity to reveal information to the regulator through its menu choice, under the assumption that the regulated entity has chosen the scheme that is "optimal" for them.

Monitoring fraction: A parameter in the CSP-1 and CSP-3 rules used to determine the frequency of inspection once an importer has demonstrated sufficient compliance with biosecurity requirements in the monitoring mode of the CSP algorithm. This parameter governs the compliance-based rate of inspection (*MF*) to be applied that enables inspection of less than 100% of consignments imported. Well-designed menus normally couple higher rewards with more stringent requirements or eligibility criteria on regulated entities.

Quarantine entry: In AIMS, an alphanumeric code that designates goods lodged in a single Import Declaration. It consists of all the goods for a single consignee that arrives on the same voyage of a vessel. A quarantine entry may consist of many container loads of goods and be associated with more than one line.

Quarantine failure: A non-compliance associated with a consignment that poses a direct biosecurity risk. For example, contamination by an actionable pest or disease is a quarantine failure.

Quarantine ruler (Q-ruler): Rule-based software functionality within AIMS that automatically assigns directions, such as inspection or documentation assessment directions, according to set criteria.

Stationary distribution: The stationary distribution of a Markov chain describes the distribution of its states after a sufficiently long time that the distribution does not change any longer. Not all Markov chains have a stationary distribution, but for some classes of transition matrices, a stationary distribution is guaranteed to exist.

Thinning (or splitting of a distribution): In probability theory, thinning refers to classifying each outcome, independently, into one of a finite number of different types. In the CBIS Sensitivity Module, inspection failure outcomes are thinned using a Bernoulli distribution to classify them into quarantine failures and failures reflecting some other source for non-compliance.

Threshold tolerance: In the CBIS Sensitivity Module, the tolerance threshold is the maximum rate of post-intervention non-compliance (leakage) on a pathway which remains consistent with the Appropriate Level of Protection (ALOP).

Tight census number (TC): A parameter in the CSP-3 algorithm which governs the number of consignments inspected at a rate of 100% following a consignment failing inspection when the importer is in monitoring mode. For the CBIS system, the tight census number is a value that can be selected by the pathway manager. In the CBIS Sensitivity Module and in original research paper (Dodge and Torrey, 1951) that proposed the CSP-3 algorithm, the tight census number is set to four.

Transition matrix: A square matrix used to describe the transitions between the states of a Markov chain. Each entry of the matrix is a nonnegative real number between zero and one inclusive representing the probability of the Markov chain moving to state, conditional on its immediate past state.

Treatment: Refers to actions, such as fumigation, cleaning or irradiation, required either by import conditions or as a remedial measure to mitigate biosecurity risks identified at inspection. Treatments reduce biosecurity risks and enable goods or conveyances to meet Australia’s Appropriate Level of Protection (ALOP).

Treatment cost: The costs incurred by an importer resulting from treatments required by the biosecurity regulator to address the presence of biosecurity risk material in a consignment and allow the consignment to enter Australia.

Unrestricted risk: The risk associated with the import of a commodity without any sanitary or phytosanitary measures applied. This is sometimes referred to using the alternative terms ‘unmitigated risk’ or ‘unmanaged risk’ elsewhere in the phytosanitary community.

1. Executive Summary

The Commonwealth Government Department of Agriculture, Water and Environment's (department's) ability to implement intervention protocols has often hampered by a limited understanding of import supply chain characteristics that may increase or decrease biosecurity risks, compliance rates, and thus approach rates at the Australian border. Characteristics that may influence biosecurity risks and the approach rate of biosecurity risk material include, for example:

- whether offshore certification has taken place;
- the level and type of processing that has occurred; and
- the production standards in the country of origin.

The overarching aim of this project is to investigate how these diverse types of information and other pathway-specific knowledge, such as biosecurity-related costs and their potential influence on stakeholder compliance, could improve border inspection protocols, particularly the roll-out of the department's Compliance-Based Intervention Scheme (CBIS). CBIS seeks to apply resources associated with inspections and other assurance methods at differentiated levels according to the likely risks posed to Australia's biosecurity status for selected plant-products. The department's current approach to identifying suitable rule parameters has relied upon analysing historical pathway data using simulation techniques; it has not considered how the rules map to the biosecurity risks on pathways.

Two approaches are used to inform the inclusion of pathway characteristics into CBIS.

1. Inspections on a case-study pathway – timber – are analysed to understand patterns in arrival of hitchhiker pests and how this information could be used in parameter selection.
2. The development of a spreadsheet-based decision-support tool that could be applied to any pathway that is a potential candidate for CBIS.

For reasons discussed in the report, the available data on inspections on the timber pathway were deemed unsuitable for guiding CBIS parameter selection and considering pre-border pathway-level information in a systematic manner. This resulted in the project's emphasis pivoting to the development of a decision-support tool for use by the department's policy and technical officers in assessing pathway eligibility for CBIS-type rules and recommending specific rule parameters. As such, the report's main contribution is to describe a framework, and associated spreadsheet-based tool (CBIS Sensitivity Module), through which the department can determine appropriate CBIS rule parameters.

1.1 Recommendations

Improve data collection to enable enhanced risk management on the timber pathway

If risk-based intervention on the timber pathway is of further interest, then more suitable data must be collected. This could be either via a snapshot survey or using the Cargo Compliance Verification approach. CBIS could be used as a border measure to manage risks associated with consignments if applied at the supplier or importer level.

Use the CBIS Sensitivity Module as an input to decision-making

The spreadsheet module developed as part of this project can guide department officers in assessing and recommending appropriate parameters for pathways under CBIS. Critically, this approach does not rely on data on past interventions, enabling a broader application of this approach.

Outputs from the module, however, should not form the sole basis for decisions around biosecurity interventions. Biosecurity assurance practices will need to be informed by a range of quantitative and qualitative considerations salient to specific pathways and interventions, such as knowledge of production processes, an understanding of the efficacy of pre-border measures and an awareness of regulatory risk appetite, in addition to this report's structured decision-making framework or other analytical methods. There will remain a significant role for overlaying expert judgement in making decisions about interventions for biosecurity assurance.

Quantify risk appetite consistent with Australia's Appropriate Level of Protection

To progress the wider adoption of the CBIS across the department, efforts will need to be made to quantify the department's risk appetite through developing threshold rates of post-intervention non-compliance consistent with Australia's Appropriate Level of Protection (ALOP). Recommending or selecting parameters for compliance-based interventions involves making trade-offs that are quantifiable, as shown in the CBIS Sensitivity Module. Discriminating between alternative trade-offs and determining whether suggested parameterisations are consistent with ALOP requires the development of benchmarks around what "reducing risk to a very low level, but not to zero" means at an operational level.

The CBIS Sensitivity Module proposes one measure to assess how these thresholds could be formulated through a "rule of thumb" that considers the expected benefits of not intervening relative to the expected costs of leakage. There could be many other credible and defensible ways of formulating such benchmarks, consistent with scientific and economic advice, and these could be considered as part of a future work program. Whichever approach is adopted, it is important these benchmarks are constructed using a consistent framework across the department. The threshold rates of post-intervention non-compliance need not be made public, in part because updated scientific and economic assessments may result in significant shifts in these estimates.

Routinely incorporate considerations of uncertainty into regulatory decision-making

To aid decisions around whether certain pathways are suitable for compliance-based interventions and, if so, what rule parameters may be appropriate, the department should develop and implement processes to more formally account for uncertainties associated with key inputs. For example, in the case of the CBIS Sensitivity Module, there is likely to be considerable uncertainty about the monetary value of potential consequences of biosecurity risk material leakage post-border. Rather than discarding a quantitative approach, the department can realise significant benefits from enabling judgements around eligibility and possible rule parameters to be informed by credible interval estimates, drawing on available pertinent information and objective assessments. Formalising the use of meaningful ranges, as opposed to point estimates, to support expert judgement will improve the rigour of regulatory and policy advice provided by the department.

2. Introduction

The Department of Agriculture, Water and Environment's (the department's) ability to implement intervention protocols on pathways is often constrained by limited understanding of how characteristics of import supply chains (pathways) may increase or decrease biosecurity risks, compliance rates, and thus approach rates at the Australian border. Pathway characteristics that may change biosecurity risks include:

- whether offshore certification has taken place;
- the complexity of the product and the level and type of processing;
- whether certain pests are known to be present in the growing area;
- the detectability of pests in the system;[1]
- the length of journey; and
- the standards in the country of origin.

This project investigates how characteristics of an import supply chain and other pathway-specific information may affect biosecurity risk at the Australian border, with a focus on the further improving the roll-out of the Compliance-Based Intervention Scheme (CBIS). The current application of CBIS is based predominantly on onshore interception data and scientific risk assessment; it does not consider how the rules map to the biosecurity risks on the pathway.

2.1 Objectives

The overarching objective of this two-year project was to improve risk-management decisions at the border, including the further roll-out of CBIS, using information on pre-border pathway characteristics. The project's scope was revised in its second year to use a single plant-product pathway – timber – to demonstrate how the CBIS rules could map to the biosecurity risks on a pathway. The motivation for this case study choice was to assess whether the border biosecurity interventions for the timber pathway could be managed using the department's CBIS. Presently, border biosecurity risk management on the timber pathway comprises a documentation check for suitable treatment and inspection if the documentation check is rejected.

Unfortunately, the available departmental data on the timber pathway were not suitable for aiding parameter guidance because it was unrepresentative of the pathway more generally, as consignments are only inspected when evidence of treatment is not provided through appropriate documentation. To develop a dataset that formally supports statistical analysis that will aid parameter selection, the department will need to inspect a representative sample of lines accompanied by treatment documentation. As a result of these data shortcomings, attention turned to developing a more general framework for guiding CBIS rule parameter recommendations which can also incorporate pre-border information.

Understanding whether and how pre-border characteristics and pathway-specific information influence biosecurity risks is an important step in assessing the suitability of pathways for CBIS and the appropriateness of rule parameters, including for those commodities currently on CBIS. It was also hoped the more general, theoretically

[1] This is important in situations where pathogens may be cryptic, or plants may be asymptomatic or hard to sample for in production or post-production.

based framework would uncover or illustrate rules-of-thumb about a pathway's characteristics to guide the wider roll-out of CBIS.

2.2 Methodology

To understand how pathway characteristics influence biosecurity risks, and thus the selection of CBIS parameters, the second year of the project included two distinct stages, namely:

1. an analysis of historical data for the timber pathway; and
2. the development of structured decision-making framework and accompanying spreadsheet-based tool that allows users to assess the appropriateness of alternative rules for pathways that may be eligible for the CBIS.

2.2.1 Analysis of the timber pathway

A statistical analysis of departmental data for timber inspections was undertaken in the hope of revealing:

- trends and patterns in non-compliance over time, with a focus on hitchhiker pests listed;[2]
- whether information on patterns in non-compliance could be used to assist in designing on-arrival inspection strategies for timber, including CBIS; and
- whether information on patterns in non-compliance could be used to engage trading partners to improve the management of goods prior to export.

Key findings from analysing the timber pathway are reported in Chapter 3, with more detailed analysis presented in Appendices A and B.

2.2.2 Intervention design decision-support tool

One of the challenges in implementing compliance-based interventions such as CBIS is determining appropriate rule parameters for managing a given set of risks on a pathway. Determining appropriate decision rules will involve using information on:

- the costs stakeholders face in undergoing biosecurity interventions;
- the consequences of biosecurity risk material leakage;
- pathway-specific pre-border information, including assurance methods; and
- the maximum (tolerated) level of leakage, consistent with Australia's ALOP.

Some of these impacts may be informed by analysing administrative data on inspections or assurance measures, particularly in relation to pests and diseases detected through these processes. Chapter 4 outlines an approach that combines modelling with other considerations to inform the selection of appropriate CBIS rules. Appendix D provides more detail on implementing the mathematical modelling that underpins the proposed framework for selecting rule parameters.

[2] While these pests are referred to as "hitchhiker pests" by the department, they are referred to as "contaminating pests" under the International Plant Protection Convention (IPPC) definition (FAO, 2007). These pests are carried by a commodity and, in the case of plants and plant products, do not infest those plants or plant products. Henceforth, we use the term "hitchhiker pests" to refer to those pests intercepted by the department and "contaminating pests" for the more general class of pests.

3. Analysis of the timber pathway

Timber products (Harmonised System tariff code 4407)[3] are an historic trade pathway. Import conditions have been adjusted over time in response to intelligence and improved information in relation to emerging biosecurity risks associated with timber. Raw and unprocessed timber is considered to have an 'unrestricted risk'[4] of introduction of actionable arthropod and pathogens that is above ALOP. To reduce risk to a very low level, timber and timber products are required to undergo a level of physical/chemical processing and/or treatment. This treatment may occur before export or on arrival (Figure 1).

Most imported timber products are released on the provision of evidence of treatment and do not receive any onshore intervention (top box in Figure 1). However, some importers of tariff group 4407 from certain countries/timber species choose not to treat before export, which necessitates inspection or treatment onshore (bottom box in Figure 1). Inspection of these entries often results in detections of hitchhiker pests. From these detections, there is some suspicion that the timber pathway is a major pathway for hitchhiker pests. Hitchhiker pests are notoriously difficult to regulate, given their ability to contaminate at virtually any time between treatment and export.

The focus of this analysis is contaminating pests on all timber products falling under tariff code 4407. This tariff code includes sawn, sliced and peeled wood of a thickness exceeding 6 mm, such as treated or untreated weatherboards and wood cut to size for making staves. It incorporates timber products derived from:

- conifers, such as pine (*Pinus spp.*), fir (*Abies spp.*) and spruce (*Picea spp.*);
- tropical wood, such as mahogany (*Swietenia spp.*) and balsa; and
- other trees, such as oak (*Quercus spp.*), maple (*Acer spp.*) and ebony (*Diospyros spp.*).

We analysed data from the department's Agricultural Import Management System (AIMS) and Incidents databases with the aim of assisting the design of on-arrival inspection strategies, including the use of CBIS, to improve risk management on the pathway. Figure 1 identifies a temporal flow of activities and actions preceding import, and recognises that the biosecurity risk should decrease when progressing in time; however, it is hard to translate the above framework directly into parameter values for CBIS without further scientific information.

3.1 Data Analysis

We report the full data analysis in Appendix A, and an earlier, exploratory analysis is reported in Appendix B. The following sections summarise key information from the full data analysis which was undertaken at the line level.

[3] Formally, tariff code 4407 is described as "wood sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end-jointed, of a thickness exceeding 6 mm". For further details on what is covered under tariff code 4407, see Table 11 in Appendix A.

[4] 'Unrestricted risk' is the risk associated with the import of the commodity without any sanitary or phytosanitary measures applied. This is sometimes referred to using the alternative terms 'unmitigated risk' or 'unmanaged risk' elsewhere in the phytosanitary community.

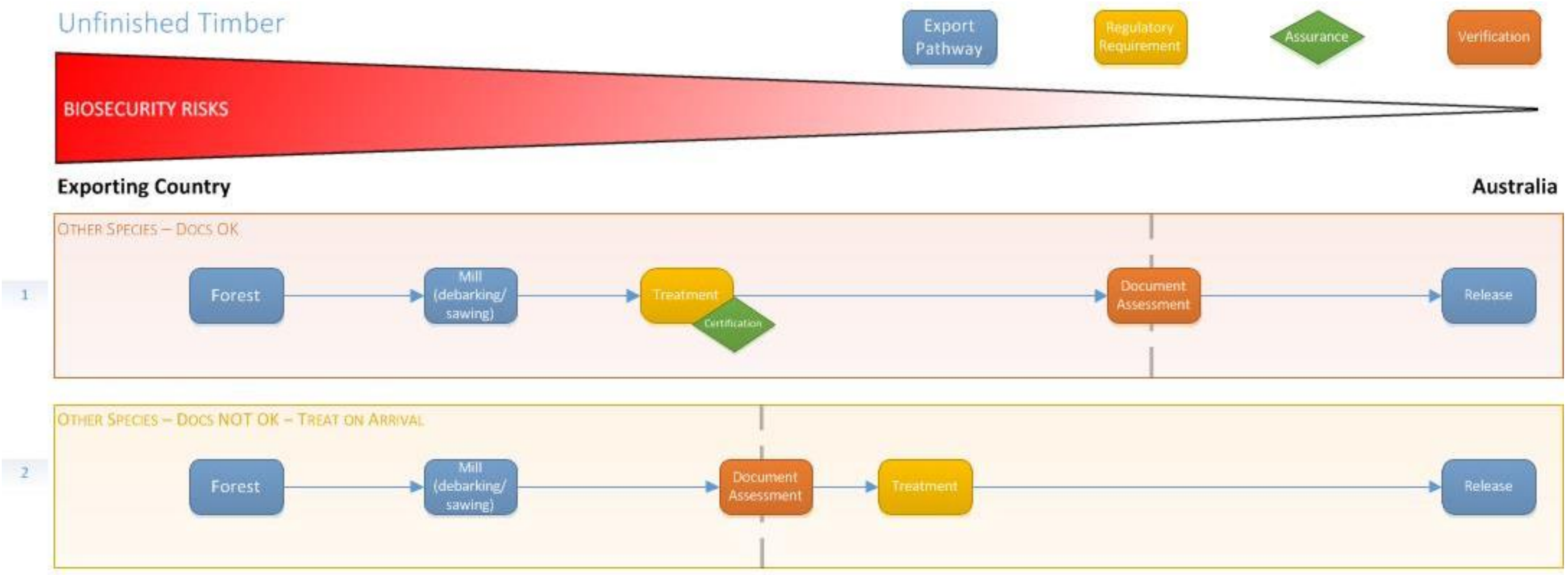

Figure 1. Risk management measures to reduce biosecurity risks associated with timber. The vertical dashed line represents the border assessment of whether goods comply with import conditions. The Biosecurity risk of goods not treated offshore arriving at the Australian border is larger compared to goods that arrive after treatment offshore.

3.1.1 Dataset

Data from the department's AIMS and Incidents databases consisted of border inspection records for 120 459 timber lines that arrived during the period 2008-2018 inclusive. The lines are sourced from 79 countries. Pathway activity includes 2 289 suppliers and 1 048 importers. Key points to note are that:

- of the lines imported, only a small fraction (5.5 per cent) were inspected, noting that inspection may occur when evidence of treatment is not provided;
- of the 39 tariff codes inspected (within 4407) only a handful were inspected at more than 50 per cent; the most substantial tariff codes have inspection rates around or below 5 per cent;
- of the 79 exporting countries, only eight are inspected at 100 per cent, while the four most substantial countries in terms of consignment counts all have inspection rates at or below 5 per cent;
- nearly 75 per cent of the importers imported their consignments from only one country, but this was barely 5 per cent of the pathway volume in terms of line count; and
- more than 85 per cent of suppliers supplied the consignments from only one country, but this single-country supplier activity represented only about half of arriving lines (Table 1).

Table 1. Count of suppliers by the number of countries from which they export and count of corresponding lines from suppliers

Countries	Suppliers	Lines
1	1980	62995
2	211	17911
3	66	13995
4	9	5628
5	2	6024
6	2	5616
7	1	4227
8	1	287
9	1	2311
12	1	1465

3.1.2 Interceptions of hitchhiker pests

For the purposes of this analysis, *interception*[5] refers to the detection of at least one hitchhiker pest of interest during inspection, where hitchhiker pests are those included in a list of species provided by the department. Key points to note are:

- lines that have been inspected are sourced from 60 countries;
- the inspected pathway includes 780 suppliers and 453 importers; and

[5] This use of the term differs slightly from the IPPC definition that relates to "the detection of a pest during inspection or testing of an imported consignment" (FAO, 2007).

- for the 6 664 timber consignments inspected, only a small fraction of inspections (2.3 per cent) resulted in detections of hitchhiker pests.

Of particular interest to the department was:

- whether there are any patterns in interceptions of hitchhiker pests over time, for example, from particular countries, suppliers, treatments, sources, timber types or importers;
- whether there is any seasonality in interceptions of ‘hitchhiker’ pests found on arrival;
- whether the above can be used to engage with trading partners to improve the management of these goods prior to export; and
- whether the above information can be used to assist in the design of on-arrival inspection strategies, possibly including the use of CBIS.

In the available data, the selection of consignments for inspections is not random nor representative; rather, it is based on whether treatment information was provided. The vast majority of consignments arriving in Australia are not inspected as they have evidence of some risk-mitigating treatment.[6] As ‘treated’ goods have had some form of pest mitigation applied during the supply chain, it is assumed, but not definitively known, whether the pattern of biosecurity contamination is lower for the uninspected consignments as for the inspected consignments.

Because of these limitations, our data is less amenable to more sophisticated statistical approaches used in the growing body of studies analysing border interceptions.[7] Despite these shortcomings, we fitted simple statistical models to the data to provide useful insights, rather than definitive conclusions.

Interception rates over time

Higher interception rates have been experienced in the most recent four years than the years preceding – the recent rate being more than double the earlier rate (Figure 2). Understanding whether this change in interception rates is explained by some change in the ‘environment’ is hampered by the dataset’s shortcomings. For instance, policy changes, biosecurity intervention focus shifts, etc., were not considered when data was obtained or in the subsequent analysis.

When the identity of the exporting country is taken into account, there is very little temporal pattern left. It may be possible that the apparent change in interception rate across *time*, observed in Figure 2, is actually a change in *space*, that is, a change of pathway from being dominated by one country to being dominated by another.

[6] It would also be possible to explore differences in temporal or spatial patterns in treated and untreated timber, which could provide insights into why some offshore treatments are universal for some countries or tariff codes, but not others. Furthermore, we note some treatment approaches may be specific to particular tariff codes or identified pests but could not be conducted in the exporting country due to the infrastructure required. Given our focus is on understanding hitchhiker pests, and there is an absence of data on this for treated timber, we leave these considerations for future research once more appropriate data has been collected.

[7] Recent examples of these studies include Eschen et al. (2015, 2019), Kenis et al. (2007), Kim et al. (2018) and Suhr et al. (2019).

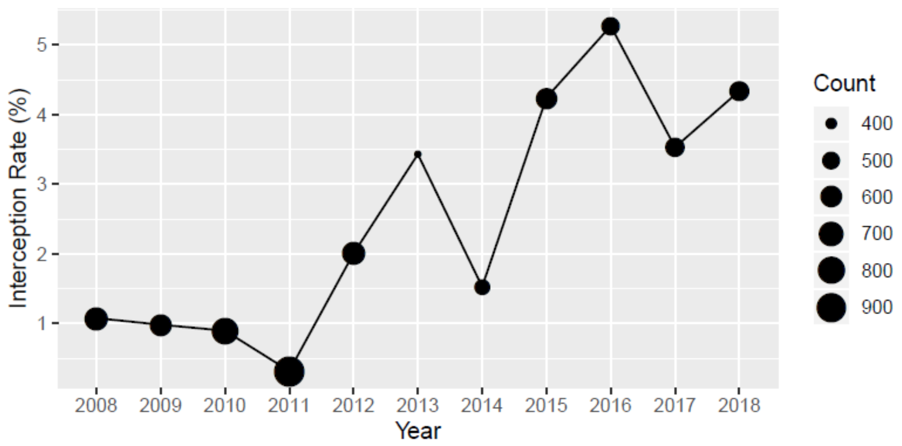

Figure 2. Interception rate for inspected consignments, presented by year. Count refers to the number of inspected consignments.

Spatial differences in interception rates

A generalised linear mixed-effects model was fitted to assess evidence around the variation in interception rates between the various countries, suppliers and importers.[8] The results indicate that the identity of the supplier and importer show strong statistical patterns, with weaker statistical patterns for countries. This can be explained by the observation that the great majority of suppliers and importers are single-country operations, so much of the important country-to-country variation can also be explained by importer-to-importer variation, or supplier-to-supplier variation.

Seasonality in interception rates

To test for within-year effects for interception rates, it was necessary to distinguish between exporting countries that are situated in the northern hemisphere, southern hemisphere and equatorial zone. Table 2 shows the difference in inspection results for lines arriving from exporting countries within the different global regions. Most inspections were performed for northern hemisphere exporting countries, which also had the highest proportion of interceptions, approximately fivefold the southern-hemisphere countries. The interception rate for equatorial exporting countries was very low.

Table 2. Inspection outcomes by global region of exporting country.

	Equatorial zone	Northern hemisphere	Southern hemisphere
Interception	2	134	15
No interception	512	3 756	2 245
Total	514	3 890	2 260
Interception rate (%)	**0.39**	**3.44**	**0.66**

The statistical model fitted to assess the hemispherical and day-within-year signals in Appendix A showed no statistical evidence of a temporal difference, but some

[8] With data on inspections from treated timber imports, one could analyse the network of suppliers and importers for different tariff codes to identify heterogeneity in treated and untreated timber imports. Furthermore, network metrics associated with either supplier or importer nodes could have predictive value in risk analysis.

evidence of a difference between the interception rates for consignments arriving from exporting countries within the different global regions. The lack of a seasonal effect persists when countries from the different hemispheres are analysed separately. One potential contributor to a lack of signal may be the variable travel time – some consignments are seven to eight weeks *en route*, which would considerably complicate seasonal signals.[9]

3.2 Recommendation for CBIS

The motivation for this analysis was to determine whether the border biosecurity interventions for the timber pathway could be managed using CBIS. The conditions under which CBIS might be suitable for a pathway are as follows:

1. the possibility of leakage must be tolerable;
2. the approach rate of the whole pathway *or identifiable sub-pathways* must be reliably low; and
3. the pathway's inspection history must be made readily available so that the pathway mode can be determined and the appropriate measures taken as consignments arrive.

In this analysis, a tolerable amount of leakage could not be pre-determined. Therefore, the reported data analysis focuses on the second of these conditions. Presently, border biosecurity risk management on the timber pathway comprises a documentation check for suitable treatment and inspection or onshore treatment if the documentation check is rejected. Therefore, all consignments are either accompanied by acceptable documentation or the unacceptable risk is managed by inspected or onshore treatment.

Some consignments that lack suitable documentation are inspected, but the failure rate is low, with notable exceptions. Most inspections are performed on consignments from one particular country, for which the failure rate is about 4 per cent. CBIS by country does not seem particularly useful based on this outcome. It is possible that better discrimination would be established if the CBIS program were to manage risk by supplier or importer than by country.

It is possible that the documentary evidence of treatment is incorrect or misleading in some cases, meaning that a portion of the lines not inspected represent untreated timber imports. The only way to determine whether this conjecture is true, or even material, is to inspect a sample of lines arriving with documentation that would otherwise be cleared without further intervention.

Furthermore, to develop a dataset that formally supports the kind of analysis envisioned here, it is necessary for the department to inspect a representative sample of lines that are accompanied by treatment documentation.

We thus have the following recommendations:

- CBIS could be used as a border measure to manage biosecurity risk of consignments, if it were applied at the supplier or importer level.

[9] The duration of transport may also influence the likelihood of pest survival – something which also complicates temporal and country-level assessments of interceptions.

- If risk-based intervention of the timber pathway is of further interest, then a more suitable dataset should be collected, either via a snapshot survey or using the Cargo Compliance Verification approach.

4. Developing Guidance on Rule Parameter Selection

One of the challenges in implementing compliance-based interventions is determining the appropriate rule parameters for managing a given set of risks on a pathway. The department's current approach to identifying suitable rule parameters relies on analysing historical pathway data using simulation techniques. However, there is a renewed desired to consider how CBIS rules could be applied in contexts where import data is unavailable or does not fully match the potential scope for application.

This chapter describes a framework through which the department can determine appropriate CBIS rule parameters for a variety of pathways. It draws on an understanding of the scientific and economic principles that underpin biosecurity regulation and uses probability modelling techniques and a more detailed consideration of risk management to identify suitable rule parameters based on applying CBIS at the line, rather than quarantine entry, level. Rather than relying on administrative data, the framework illustrated in this chapter requires information on things such as compliance costs, the consequences of leakage and pathway-specific pre-border information to inform parameter selection.

Accompanying this chapter, an Excel spreadsheet-based decision tool – the CBIS Sensitivity Module – has been developed to aid the department implement this framework. Throughout the chapter, we refer to outputs from this Module to illustrate the concepts underpinning this structured decision-making framework.

The chapter first outlines the continuous sampling plan algorithms that underpin the CBIS and the framework for regulatory decision-making offered by *menus of regulatory contracts*, before demonstrating key aspects of the modelling approach used to characterise the properties of candidate CBIS rules. The focus of the chapter is to outline an approach that combines modelling with other considerations to inform the selection and possible staged implementation of appropriate CBIS rules on a range of pathways. For such an approach to be successful, processes to more formally account for uncertainties associated with the key inputs to recommendations will need to be developed and implemented. In closing, the chapter notes how such an approach can be used to inform the management of hitchhiker pests on the timber pathway.

4.1 Continuous sampling plan algorithms

The CBIS uses two continuous sampling plan (CSP) algorithms – the CSP-1 and CSP-3 algorithms – to determine whether a given consignment requires inspection on a range of plant-product pathways, including for a range of dried fruit and herbs, fresh fruit, nuts, grains and seeds.[10]

4.1.1 CSP-1 algorithm

The CSP-1 algorithm (Figure 3) is the most basic of the CSP family of rules and was introduced in Dodge (1943). When a new importer starts on this algorithm, they are

[10] For a current list of plant-products covered by the scheme, see http://www.agriculture.gov.au/import/goods/plant-products/risk-return.

usually subject to mandatory inspections (in “census mode”) until they build up a good compliance record. Two key parameters that need to be chosen in this rule are:

- the clearance number (*CN*) – the number of successive consignments that must pass inspection for the importer to be eligible for a reduced inspection frequency; and
- the monitoring fraction (*MF*) – the reduced inspection frequency and probability that a given consignment is inspected in “monitoring mode”.

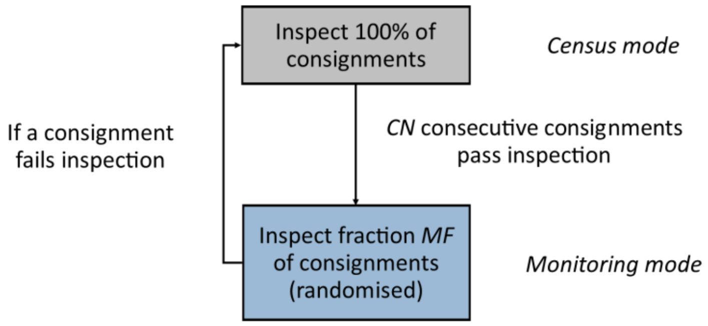

Figure 3. Schematic representation of the CSP-1 algorithm.

If an importer’s consignment fails inspection when the importer is in “monitoring mode”, their subsequent consignments are subject to mandatory inspection in “census” mode. The importer only receives the reduced inspection frequency again after another *CN* successive consignments pass inspection.

4.1.2 CSP-3 algorithm

The CSP-3 algorithm (Figure 4), documented in Dodge and Torrey (1951), differs from the CSP-1 rule in terms of what happens to an importer following an inspection failure in “monitoring mode”. This rule has less severe consequences for occasional non-compliance when an importer is on the reduced inspection frequency *MF* relative to the CSP-1 rule, but at the “cost” of a more complex penalty mechanism.

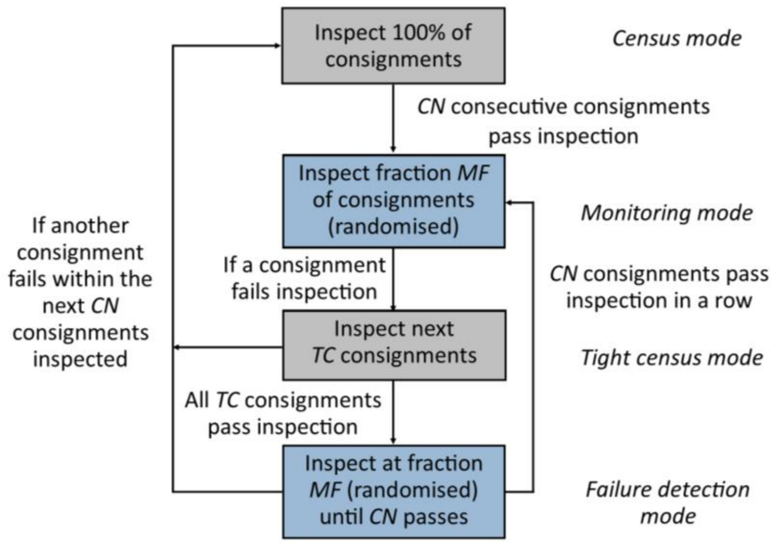

Figure 4. Schematic representation of the CSP-3 algorithm.

In the CSP-3 algorithm,[11] if an importer's consignment fails inspection in monitoring mode, the next *TC* consignments are subject to mandatory inspection in "tight census mode". This is designed to protect against a sudden systematic problem that would significantly raise the likelihood of a consignment failing inspection. However, unlike the CSP-1 algorithm, the importer does not need to demonstrate *CN* consecutive passes to return to a lower inspection frequency.

If the next *TC* consignments following a failure pass inspection, the importer's consignments go back to being inspected at the reduced rate (*MF*) while the regulator keeps track of the number of inspections passed since the last failure. This part of the algorithm is usually referred to as "failure detection mode". Provided the importer passes inspection *CN* times since their last failure, the importer remains eligible to be inspected at the reduced rate of inspection; otherwise, on recording another failure within *CN* inspections of the previous one, the importer's consignments revert to mandatory inspection until they pass inspection *CN* times in a row. Intuitively, this provides less of a "cost" to the importer if recording a failure in one inspection does not increase the probability that future consignments will be more likely to fail.

The tight census number, *TC*, is typically set to four, as suggested in the original Dodge and Torrey (1951) algorithm and implemented in the statistical analysis of Robinson et al. (2012). It is possible for the value *TC* to be another "free" parameter selected by the pathway manager in establishing a rule for a given pathway; indeed, the ability to change *TC* from four has been incorporated into the department's information technology systems that underpin the Q-ruler. To simplify the analysis and decision-making process, we set *TC* to be four for the remainder of this chapter.

For most pathways, the CBIS uses the CSP-3 algorithm to determine inspections. This rule was adopted and introduced following recommendations in Robinson et al. (2012) based on a statistical analysis of the department's administrative data for several plant-product pathways. Subsequent analysis of the CSP rules in the game-theoretic context in CEBRA Project 1304C, including the analysis of Rossiter and Hester (2017), suggested that the CSP-1 algorithm would be preferable from the department's perspective, particularly where the consequences of biosecurity risk material leakage are perceived to be relatively large. From a practical perspective, the CSP-1 algorithm is simpler and more easily able to be communicated to stakeholders, with stakeholders also likely to develop a clearer understanding of the incentive properties of the inspection rule.[12]

[11] This description follows the simplification in the algorithm suggested by previous research commissioned for the department; see Robinson et al. (2012) for more details.

[12] The CSP-1 and CSP-3 algorithms were also compared in the laboratory experiments as part of CEBRA Project 1404C. While the experiments did not find consistent systematic differences in the supplier choices of subjects between directly comparable CSP-1 and CSP-3 treatments, they showed that subjects tended to choose suppliers with lower biosecurity risk material approach rates when they understood the inspection rules better. Further analysis also confirmed a regulator who cared significantly about the consequences of pathway leakage would be better off selecting the CSP-1 rather than CSP-3 rule with the same *CN* and *MF* values. See Rossiter et al. (2018a, 2018b) for more details about findings from the economics experiments.

4.1.3 Concepts of "failing inspection" for analysing CBIS rules

For the CSP-1 and CSP-3 algorithms to be used in biosecurity operations, a clear definition of what constitutes "failing inspection" is required. Two definitions of failing inspection have been used for the purposes of implementing the CBIS for border inspections.

Inspection failures occur when a non-compliance, such as the incorrect declaration of goods, packaging failures and/or evidence suggesting the possible presence of biosecurity risk material, is detected at inspection. In AIMS data, this is normally identified through an "inspection not okay" outcome against an inspection direction. Many applications of the CBIS have used the "inspection failure" concept as the failure definition for the CSP-1 and CSP-3 algorithms.

There are a variety of reasons why an inspection failure may occur and only a minority of these are due to pests and diseases not already present in Australia. A narrower definition of failing inspection, focused on circumstances when a consignment poses a direct biosecurity risk, is a **quarantine failure**. This is a subset of an inspection failure where follow-up investigations of a consignment with an "inspection not okay" result finds an actionable pest or disease. This failure concept has been applied by the department to select fresh fruits, including lemons, limes, blueberries, cherries and select species of stone fruits, imported under the Offshore Pre-shipment Inspection (OPI) program from New Zealand and/or the United States.

The discussion in the remainder of the chapter encompasses both failure definitions, since both are currently used by the department. Henceforth, the term *approach rate* is used to refer to the proportion of failures of the type on which the CSP rule is based arriving at the border. Depending on the context, this may refer to either inspection or quarantine failures.

4.2 Insights from economic theory for "designing" regulation

The theory of incentives, incentive regulation and the economics of auditing offer insights that can help design biosecurity intervention protocols that might reduce system costs.[13] As noted in CEBRA Project 1304C (Rossiter et al., 2016), economic theory suggests a range of control measures, including:

- focusing interventions on compliance history and outcomes;
- offering menus of regulatory contracts as part of biosecurity regulation;
- modify information system and pathway definitions according to biosecurity risk profiles;
- changing the relative costs of undergoing interventions;[14]
- basing intervention protocols across different dimensions, such as using importer–supplier combinations for assessing relative biosecurity risk; and
- leveraging compliance history across multiple pathways.

[13] For a more extensive discussion of the economic theory underpinning the design of effective regulatory frameworks, see Chapter 4 and Appendix C of CEBRA Project 1304C (Rossiter et al., 2016).

[14] We acknowledge this may be difficult, given the department is required to undertake its intervention activities on a cost-recovery basis.

For this analysis, the first two of these aspects are the most important. While the third to sixth items need to be considered as part of regulatory design, they will largely be taken as given in structuring intervention rules and determining rule parameters. As we show later, the analytical methods used in this report can be adapted for designing options, including those as constructed as part of a menu of regulatory contracts.

By their very nature, the CSP algorithms focus on an entity's compliance history. An outcome-based focus gives biosecurity system stakeholders, including importers and suppliers, more choice in how they meet regulatory requirements and provide assurances of biosecurity standards. For example, stakeholders could demonstrate their internal control mechanisms result in the effective pre-border management of biosecurity risks through home-country process audits. This could mean consignments that provide this level of assurance may be eligible for alternative intervention protocols, relative to others on the pathway, through an approved arrangement. Such arrangements could involve CBIS-style rules for monitoring ongoing compliance.

Focusing on outcomes and rewarding compliance could also foster innovation through encouraging investigation of alternative biosecurity risk mitigation strategies and demonstrating they yield equivalent, or potentially superior, biosecurity outcomes to current standards. The department can harness private-sector incentives for establishing equivalence, through being able to replace mandated conditions with requirements that deliver equivalent biosecurity outcomes at lower cost, to reduce compliance costs while maintaining Australia's high biosecurity status.[15] Different treatments or intervention protocols, including CBIS-style rules, may then be applied to offer an equivalent standard of biosecurity assurance across all stakeholders on a given pathway. Furthermore, if the alternative mitigation strategies are developed by or supported by a National Plant Protection Organisation or another representative body, the department may be able to leverage third-party accreditation schemes to verify adherence to those strategies.

Alongside an explicit focus on outcomes, offering a suite of options to the regulated entity – a *menu of regulatory contracts* – can allow the regulator to extract improved performance using the entity's information advantage.[16] While this can make the regulatory task more complicated, the expected gains from "win-win" situations may more than offset this cost.[17]

In a biosecurity context, reward structures can be designed that provide increasing benefits for higher levels of biosecurity compliance, with the options offered as part of the menu being interdependent in terms of trade-offs to induce better behaviour.

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[15] The notion of equivalence in sanitary and phytosanitary protection is established in Article 4 of the SPS Agreement. Care needs to be taken to collect and evaluate appropriate evidence to demonstrate equivalence. The charging mechanism associated with assessing and establishing approved arrangements would also need to be designed carefully to recover departmental costs while not undermining incentives for innovation in biosecurity risk mitigation.

[16] See Sappington (1994) for a more extensive discussion of incentive regulation and design of menus of regulatory contracts.

[17] A common example of this is in motor vehicle insurance, where the purchaser of insurance is asked to choose between a menu of contracts including, at one extreme, a high excess but low premium and, at the other, a low excess with high premium. Confronted with these options, the driver maps in private information about their driving habits and capabilities (influencing the probability of making a claim) and the premium and chooses the excess/premium option that maximises their wellbeing.

From an operational perspective, these menus may be useful for constructing “tiers” of approved arrangements on different pathways. Developing standardised arrangements would significantly simplify the administration of a more flexible outcomes-based system for biosecurity risk management, making “off the shelf” arrangements available to a larger number of stakeholders with low to moderate import volumes. Higher tiers in the compliance agreement hierarchy, corresponding to lower levels of intervention by the department, could be offered to stakeholders who:

- demonstrate routine compliance with requirements over an extensive history;
- are integrated with sophisticated systems for monitoring and reducing biosecurity risks through the supply chain; and/or
- demonstrate adherence to effective biosecurity control through mechanisms such as internationally accredited and independently audited programs or other process controls.

4.3 Modelling CSP rule properties

4.3.1 Modelling CBIS rule properties using Markov-chain analysis

The CSP-1 and CSP-3 rules can be expressed as a *Markov chain*, because the future ‘state’ of the rule is able to be expressed through knowledge of the current ‘state’ of the rule alone; for these rules, knowledge of past states that led to the current state are not required. Because of this representation, several properties can be modelled using the theory of *stochastic processes*; specifically, the expected long-run (equilibrium) behaviour of importers with a given inspection failure rate can be examined based on the Markov chain’s *stationary distribution*.[18] See Appendix C for more details on calculating these stationary distributions and associated key metrics.

In undertaking this modelling exercise, several assumptions need to be made; however, it is possible to weaken many of these assumptions. Three key assumptions are discussed in more detail below.

1. The probability of failing inspection is constant (e.g. 5 per cent) and assumed to be independent of past (and future) inspection outcomes. Equivalently, this is saying that the probability of failing the next inspection does not increase or decrease if the last inspection outcome was a failure.[19]
2. Where the rule chosen uses an “inspection failure” to define the notion of a failure, the rate at which biosecurity risk material approaches the border (i.e. a quarantine failure) represents a *thinning* of the inspection failure distribution. This means that each inspection failure has a fixed probability of being a quarantine failure, which is independent of past (and future) outcomes for the

[18] This modelling strategy was first proposed in CEBRA Project 1608C (Rossiter et al., 2020) and has since been adapted for this CEBRA project. The project team gratefully acknowledges feedback received from Barney Caton from the US Department of Agriculture’s Animal and Plant Health Inspection Service which has influenced the modifications of this approach.

[19] For example, this means ignoring the potential for strategic behaviour when in monitoring mode by reducing mitigation effort and raising the biosecurity risk material approach rate (Rossiter and Hester, 2017). Parameterising what would happen to the approach rate in these modes would be difficult in practice, as it could require in-depth knowledge of the incentives facing stakeholders on a specific pathway.

inspection/quarantine failure distinction. This assumption enables the analysis of the leakage of biosecurity risk material implied by consignments that would be subject to release on compliant documentation alone.

3. Biosecurity inspections at the border are assumed to be "perfect" and not subject to decision errors by inspection staff. As we illustrate later in Chapter 4.4.4, this assumption provides a comparison no less favourable for CBIS rules with mandatory inspection regimes.

While the first two assumptions may seem restrictive, their applicability can be tested for pathways currently subject to mandatory inspection. The main element that requires testing is the assumption that inspection failures are serially independent.[20] Discernible patterns in failure rates may reflect seasonal influences on pest and disease loadings on the pathway[21] or other features of the production process that could indicate process failures of a more systemic nature. Fisher's exact test, or the (approximate) chi-squared test of independence, can be used to test the null hypothesis of serial independence of failures against an alternative hypothesis of first-order dependence for each stakeholder using the 2x2 contingency table format as illustrated below in Table 3.

Table 3.Contingency table for assessing serial independence of failures for a given stakeholder

		Outcome of current inspection		
		Pass	**Fail**	**Total**
Outcome of previous inspection	**Pass**	*w*	*x*	*w+x*
	Fail	*y*	*z*	*y+z*
	Total	*w+y*	*x+z*	*w+x+y+z (=n)*

A similar process can be adopted to assess whether the thinning assumption relating to quarantine and inspection failures, where relevant, is also valid. Because these procedures involve testing multiple stakeholders to infer whether the assumption of serial independence is appropriate on the pathway, the significance level for individual tests should be adjusted using a standard correction method, such as Bonferroni's method, to control the overall significance of the test.

4.3.2 Testing Markov-chain modelling assumptions using inspection data

We now illustrate how to test assumptions 1 and 2 at the pathway level using the timber and timber products inspection data referred to in Chapter 3. While the inspection data is not representative of the entire pathway, it can be used to

[20] The stability of the approach rate over time is a less critical issue for the metrics described in the next subsection, since the focus is on assessing potential leakage under a "worst case" scenario. The main caveat to this is if there is strategic behaviour on behalf of the importer or supplier that increases the approach rate when subject to a lower frequency of inspection.

[21] For pathways with sufficiently high volumes, slow-moving seasonal patterns are unlikely to significantly undermine the assumption of serial independence. Furthermore, using the average outgoing quality limit assess risks on the pathway, as a conservative decision rule, should mitigate potential biases arising from the assumption of serial independence being violated.

demonstrate the testing procedure for whether there is sufficient evidence to suggest these assumptions may not hold.

Table 4 shows the results of testing the serial independence assumption of inspection failures at the importer level after sorting the available inspection data by importer and then time of inspection. We use Fisher's exact test and adjust the significance level of individual importer-level tests to ensure an overall significance level of 5 per cent across the pathway.

Table 4. Assessing the independence assumption for inspection failures on the timber and timber products pathway: importer-level analysis

Importer	p-value*	Pass to Pass	Pass to Fail	Fail to Pass	Fail to Fail
3	0.0794	274	10	10	2
5	**0.0006**	**305**	**44**	**45**	**20**
6	**0.0000**	**259**	**3**	**3**	**5**
8	**0.0000**	**103**	**12**	**11**	**12**
9	0.2780	123	6	5	1
10	**0.0001**	**12**	**1**	**1**	**9**
19	0.1066	34	1	1	1
21	1.0000	182	30	30	4
27	0.1729	23	3	3	2
34	0.0052	98	4	4	3
41	0.0688	22	3	3	3
42	**0.0000**	**215**	**19**	**19**	**13**
44	0.0039	331	80	80	39
49	0.0299	22	4	4	5
55	**0.0000**	**73**	**14**	**15**	**30**
64	0.1900	96	39	38	24
70	**0.0000**	**183**	**19**	**19**	**19**
73	0.1764	79	3	3	1
82	**0.0000**	**98**	**6**	**5**	**16**
100	0.0754	21	3	3	3
120	0.5107	19	3	3	1
122	0.0909	7	1	2	4
134	0.0272	19	3	4	5
144	0.4424	79	12	12	3
157	1.0000	1	1	2	2
159	1.0000	1	1	1	4
161	0.4221	14	2	2	1
168	0.3778	7	1	1	1
176	**0.0000**	**41**	**3**	**3**	**15**
182	0.1026	2	5	5	1

Notes: * Probability values are based on Fisher's exact test with a two-sided alternative hypothesis. P-values reported to be zero to four significant figures should be read as less than 0.00005. Shaded and bolded rows indicate that the p-value attained is less than the threshold required that would indicate a 5 per cent level of significance for the pathway overall, accounting for the multiple hypothesis tests. Only includes importers where finite odds ratios can be computed – that is, each cell in the contingency table has a minimum value of one.

Our analysis suggests the first assumption for the Markov chain analytical framework would not hold if a rule were to be applied using the "inspection failure" concept as the definition of failure. The null hypothesis of serial independence is rejected for nine of the 30 importers for which we can compute finite odds ratios. The main reason for this appears to be there is a tendency for inspection failures to be clustered, resulting in "Fail to Fail" transitions generally being larger than would be expected under the assumption of serial independence.

The outcomes shown in Table 4 suggest it would not be appropriate to use the Markov-chain modelling approach to inform an assessment of suitable rule parameters for the timber pathway if the rule were based on the inspection failure concept. Instead, other methods, such as the well-established simulation methods developed by Arthur and Zhao (2014), could be used in preference to the Markov-chain analytical framework.

On the other hand, the department could elect to use hitchhiker pest interceptions – a form of quarantine failure – to define a failure according to a candidate CBIS rule. Table 5 suggests using Markov-chain analysis would be reasonable in these circumstances, as there does not seem to be sufficient evidence at the pathway level to suggest the serial independence assumption is violated.

Table 5. Assessing the independence assumption for interceptions on the timber and timber products pathway: importer-level analysis

Importer	p-value	Non-interception to Non-interception	Non-interception to Interception	Interception to Non-interception	Interception to Interception
5	0.2888	374	19	19	2
44	0.0213	466	29	29	6
64	1.0000	143	25	25	4
70	0.1893	227	6	6	1
100	0.1310	27	1	1	1

Notes: * Probability values are based on Fisher's exact test with a two-sided alternative hypothesis. After accounting for the multiple hypothesis tests, no individual importer tests attained a p-value below the threshold required that would indicate a 5 per cent level of significance for the pathway overall. Only includes importers where finite odds ratios can be computed – that is, each cell in the contingency table has a minimum value of one.

For completeness, the results of testing the assumption that interceptions represent a *thinning* of the inspection failure distribution in Table 6 suggests this assumption appears to be reasonable, as no importer-level tests of this hypothesis can be rejected if a 5 per cent level of significance at the pathway level is maintained.

Table 6. Assessing the assumption that interceptions are a *thinning* of inspection failures on the timber and timber products pathway: importer-level analysis

Importer	p-value	Non-interception to Non-interception	Non-interception to Interception	Interception to Non-interception	Interception to Interception
4	1.0000	1	2	2	1
5	1.0000	29	15	14	6
21	0.5843	22	4	5	2
44	0.5100	61	23	23	12
55	1.0000	29	7	7	1
64	0.6106	19	14	14	15
70	0.5963	25	5	5	2

Notes: * Probability values are based on Fisher's exact test with a two-sided alternative hypothesis. After accounting for the multiple hypothesis tests, no individual importer tests attained a p-value below the threshold required that would indicate a 5 per cent level of significance for the pathway overall. Only includes importers where finite odds ratios can be computed – that is, each cell in the contingency table has a minimum value of one.

4.4 Illustrating trade-offs with different CBIS rule configurations and parameters

The stationary distributions generated through the Markov-chain modelling approach can be used to compare two measures of interest for selecting the rule parameters, namely:

- how the long-run share of consignments saving inspection changes for importers with different failure rates; and
- how the rate of *stakeholder-specific* biosecurity risk material leakage varies according to failure rates.

Taken together, these measures demonstrate the trade-offs associated with choosing different CSP algorithms and/or values for the *CN* and *MF*. The first metric documents the relative strength of incentives, in the form of rewards, experienced by biosecurity system stakeholders with different failure rates, while the second assesses the risk to the department's overarching objective of managing the potential leakage of biosecurity risk material into Australia.

The modelling assumptions outlined in the previous section mean the second metric uses the concept of *average outgoing quality* (AOQ) from the statistical quality control literature; see for instance, Dodge (1943) for an early exposition or Stephens (2001) for a contemporary perspective focused on applications. The AOQ for a sampling plan describes the expected relationship between the incoming (pre-intervention) rate of non-compliance, measured by the approach rate of the relevant "failure" concept, and the outgoing (post-intervention) rate of non-compliance after completing the specified intervention protocols. Tracing out the biosecurity risk material leakage as the rate of non-compliance varies gives an *average outgoing quality curve* (AOQ curve), whose maximum value is the *average outgoing quality limit* (AOQL). The AOQL provides a "worst case" scenario for the post-intervention rate of non-compliance; regardless of the approach rate, the post-intervention rate of non-compliance should be no higher than the AOQL over an extended period of time (i.e. the long run).

Both concepts are shown below in Figure 5 for the CSP-1 rule with *CN* = 10 and *MF* = 0.5, which highlights the typical "hump shape" of the AOQ curve. When incoming consignments are highly compliant (i.e. have low approach rates), the rate of post-intervention non-compliance will also be low. If the incoming approach rate is high, most consignments will fail the intervention and undergo some form of treatment to rectify the presence of biosecurity risk material, thereby ensuring a low rate of post-intervention non-compliance. As a result, the AOQL typically occurs at an intermediate failure rate, thereby generating a peaked profile as shown in Figure 5.

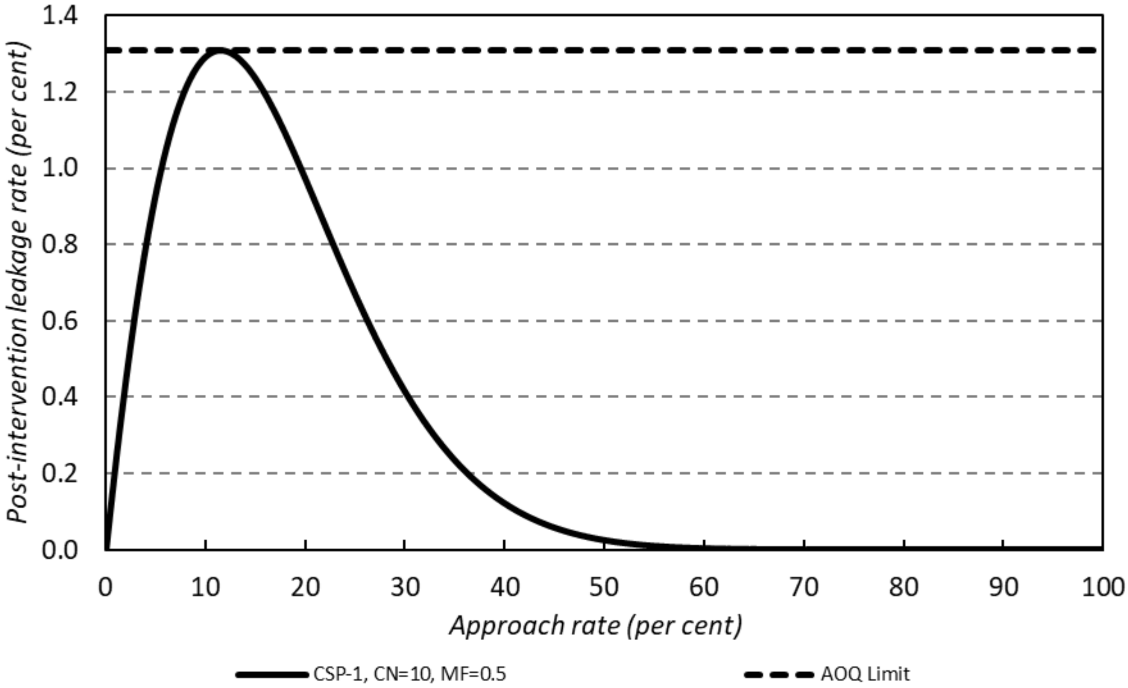

Figure 5. Average outgoing quality (AOQ) curve and limit for the CSP-1 algorithm with CN = 10 and MF = 0.5.

Unlike the simulation methods of Arthur and Zhao (2014) now well-established in the department, the Markov-chain modelling framework uses the stakeholder as the basis for applying the CBIS rule, rather than the pathway, as the unit of analysis for comparing different rule parametrisations. This reflects requirements of the Markov chain methodology and its application to the CSP algorithms, since we are making assumptions about the incidence of *stakeholder-specific*, rather than pathway-level, patterns in pre-intervention compliance as part of implementing the relevant CBIS rules. Direct pathway-level comparisons are rendered inappropriate, though it is possible to generate pathway-level cameos for comparison purposes.[22] Since the department applies CBIS at the importer level currently, henceforth we assume that the stakeholder unit is the importer without loss of generality.[23]

[22] For completeness, the CBIS Sensitivity Module developed for this project includes a component where pathway-level cameos can be generated. This allows department officers to make comparisons between the established data-driven pathway-level analysis and the Markov-chain approach for threshold metrics.

[23] It is possible for CBIS rules to be applied based on stakeholder combinations, such as importer and supplier, or importer and country of origin, rather than pooling information across all suppliers and

Relative to the simulated method approach, using the AOQL also provides a greater degree of assurance for the department, given this represents a worst-case scenario for any individual importer. Therefore, at the pathway level, overall post-intervention non-compliance would be highly unlikely to exceed the rate specified through the AOQL. Such departures from modelled behaviours would likely occur only if the underpinning assumptions of the Markov-chain framework were grossly violated.

An advantage of using the Markov-chain approach is that it can be applied without referring to administrative data on the pathway, since these methods rely on the properties of the algorithms themselves. Furthermore, this modelling framework enables “rules of thumb” to be developed to help understand the consequences of different choices. We demonstrate these notional rules of thumb in the remainder of this section, drawing on output from the user-defined inputs and charts of the CBIS Sensitivity Module.[24]

4.4.1 Choosing the clearance number (*CN*)

For the clearance number *CN*, two rules of thumb can be demonstrated, which we illustrate below.

1. *Share of saved inspections*
   The higher the value of CN, the faster the rewards for compliance disappear for even moderately compliant importers, such that rules with a higher CN offer relatively stronger rewards for importers with superior compliance.

2. *Post-intervention leakage rate*
   The higher the value of CN, the lower the post-intervention rate of non-compliance rate for all approach rates. As CN rises, the maximum modelled rate of biosecurity risk material leakage, which corresponds to the rule’s average outgoing quality limit, is reached at a lower approach rate.

The first rule of thumb is intuitive, given the clearance number represents a “hurdle requirement” that importers must meet before being rewarded through being able to save inspections. The higher the clearance number *CN*, the higher the hurdle requirement and the more difficult it becomes for importers with higher failure rates to enter monitoring mode.[25] Furthermore, for a given monitoring fraction *MF*, a higher failure rate is associated with fewer expected consignments brought in under

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countries of origin for a given importer. To date, AIMS limitations have meant only one dimension – usually the importer – has been used as the basis for CBIS rules.

[24] This spreadsheet model was developed as part of this project to help guide policy and technical officers on what rules and parameters may be appropriate for a given pathway and to better understand the trade-offs associated with different rule choices.

[25] If the tight census number, *TC*, is allowed to differ from four in the CSP-3 algorithm, similar arguments can be made to establish that a higher value of *TC*, all else held constant, will result in the rewards for compliance disappearing at a faster rate, a lower post-intervention rate of non-compliance rate for all approach rates, and the average outgoing quality limit being reached at a lower approach rate.

monitoring mode. Together, these effects combine to deliver the second rule of thumb.

For illustrating all rules of thumb presented in this subsection, we assume that an inspection failure constitutes a “failure” under the possible CBIS rule – consistent with the Q-ruler’s formulation – with half of all inspection failures assumed to be quarantine failures. Note that if historical data were available for a given pathway, the proportion of inspection failures that are quarantine failures could have been be informed by AIMS data, subject to the caveat that past trends may not always accurately indicate future patterns.

Figure 6 below demonstrates how the modelled long-run share of saved inspections varies according to an importer’s approach rate (in this case, based on inspection failures) for the CSP-3 algorithm where *MF* = 0.5 and *CN* can take the value 5 (Rule 1, in black), 10 (Rule 2, in orange) or 20 (Rule 3, in red).

Since *MF* = 0.5 for all three rules, the maximum benefit a fully compliant importer can receive is, in the long run, to save inspection on half of their consignments. Where the three rules differ is how rapidly the relative rewards diminish as an importer’s failure rate rises. For instance, if an importer’s approach rate (corresponding to the inspection failure rate in this illustration) was 10 per cent, an importer under Rule 1 (*CN* = 5) could still be expected to save inspection for around 38.6 per cent of their consignments; this share of saved inspections reduces to 31.3 per cent under Rule 2 (*CN* = 10) or 15.7 per cent under Rule 3 (*CN* = 20). The differences for higher inspection failure rates are starker – an importer whose inspection failure rate is 20 per cent could expect to save inspection on 26.2 per cent, 12.3 per cent or 1.6 per cent in the long run under Rules 1, 2 and 3 respectively.

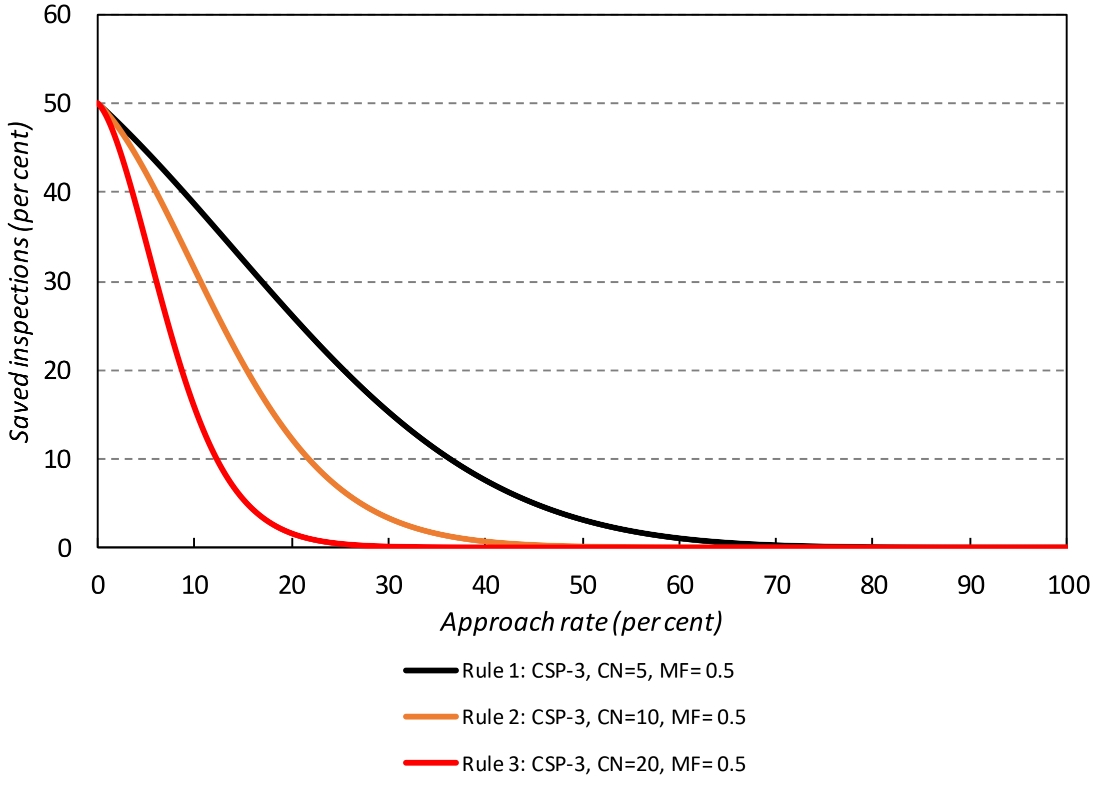

Figure 6. Comparison for the modelled percentage of saved inspections under the CSP-3 algorithm with MF = 0.5 and different CN values (5, 10 and 20).

Figure 7 below shows the respective AOQ curves for the three rules, with the AOQL values for each rule represented by dashed lines at the maximum point. As posited in the rule of thumb outlined earlier, Rule 1, with the lowest qualification requirement (of only five consecutive passes) to enter monitoring mode from census mode has the highest modelled leakage rate of 2.62 per cent. Because less-compliant importers can qualify for monitoring mode more easily, the maximum post-intervention non-compliance rate is achieved at an approach rate of 21.0 per cent. In contrast, Rule 2 has a maximum modelled leakage rate of 1.61 per cent (attained at an approach rate of 12.2 per cent), with Rule 3 having a post-intervention leakage rate of 0.91 per cent (attained at an approach rate of 6.8 per cent). It is also worth noting more generally that the differences between the post-intervention leakage rates are much smaller at low approach rates – particularly those under 5 per cent.

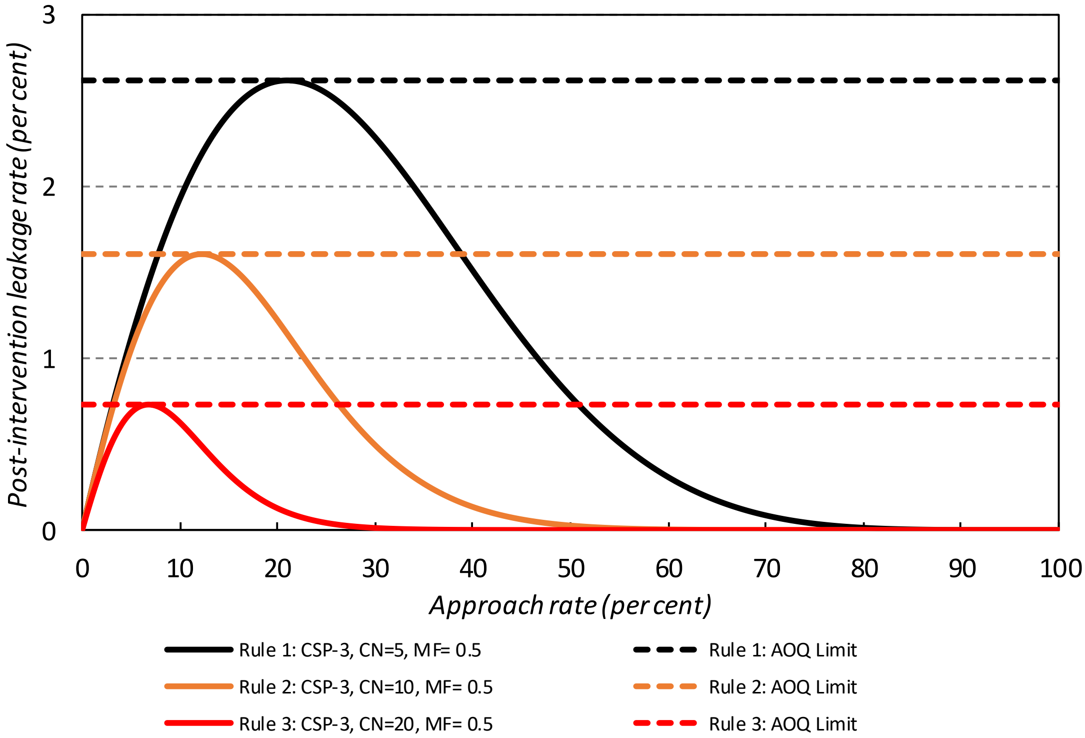

Figure 7. Comparison for the modelled post-intervention leakage rate for the CSP-3 algorithm with MF = 0.5 and different CN values (5, 10 and 20).

4.4.2 Choosing the monitoring fraction (*MF*)

For the monitoring fraction *MF*, two rules of thumb are as follows.

1. *Share of saved inspections*
   The higher the value of MF, the lower the share of saved inspections for all approach rates. When comparing two rules with the same clearance number CN, the rule with the higher MF will have a faster withdrawal of the rewards for compliance at lower approach rates.

2. *Post-intervention leakage rate*
   The higher the value of MF, the higher the rate of post-intervention non-compliance for all approach rates. As MF rises, the maximum modelled rate of biosecurity risk material leakage is reached at a higher approach rate.

These two principles reflect that 1-*MF* is the maximum reward for full compliance with requirements in terms of the share of saved inspections and that for any approach rate, once in monitoring mode, a higher *MF* reduces the expected number of consignments until a failure is detected. As such, a higher monitoring fraction means importers with higher approach rates spend less time in monitoring mode than their more-compliant counterparts, given less-compliant importers are "screened out" more quickly. A higher *MF* also implies a lower likelihood of leakage for a given approach rate, which combined with a lower share of saved inspections, means the AOQL is reached at a lower approach rate.

Figure 8 demonstrates how the modelled long-run share of saved inspections varies according to an importer's approach rate for the CSP-3 algorithm where *CN* = 10 and *MF* can take the value 0.1 (Rule 1, in black), 0.25 (Rule 2, in orange) or 0.5 (Rule 3, in red). As per the previous illustration, we retain the inspection failure as what constitutes a "failure" under the candidate CBIS rules, with half of all inspection failures assumed to be quarantine failures.

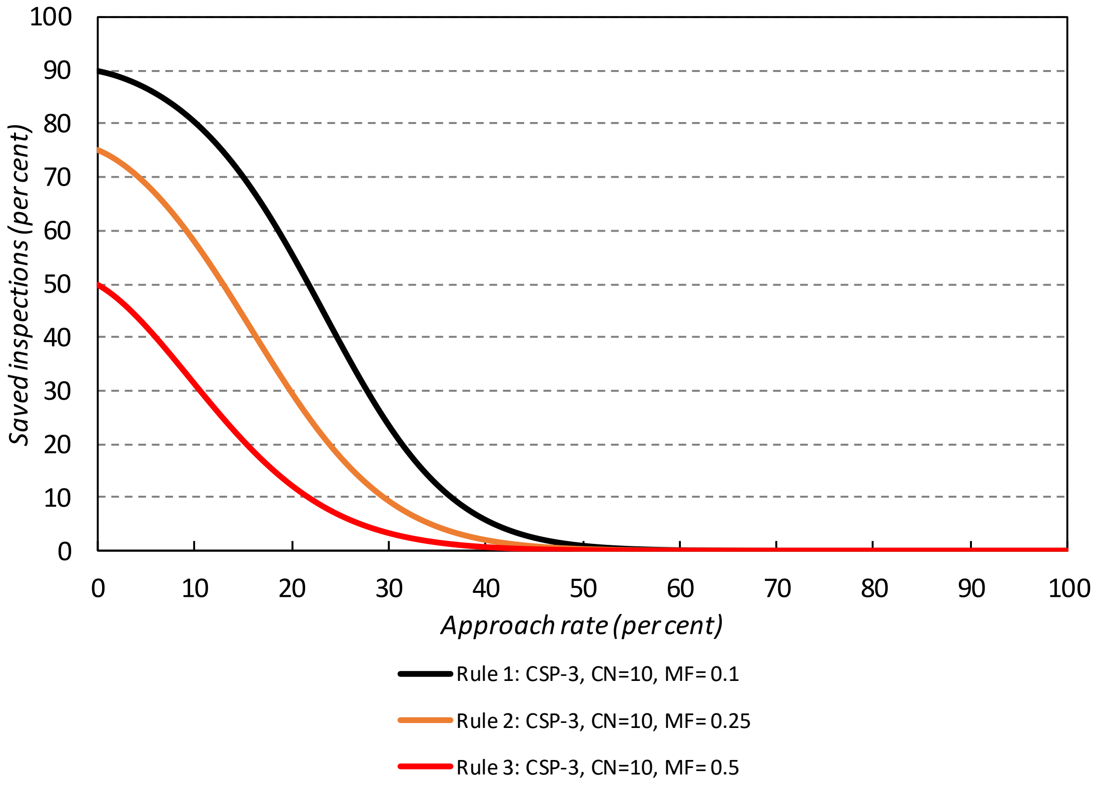

Figure 8.Comparison for the modelled percentage of saved inspections under the CSP-3 algorithm with CN = 10 and different MF values (0.1, 0.25 and 0.5).

For any approach rate, the share of saved inspections for Rule 3 is always lower than that of Rules 1 and 2. Furthermore, the slope of the curve describing the share of saved inspections for Rule 3 also has the steepest (negative) gradient up to an approach rate of 7.6 per cent, with Rule 2 having the steepest slope of the three rules between approach rates of 7.7 per cent and 17.6 per cent. This illustrates the second part of the rule of thumb relating to saved inspections, in that the rewards for compliance are withdrawn at a faster rate for lower approach rates when the value of

MF is higher. In part, this reflects that the point of inflection[26] in the saved inspections curves in Figure 8 occur at lower approach rates for higher values of *MF*; the approach rates that represent the maximum rate of decline in the saved inspections curve are 23.4 per cent (Rule 1), 15.9 per cent (Rule 2) and 9.5 per cent (Rule 3).

Figure 9 shows the respective AOQ curves for the three rules, with the AOQL values for each rule represented by dashed lines at the maximum point. As posited in the rule of thumb, Rule 1, with the lowest monitoring fraction has the highest modelled leakage rate of 5.59 per cent. Because less compliant importers can expect to stay longer in monitoring mode when the monitoring fraction is lower, the maximum post-intervention non-compliance rate is achieved at an approach rate of 19.0 per cent.[27] In contrast, Rule 2 has a maximum modelled leakage rate of 3.29 per cent (attained at an approach rate of 15.0 per cent), with Rule 3 has a maximum post-intervention leakage rate of 1.61 per cent (attained at an approach rate of 12.2 per cent).

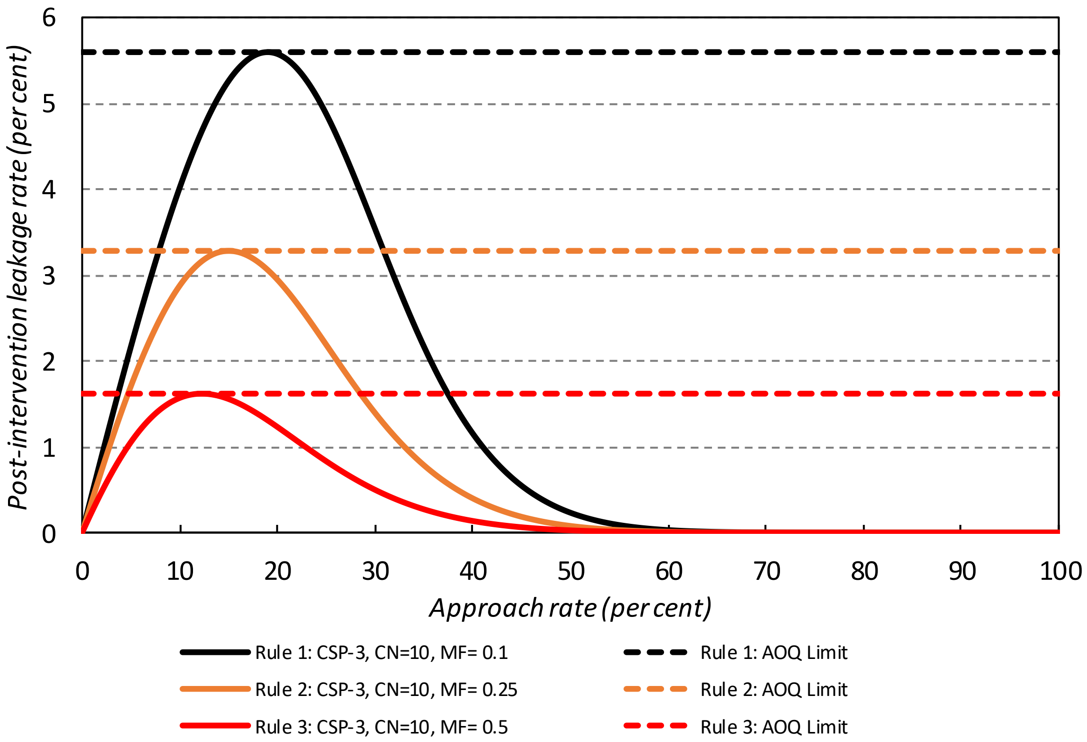

Figure 9. Comparison for the modelled post-intervention leakage rate for the CSP-3 algorithm with CN = 10 and different MF values (0.1, 0.25 and 0.5).

4.4.3 Comparing the CSP-1 and CSP-3 algorithms

For the CSP-1 and CSP-3 algorithms with the same *CN* and *MF* values, we highlight the following “rules of thumb”.

[26] The point of inflection in this curve refers to the approach rate around which the saved inspections curve has its fastest rate of decline and where it changes from being concave to convex.

[27] These estimated maximum and minimum points are based on a “grid search” over a coarse grid of approach rates, with a 0.1 percentage point difference between grid steps. This calculation mirrors the approach used in the CBIS Sensitivity Module.

1. *Share of saved inspections*
   The CSP-1 algorithm admits a lower share of saved inspections across all approach rates relative to the CSP-3 algorithm with the same clearance number CN *and monitoring fraction* MF*. The difference between the two rules' outcomes increases with a higher* CN *or lower* MF.

2. *Post-intervention leakage rate*
   The CSP-1 algorithm admits a lower rate of post-intervention non-compliance for all approach rates relative to the CSP-3 algorithm with the same clearance number CN *and monitoring fraction* MF*. The maximum modelled rate of biosecurity risk material leakage for the CSP-1 algorithm is reached at a lower approach rate than for the CSP-3 algorithm. The difference between the two rules' outcomes increases with a higher* CN *or lower* MF*.*

These two rules of thumb reflect that the CSP-1 algorithm provides a stronger penalty for failing in monitoring mode, whereas the CSP-3 algorithm offers a "second chance" to importers with occasional non-compliance. For low values of the clearance number *CN*, the penalties associated with failing inspection in the CSP-1 and CSP-3 algorithms are broadly similar, meaning the differences in saved inspections and post-intervention non-compliance rates are small. A higher monitoring fraction *MF* also makes the implications of the penalty structures of the CSP-1 and CSP-3 algorithms more similar.

Figure 10 below demonstrates how the modelled long-run share of saved inspections varies according to an importer's approach rate for the CSP-3 (Rule 1, in black) and CSP-1 (Rule 2, in orange) algorithms where *CN* = 15 and *MF* = 0.1. Again, we assume an inspection failure defines the basis for a failure for the possible CBIS rules, with half of all inspection failures assumed to be quarantine failures.

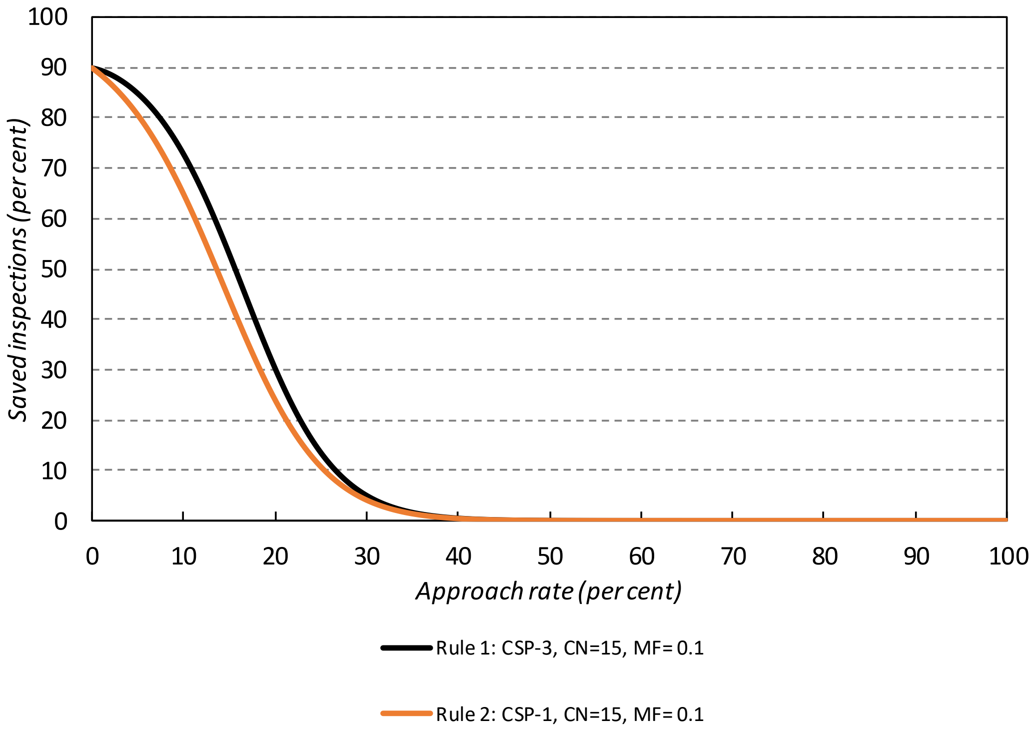

Figure 10. Comparison for the modelled percentage of saved inspections under the CSP-1 and CSP-3 algorithms with CN = 15 and MF = 0.1.

For any approach rate, the share of saved inspections for the CSP-1 algorithm (Rule 2) is less than the CSP-3 algorithm (Rule 1). The maximum difference between the share of saved inspections, at around 9.1 percentage points, is achieved when the approach rate is 13.8 per cent. Table 7 highlights that the “wedge” between the two rules’ outcomes is larger when the monitoring fraction is lower or the clearance number is higher. The difference is more striking when the clearance number is much larger, reflecting that the larger difference in the effective penalty mechanism of the two rules.

Table 7. Maximum percentage-point difference in modelled rate of saved inspections under CSP-1 and CSP-3 algorithms with different CN and MF values.

		Clearance number	
		5	**15**
Monitoring fraction	**0.1**	1.66 (28.3)	9.11 (13.8)
	0.5	1.63 (14.6)	7.07 (6.4)

Note: Numbers in parentheses refer to the approach rate (for inspection failures) in percentage terms at which the maximum difference is obtained.

Figure 11 shows the respective AOQ curves for the two rules, with the AOQL values for each rule represented by dashed lines at the maximum point. Consistent with the earlier statements, the CSP-1 algorithm (Rule 2) has a lower maximum modelled leakage rate (3.43 per cent, attained at an approach rate of 12.7 per cent) compared to the CSP-3 algorithm (4.03 per cent, attained at an approach rate of 13.7 per cent). Table 8 also highlights that the difference in maximum modelled leakage rates rises when the monitoring fraction is lower or the clearance number is higher.

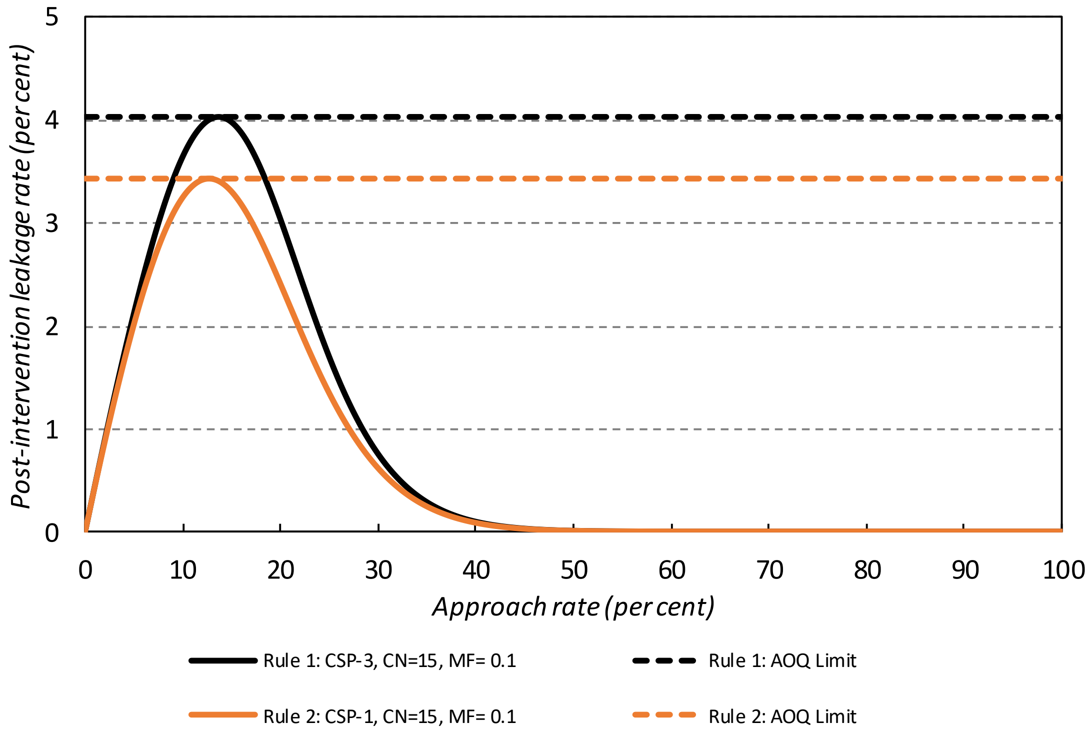

Figure 11. Comparison for the modelled post-intervention leakage rate for the CSP-1 and CSP-3 algorithms with CN = 15 and MF = 0.1.

Table 8. Maximum modelled leakage rates under CSP-1 and CSP-3 algorithms with different CN and MF values.

		Algorithm	**Clearance number**	
			5	**15**
Monitoring fraction	**0.1**	CSP-1	9.07	3.43
		CSP-3	9.33	4.03
	0.5	CSP-1	2.47	0.89
		CSP-3	2.62	1.17

4.4.4 The effect of inspection decision-errors on CBIS rule comparisons

In Chapter 4.3, we indicated the assumption of “perfect” inspections at the border provided a comparison no less favourable for CBIS rules with mandatory inspection regimes. Under imperfect inspections, leakage of biosecurity risk material can occur in pathways subject to CSP-type inspection rules because:

- contaminated consignments are not inspected in monitoring mode or, for the CSP-3 algorithm, failure detection mode; or
- the biosecurity regulator fails to pick up contamination in some consignments that are not inspected.

The second source of failure is the “new” source of leakage relative to the assumption of perfect inspections. Appendix C derives the long-run post-intervention rate of non-compliance for the CSP-1 algorithm under imperfect inspections.

Under a mandatory inspection regime, if the rate of inspection effectiveness is taken to be constant, then the rate of leakage will be proportional to the approach rate. This is shown by the dashed line in Figure 12 for a mandatory inspection regime where inspections are 90 per cent[28] effective in detecting biosecurity risk material when present in a consignment. The solid line in Figure 12 indicates the implied long-run leakage rate for a CSP-1 algorithm with *CN* = 10 and *MF* = 0.1, also assuming a 90 per cent rate of inspection effectiveness.

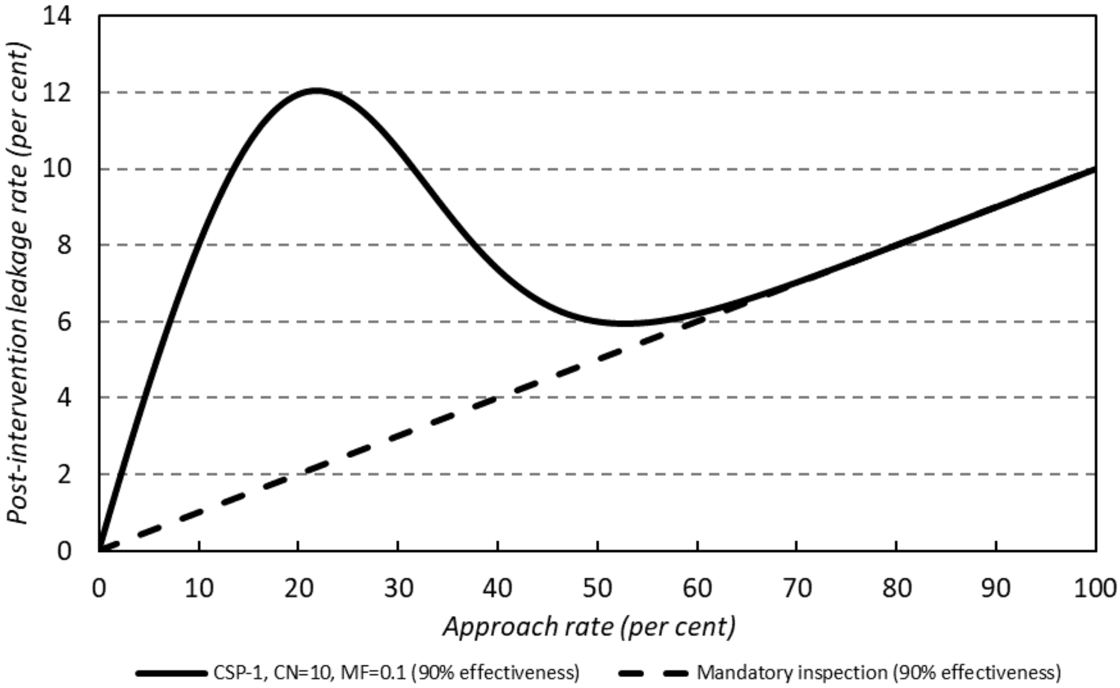

Figure 12. Comparison for the modelled post-intervention leakage rate for the CSP-1 algorithm with CN = 10 and MF = 0.1 and a mandatory inspection regime, assuming 90 per cent inspection effectiveness.

A feature of Figure 12 is that the CSP-1 algorithm's leakage rate has two critical points – one local maximum and one local minimum. The local maximum post-intervention rate of non-compliance of just under 12.1 per cent occurs at an approach rate of 21.9 per cent, while the local minimum leakage rate of 5.9 per cent occurs at an approach rate of 52.8 per cent.[29] Beyond the local minimum, the approach rate increases and asymptotes to the leakage profile for a mandatory inspection regime.

Figure 13 compares the performance of CSP rules relative to mandatory inspections under perfect (red line) and imperfect inspections (black line). For imperfect inspections, the black line in Figure 13 shows the difference between the solid and dashed lines in Figure 12. The maximum "wedge" between the CSP-1 algorithm with

[28] Robinson et al. (2012) also assumed a 90 per cent inspection effectiveness rate in devising recommended sampling plans for several plant-based pathways.

[29] As with estimates elsewhere in this chapter, these estimated maximum and minimum points are based on numerical solutions over a coarse grid of approach rates, with a 0.1 percentage point difference between grid steps.

CN = 10 and *MF* = 0.1 and mandatory inspections is 9.95 per cent in both cases,[30] although this maximum occurs at an approach rate of around 18.1 per cent under perfect inspections and around 20.2 per cent under inspections which are 90 per cent effective. Furthermore, the (black) "difference" curve associated with imperfect inspections looks like a "stretched" version of the (red) AOQ curve under perfect inspections.

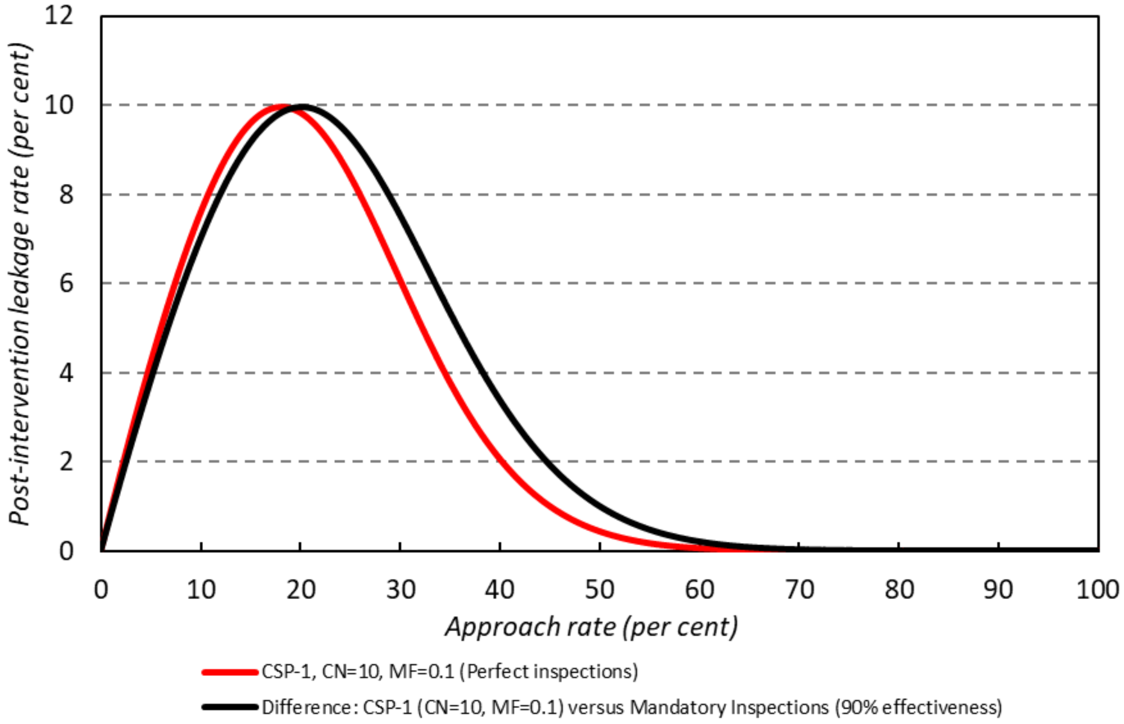

Figure 13. Difference between post-intervention leakage rates for a CSP-1 rule with CN = 10 and MF = 0.1 and mandatory inspections under perfect and imperfect (90 per cent effective) inspections.

In Appendix C, we show these observed patterns can be generalised and verified mathematically in that:

- the maximum difference between the long-run post-intervention rate of non-compliance for CSP rules and mandatory inspection regimes under imperfect inspections equals the AOQL under perfect inspections;
- this maximum difference under imperfect inspections occurs at an approach rate $1/(1-\delta)$ times the approach rate associated with the AOQL under perfect inspections, where the former assumes inspections are $100.(1-\delta)$ per cent effective; and
- more generally, the entire "difference" curve is dilated (i.e. "stretched") along the horizontal axis (i.e. pre-intervention approach rate) by a factor of $1/(1-\delta)$ times.

[30] For imperfect inspections, the corresponding rates of post-intervention non-compliance at this maximum difference are 11.97 per cent for the CSP-1 algorithm and 2.02 per cent for the mandatory inspection protocol. Note the maximum difference does not correspond to the maximum in the solid curve in Figure 12.

These results mean the department can make decisions around candidate CBIS rules assuming perfect inspections while making allowances, where appropriate, for inspection or intervention processes that may be imperfect.

4.5 Selecting appropriate rule parameters for CBIS candidate pathways

The Markov-chain approach outlined in this chapter does not provide a definitive answer on which CSP rule parameters should be adopted on a pathway. Instead, it provides a useful framework for considering and quantifying potential trade-offs associated with different parameter choices.

This section outlines one way to guide the department's policy and technical officers in assessing which rules and rule parameters could be suitable for managing a given pathway or assurance mechanism. Note that the Markov-chain approach, based on analysis at the *stakeholder* level, allows us to make recommendations for rule parameters at the *pathway* level.[31] This is because the use of the AOQL concept provides a high level of assurance that non-compliance at the pathway level should not exceed the AOQL over the long run, as outlined in Chapter 4.4.

A key element of this approach requires quantifying the department's maximum tolerance for post-intervention non-compliance that is consistent with Australia's ALOP. This focus on quantification departs from the usual practice in conducting Biosecurity Import Risk Analyses under the *Biosecurity Act 2015* and the Biosecurity Regulation 2016, in which the department adopts a formal methodology for assessing biosecurity risk and includes assessment tools, such as a risk estimation matrix (Australian Government Department of Agriculture and Water Resources, 2016). For recommending CBIS rule parameters, however, more fine-scale differentiation through quantifiable benchmarks is required to distinguish which parameter combinations offer "acceptable" risk profiles consistent with maintaining Australia's high biosecurity status and which do not.

In this report, we offer one approach, based on the "loss function" concept in Rossiter and Hester (2017), to calculate a candidate tolerance threshold for non-compliance. As part of this framework, it must be acknowledged that obtaining credible and defensible estimates of likelihood and cost components as inputs to this threshold estimate can be challenging and subject to considerable uncertainty.

To aid decisions around whether certain pathways are suitable for compliance-based interventions and, if so, what rule parameters may be appropriate, we recommend the department develop and implement processes to more formally account for uncertainties associated with key decision-making inputs, including the threshold tolerance for post-intervention non-compliance. This will enable the department to realise significant benefits from recommendations around eligibility and possible rule parameters being informed by credible interval estimates,[32] drawing on available

[31] As noted in Chapter 4.2, this approach will work best when pathway definitions are structured so that items with similar biosecurity risk profiles are grouped together. This may involve the department splitting and/or combining tariff codes to obtain workable pathway definitions.

[32] Care needs to be taken in applying this approach to ensure justification for stringent biosecurity risk management measures is not based on the lower limit of the threshold leakage interval, which is designed to represent a worst-case scenario. Such an approach could be problematic in the context of

pertinent information and objective assessments.[33] Formalising the use of meaningful interval estimates, as opposed to point estimates, to support expert judgement will also improve the rigour of regulatory and policy advice provided by the department.

Once a suitable point or interval estimate of this tolerance threshold is established, the AOQL values generated under different parameter combinations of *CN* and *MF* and other assumptions can be checked to see which rules are consistent with the department's tolerance. It then considers three aspects that might affect how the department can adopt this framework to pathways in practice, namely how to:

- account for potential strategic behaviour by biosecurity system stakeholders;
- allow for different rules to apply if stakeholders use certain pre-border processes that mitigate risk; and
- introduce compliance-based interventions on pathways in which inspection or other assurance requirements are not currently in force.

The approach presented in this chapter provides the department with a means for structured decision-making for setting biosecurity regulation parameters. While these outputs should help policy and technical officers make recommendations about regulatory parameters, it is not anticipated the outputs will form the sole basis for advice around biosecurity interventions. No model or framework – including the simulation methods currently employed by the department – can encompass all the complexities associated with designing intervention rules or the characteristics of a particular pathway.

Alongside the framework suggested in this chapter, regulatory decisions should be informed by a range of quantitative and qualitative considerations salient to specific pathways and interventions, such as knowledge of production processes, an understanding of the efficacy of pre-border measures and an awareness of regulatory risk appetite. As such, there will remain a role for overlaying expert judgement in making regulatory decisions about interventions for biosecurity assurance to ensure policy settings remain consistent with Australia's ALOP.

4.5.1 Establishing credible threshold tolerance estimates for post-intervention non-compliance

Arriving at a credible and defensible estimate of the threshold tolerance for non-compliance with inspection or assurance requirements for a given pathway is a critical part of assessing which rule parameter combinations are likely to be consistent with Australia's ALOP. In practice, this reframes the parameter selection issue as one focused on risk management, supported by scientific assessments, rather than being of

the World Trade Organisation's (WTO's) *Agreement on the Application of Sanitary and Phytosanitary Measures* (SPS Agreement) (World Trade Organisation, 1994) and the IPPC if a trading partner did not agree with the methodology and/or range estimates and chose to dispute measures based on range estimates. We suggest this risk could be mitigated through appropriate risk communication strategies, ensuring there is appropriate transparency in decision-making and the selection of scenarios, and obtaining additional information necessary to inform objective assessments of risk.

[33] Article 5(7) in the WTO SPS Agreement states that where relevant scientific evidence is insufficient, sanitary or phytosanitary measures may be adopted provisionally on the basis of available pertinent information, including from relevant international organisations and sanitary or phytosanitary measures applied by other member countries. Additional information necessary for a more objective assessment of risk should then be obtained within a reasonable period.

a statistical nature. Given its underpinnings in science, such an approach would reinforce the consistency of Australia's biosecurity risk management approach with the WTO's SPS Agreement.

The premise of the approach in this report is that the choice of rule parameters should be consistent with maintaining Australia's ALOP and guided by the department's assessment of the relative costs of non-compliance, or leakage, and the economy-wide benefits (in terms of compliance-cost savings for business and government) of a consignment not undergoing the intervention. Specifically, the threshold tolerance could be determined by the ratio of the economy-wide benefits to the expected consequences of leakage stemming from a given consignment.

In terms of quantifying compliance-cost savings, the department would need to consider:

- the direct costs charged by the department for the intervention;
- the opportunity cost of time for the importer to attend the inspection or other intervention activity, or the attendance fees paid by the importer to the customs broker or another agent if they attend the inspection on their behalf;
- the opportunity cost of time for the broker or importer booking the commodity in for inspection or an intervention;
- the cost of any product destroyed or rendered unsaleable following the intervention;
- additional storage costs associated with delays with booking in for and completing the intervention;
- additional transport costs associated with taking consignments to and from the location where the intervention takes place; and
- any administrative costs borne by the department from undertaking the intervention not recovered from stakeholders.

Not all cost components would be relevant for each type of intervention being considered by the department. The process of establishing expected compliance-cost savings for business and government from not undertaking an intervention was outlined in CEBRA Project 1304C (Rossiter et al., 2016), with estimates produced for saving inspection on two plant-product pathways as part of CEBRA Project 1608C (Rossiter et al., 2020). The department would be able to draw on these estimates and undertake targeted stakeholder consultation to determine appropriate benchmark values for the relevant components.

Estimates of the expected consequences of non-compliance could be informed by:

- scientific assessments of the likelihood of a pest or disease establishing and spreading, given the good's range of possible end-uses,[34] where it is used and whether a given pest or disease could be contained in or hosted by a particular good;[35]

[34] Such assessments need to consider the potential for diversion of material; for example, the risks from certain species of cut flowers that have not been devitalised need to account for the possibility for them to be propagated post-border.

[35] An assessment of the pests and diseases that may be present can be informed by information contained in the department's Incidents database, in addition to more general scientific advice.

- scientific and economic assessments of the technical feasibility and costs associated with containment, eradication and other post-border management options for potential pests and diseases; and
- economic assessments of the potential temporary and longer-term impacts, including on the environment and Australian agricultural industries.[36]

To establish the evidence base for these estimates, the department could leverage existing Import Risk Analyses and estimates of consequences from the department's risk matrices as a first step, with new scientific assessments required in some circumstances to address gaps. For establishment and spread costs, the department could draw on information on recent post-border remedial actions, or actions undertaken by other countries, as a benchmark.[37]

At a practical level, there is likely to be significant uncertainty associated with some likelihood and cost components that influence the expected consequences of leakage and considerable heterogeneity in compliance and administrative cost savings experience by biosecurity system stakeholders.[38] It may therefore be preferable to produce interval estimates by varying cost and likelihood components to assess how different leakage tolerance estimates may affect CBIS rule parameter recommendations.[39]

The box below provides a worked example of how the leakage tolerance could be calculated for a given pathway.[40] Note that this example and the calculation template in the CBIS Sensitivity Module assumes:

- there is only one pest or disease the department is interested in preventing from entering Australia; and
- there is no cumulative effect from the entry of multiple consignments containing risk material on the likelihood of establishment and spread.

The latter assumption will be most vulnerable on pathways with a higher throughput of consignments. If either assumption does not adequately reflect the risks posed for a

[36] The department has developed estimates of the economic impacts of significant pests and diseases entering and becoming established in Australia. For example, an outbreak of khapra beetle (*Trogoderma granarium*) could cost Australia $15.5 billion over 20 years through revenue losses arising from reduction in production and exports (https://www.agriculture.gov.au/import/industry-advice/2020/127-2020).

[37] In practice, post-border remedial actions can vary greatly depending on the pest/s and crops/impacts in question. In such circumstances, information from other countries related to the pest of interest may be more useful to gauge potential costs. Costs will also depend on whether the remedial actions are targeting a pest for which control measures exist. For example, the US eradicates fruit fly incursions when they occur because they have ample technology and "know how" to do so; however, they have not eradicated emerald ash borer because there is no technology in place for eradication.

[38] See Chapter 7 and Appendix I.2 of Rossiter et al. (2020) for a discussion of the large differences in costs incurred by importers in undertaking border inspections.

[39] This feature has been incorporated into the CBIS Sensitivity Module to allow users to investigate different candidate tolerance thresholds for leakage. Sensitivity investigations on other input dimensions is also possible within the "Recommended CBIS Inputs" worksheet.

[40] The worked example and CBIS Sensitivity Module approach mirrors the broad structure to completing steps 2 and 3 of a pest risk assessment according to guidance from the IPPC; see, for example, International Plant Protection Convention (2009).

given pathway, then a more detailed assessment should be used to arrive at a more appropriate estimate of the expected consequences of non-compliance.

Worked example: Candidate threshold tolerance calculation

For a given pathway where the CBIS is to apply to inspections, it is estimated that saving inspection is expected to save $760 on average for importers, comprising:

- $200 in inspection fees, given a typical inspection takes between 45 minutes and 1 hour;
- $100 in inspection attendance costs, given the customs broker typically attends the full inspection;
- $20 in inspection booking opportunity costs, given it can take up to 15 minutes of a broker's time to book in the inspection;
- no costs from destroyed or unsaleable product, given the inspection process does not damage the goods;
- $240 in saved storage costs, based on an average saving of two days' storage at $120 per day; and
- $200 in transport cost savings, based on reduced transhipment requirements.

There are assumed to be no further administrative savings accruing to the department from saving inspection.

From the perspective of the expected cost of leakage:

- if a pest known to be found on the pathway makes its way past the Australian border, then there is a 0.5 per cent chance the pest will establish in a small local area. Eradication of the pest from the local area is expected to cost around $5 million; and
- if the pest establishes, there is a 1 per cent likelihood that it will spread beyond the initial establishment site, costing an additional $200 million in damages and eradication costs.

On this basis, the candidate threshold for post-intervention non-compliance would be estimated as:

Leakage tolerance threshold = $\frac{200+100+20+0+240+200+0}{0.005*(5{,}000{,}000+0.01*200{,}000{,}000)} \times 100\% \approx 2.2\%.$

4.5.2 Using the threshold tolerance for parameter recommendations

Each combination of *CN* and *MF* for a CSP algorithm produces an average outgoing quality (AOQ) curve that describes how the rate of post-intervention non-compliance varies with the approach rate. A key measure that describes the potential risk to the department's biosecurity objective is the average outgoing quality limit (AOQL), which is the maximum of the AOQ curve and represents the worst-case scenario for modelled importer-level non-compliance.

One way of establishing which rules could be suitable for adoption on a pathway is to assess which parameter combinations yield an AOQL that is no higher than the candidate threshold tolerance for post-intervention non-compliance. Once the appropriate cost and likelihood estimates are available, such a procedure is easily implementable, given it does not rely on detailed historical pathway data, and provides a high degree of assurance to the department that, at an importer or pathway level, the overall rate of post-intervention non-compliance would be anticipated to be no higher than that threshold. As has already been highlighted, obtaining likelihood and cost estimates related to establishment and spread will be non-trivial for a range of pests and diseases; however, by adopting an approach that seeks to account for these uncertainties through scenario analysis on key parameters, threshold tolerances for post-intervention non-compliance can still be developed to inform the department's regulatory settings.

The rules of thumb associated with CSP parameter selection highlighted that, all other things being equal, increasing the clearance number or raising the monitoring fraction will reduce the AOQL. Two characteristics relevant for parameter selection emerge from the analysis earlier in the chapter.

1. There is a trade-off between the value of *CN* and *MF* that will meet the threshold leakage tolerance, in that a higher *CN* will be required if the *MF* is lowered.
2. Because increasing the clearance number will lower the AOQL, for any given value of *MF*, it will be of most interest to find the minimum *CN* for a given monitoring fraction for which the threshold tolerance is satisfied.

The CBIS Sensitivity Module uses these two characteristics to recommend the minimum clearance number that can be combined with a given monitoring fraction so that the maximum leakage tolerance is not exceeded. For a range of potential *MF* values that have a natural (fraction) interpretation for communication with stakeholders, the module:

- assesses whether a clearance number of no more than 20[41] would meet the tolerance requirements; and
- reports the minimum *CN* and associated maximum modelled post-intervention non-compliance rate.

Exploration with the CBIS Sensitivity Module suggests that if the tolerance for leakage on a pathway is 1 per cent or below, there will be few if any circumstances under which a CSP algorithm on its own can meet the required maximum leakage tolerance. In these circumstances, changes to the import conditions, such as specific offshore treatments that lower the maximum feasible approach rate, may be needed before even a subset of the pathway may be suitable for management through the CBIS.

Table 9 shows the monitoring fraction and clearance number combinations for the CSP-3 algorithm that meet the maximum tolerance threshold calculated in the

[41] This maximum was suggested since rules with higher clearance numbers were deemed unlikely to be implemented, possibly except for pathways with a very large throughput. In effect, this rules out adopting an arbitrarily large *CN* so that any monitoring fraction could feasibly have an associated clearance number value that could meet requirements. It also ensures the Excel spreadsheet module is of a workable size, given the data inputs required. The approach to placing an upper bound on the clearance number reflects notions raised by departmental officers in earlier projects, including CEBRA Project 1608C, that all importer stakeholders, including those with relatively low volumes, have an opportunity to "feel" the effect of rewards afforded by CBIS rules. That said, one can implement the MATLAB function included in Appendix C to arrive at equivalent metrics for CSP algorithms where *CN* exceeds 20, which may be appropriate for high-throughput pathways.

previous subsection's worked example.[42] For this illustration, an inspection failure is taken to constitute a "failure" under the class of CBIS rules considered, with half of all inspection failures assumed to be quarantine failures. Any of these parameter combinations, or combinations where the *CN* is above the designated minimum, will not exceed the tolerance determine for the inspection or assurance measure on the pathway.

Table 9. Monitoring fraction and minimum clearance number combinations for the CSP-3 algorithm that yield a modelled maximum importer leakage rate of no more than 2.2 per cent

Monitoring fraction	Minimum clearance number	Modelled maximum importer leakage (%)
0.2	20	2.17
0.25	17	2.14
1/3	13	2.10
0.4	10	2.15
0.5	7	2.10

4.5.3 Other factors to assess in recommending specific parameter combinations

Once the suite of rules for which the tolerance around leakage has been satisfied, recommendations around which *CN* and *MF* combinations are likely to be *most* suitable for a given set of circumstances rests with consideration of the incentives for compliance.

Figure 14 illustrates the pattern for three of the eligible rules shown in Table 9, namely those corresponding to *MF* values of 0.2 (Rule 1, black), 1/3 (Rule 2, orange) and 0.5 (Rule 3, red). These illustrate the general features of how these eligible rules vary with changes in the monitoring fraction and clearance number in that the rules with the highest clearance number (and lowest monitoring fraction) offer highly compliant importers with the greatest share of saved inspections.

The rewards for compliance also tend to decay more quickly for modest to high degrees of non-compliance with requirements, allowing greater separation of the benefits for importers with low approach rates compared to those with higher approach rates. Ideally, such separation of rewards can help encourage system stakeholders to change their behaviour, such as through switching to more compliant suppliers to modifying processes to better manage the biosecurity status of their goods. As such, a default position could be to offer something akin to Rule 1, being the eligible rule with the lowest monitoring fraction to provide the greatest expected rewards to importers with a strong compliance record.

[42] Monitoring fraction options where the *CN* required would exceed 20 have been suppressed.

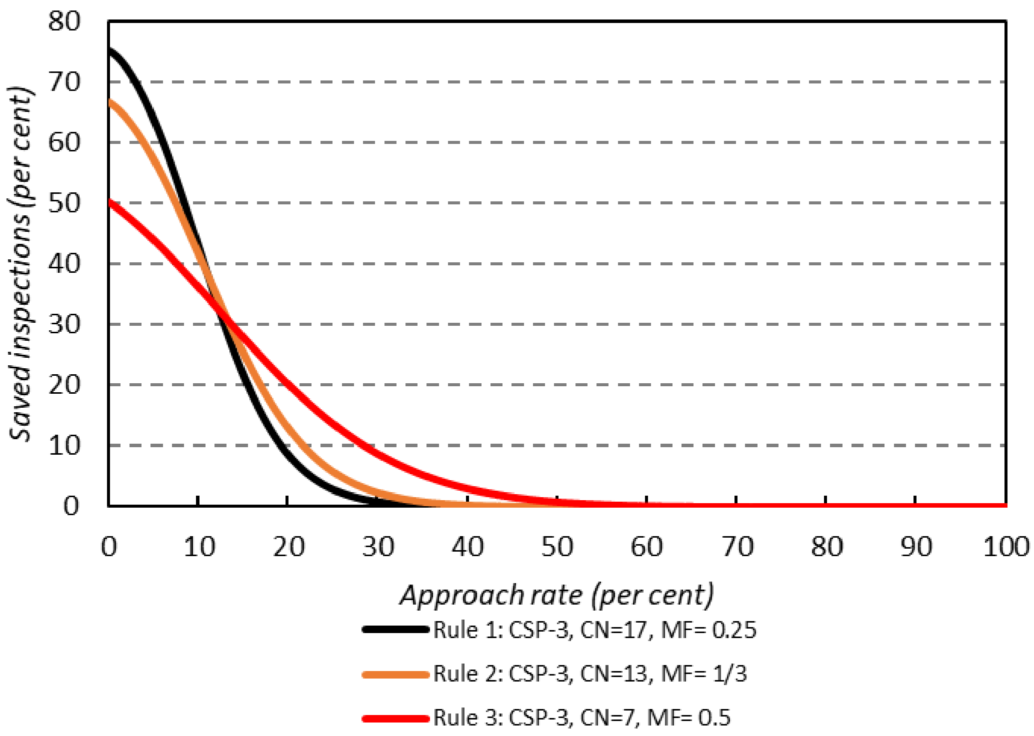

Figure 14. Comparison of the saved inspection fraction for three candidate CSP-3 parameter combinations with maximum post-intervention leakage rates less than 2.2 per cent.

However, there are countervailing factors that would result in the department preferring a rule with a higher monitoring fraction. Primarily these focus on:

- the potential for strategic behaviour (gaming) of the rules, where parties in the supply chain actively raise the approach rate for non-compliances in monitoring mode relative to census mode; and
- the throughput on the pathway, which affects how quickly importers will "feel" the rewards of holding a good compliance record.

On the first issue, the game-theoretic model by Rossiter and Hester (2017) showed that there were stronger incentives for importers to "cheat" and reduce the effort they deployed to ensure consignments were free from biosecurity risk material when subject to a lower monitoring fraction – typically below $MF = 0.25$. The potential to game the rules in large part depends on how easy it is for the importer or their agents in the supply chain to avoid (costly) risk-reducing processes. In many cases, strategic behaviour on the part of agents in the import supply chain may not be feasible; in others, processes integral to reducing the inherent biosecurity risks in products are readily verifiable on a consignment-by-consignment basis, thereby mitigating cheating potential. As such, the extent to which gaming is a credible risk can be assessed based on knowledge of the production processes for the goods. Where there is evidence of strong incentives and an ability to game the rules, the department could then recommend eligible rules with a higher monitoring fraction to limit the scope for strategic behaviour.

The department may also wish to recommend an eligible rule with a lower clearance number and higher monitoring fraction on pathways where the volume of imports is lower. On these pathways, it may take a considerable amount of time for importers to build up the required number of consecutive passes to qualify for monitoring mode, thereby blunting the incentives for compliance from the importer's perspective. More immediate rewards would be available if a rule with a lower clearance number was instead used by the department.

4.5.4 Differentiated rules based on supplementary pre-border assurance measures and information

The discussion to date has focused on applying CBIS across a whole pathway, accounting for the full range of approach rates possible for a pathway. However, appropriate CBIS rules for consignments that have completed independently verifiable[43] pre-border assurance measures known to reduce the likelihood of biosecurity risk material being present in consignments may not need to take account of all potential approach rates.[44] Completing a given treatment or undergoing a specific production process, for example, could be effective in limiting the approach rate of consignments to not exceed a pre-specified rate. This implies the eligibility criterion could be based on the maximum post-intervention non-compliance rate taken over the relevant (feasible) part of the AOQ curve, rather than the entire curve.

As part of a pragmatic approach to regulatory risk management, estimates of a candidate maximum approach rate should be based on available scientific evidence that can be independently verified. This will ensure credibility of the arrangements and help preserve Australia's high biosecurity status. The effectiveness of pre-border assurance measures or other control measures associated with a proposed maximum approach rate may need to be reliably evaluated before adoption by the department. Where there is sufficient data captured in AIMS to support a rigorous statistical analysis, it may be possible to use hypothesis tests to assess the effectiveness of some pre-border measures.[45]

This approach reflects the principle of a "menu of regulatory contracts", canvassed in CEBRA Project 1304C (Rossiter et al., 2016) and summarised in Chapter 4.2 of this report, and enables the department to better target its interventions on pathways. With the AQIS Commodity Code (ACC) now linked to the department's Q-ruler, automation of these rules for separate "streams" within a pathway is now possible. In some cases, it may allow consignments undergoing certain additional pre-border assurance measures to be eligible to more generous inspection rules. Where the department has only a very low tolerance for leakage, consignments undergoing specific and verifiable pre-border treatments may be eligible for CBIS-type rules, while others face mandatory inspection.[46]

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[43] Independent verifiability, through mechanisms such as audits or NPPO certification, is essential to provide appropriate incentives for compliance and credibility of the scheme.

[44] Appendix D provides examples of pre-border measures. For many of these activities, it may be difficult to obtain accurate estimates of their impact on the pest load and, ultimately, the approach rate, particularly where the efficacy of a treatment varies depending on the pre-mitigation pest load. This measurement challenge exists even if the activities are conducted according to requirements in highly managed systems. Other measures, like safeguarding, do not reduce the pests present but prevent new pests from attacking the commodity.

[45] This approach has been adopted by the department for cut flowers as part of a broader program to target improved compliance on that pathway.

[46] Because this approach is based on scientific assessments of the pre-border assurance measures and retains the same threshold tolerance consistent with Australia's ALOP determined at the pathway level,

In the CBIS Sensitivity Module, users have the option to provide an estimate of the maximum approach rate under additional intervention or assurance measures and test the sensitivity of potential rules to alternative assumptions about this maximum approach rate. The Module provides alternative minimum clearance number estimates for consignments subject to the risk-reducing intervention. Most commonly, the additional measure will enable a lower minimum clearance number to be used for meeting the threshold tolerance for the rate of post-intervention non-compliance; in some circumstances, the additional measure may even enable rule combinations with lower monitoring fractions to be applied.

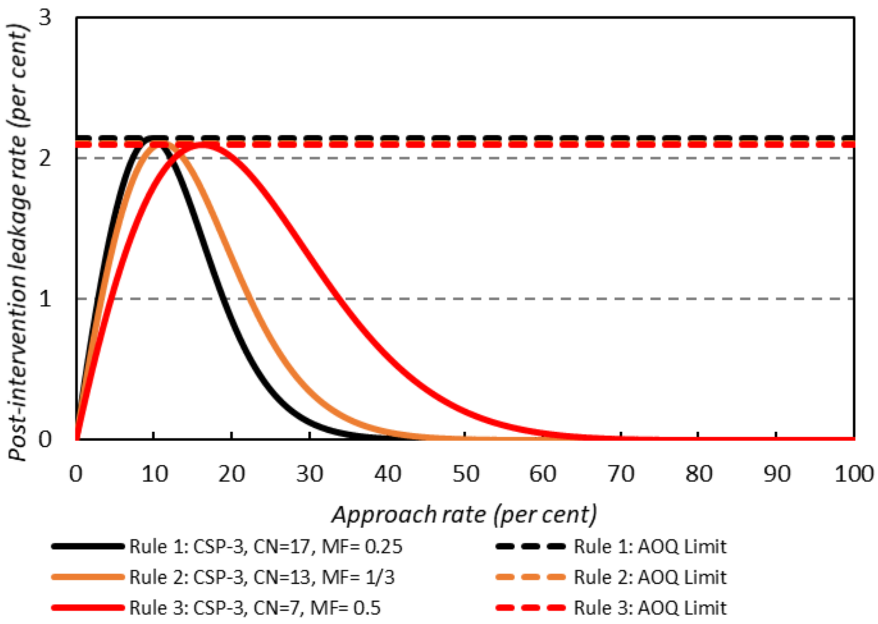
Table 10 and Figure 15 compare the minimum clearance numbers for the pathway as a whole (second column of Table 10 and Figure 15, panel a) with the situation where an additional pre-border assurance measure is effective at preventing the inspection failure rate going higher than 8 per cent (third column of Table 10 and Figure 15, panel b) under the assumption that the intervention is always effective.

Table 10. Monitoring fraction and minimum clearance number combinations for the CSP-3 algorithm with and without additional assurance measures that guarantee an approach rate of no higher than 8 per cent.

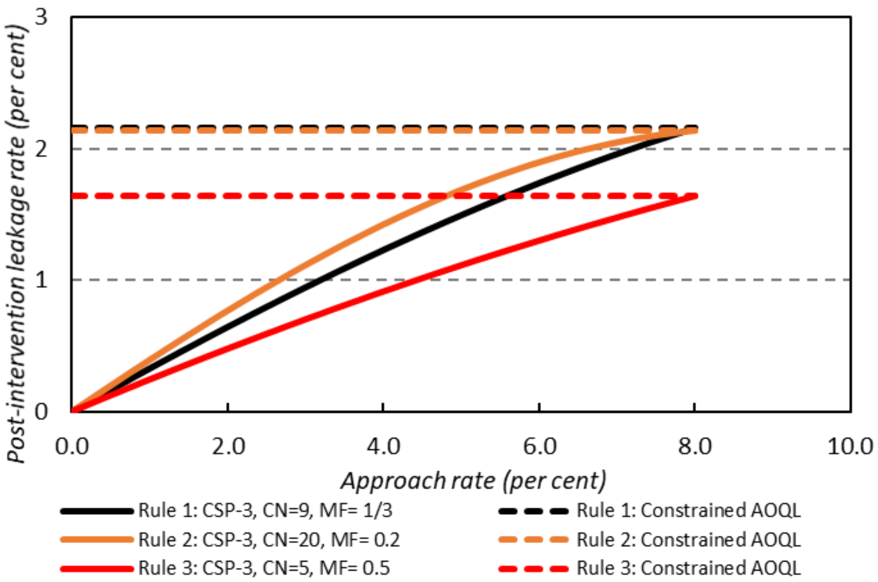
Monitoring fraction	Minimum clearance number		
	Applicable to whole pathway	Applicable to importers with the additional process or intervention (Perfect interventions)	Applicable to importers with the additional process or intervention (90 per cent intervention effectiveness)
0.2	20	20	18
0.25	17	16	13
1/3	13	9	5
0.4	10	5	5
0.5	7	5	5

In most cases, the minimum clearance number required to meet the 2.2 per cent post-intervention non-compliance threshold is lower for consignments completing the additional pre-border assurance measure. When the monitoring fraction of one-fifth (0.2) is selected, the minimum clearance numbers are the same in both cases. In general, this occurs when the peak in the AOQ curve for a given parameter combination occurs at a lower approach rate than the guaranteed maximum established by the additional pre-border measure (refer to Figure 15, panel b); however, in this specific instance, it happens despite the peak in the AOQ curve occurring above 8 per cent because the constrained AOQL for the CSP-3 algorithm with $CN = 19$ and $MF = 0.2$ comes in at 2.21 per cent.

it does not result in the type of “arbitrary or unjustifiable distinctions” alluded to in Article 5(5) of the WTO’s SPS Agreement.



(a)



(b)

Figure 15. Comparison of candidate CSP-3 parameter combinations with maximum post-intervention leakage rates less than 2.2 per cent across the whole pathway (panel a) or a subset with an additional pre-border assurance measure effective at preventing the inspection failure rate going higher than 8 per cent (panel b).

Given the earlier discussion of imperfect interventions, the fourth column of Table 10 shows the impact of accounting for an intervention that is only 90 per cent effective in detecting (or remedying) biosecurity risk material. This lower effectiveness in interventions means the 8 per cent threshold approach rate is equivalent to specifying a 7.2 per cent threshold under a "perfect" intervention assumption. The fourth column highlights that the minimum values of *CN* are lower when accounting for imperfect inspection processes. While this approach to adjusting for imperfect inspections could be used in situations where evidence of the reliability of interventions is available, the more conservative and recommended approach is to use the perfect inspection thresholds in assessing candidate CBIS rules for a given pathway and intervention.

4.5.5 Implementing CBIS for new interventions

The initial roll-out of the CBIS was on pathways where more targeted inspection regimes were replacing mandatory inspection requirements, meaning they offered compliance-cost savings to biosecurity system stakeholders adhering to the department's import conditions. Given biosecurity risk identification reflects evolving scientific knowledge, there are likely to be circumstances in which new risks are identified or instances where some pre-border measures are not being effectively implemented. This may require new interventions at the border to be introduced for risk management or verification purposes, imposing additional regulatory burden on stakeholders.

In some circumstances where a risk has been identified, there may be limited evidence available to the department to establish whether non-compliances are being identified at the border. As part of establishing new interventions at the border in situations where the tolerance for non-compliance is above a certain threshold (say, 1 per cent), one option would be to introduce the additional intervention as part of a two-step process.[47]

1. The department could communicate the newly identified risk to stakeholders and explain that it wishes to build an evidence base to establish whether this risk is present in consignments landing in Australia. As part of this, randomised testing or inspection (which may be stratified by country, if appropriate) could be carried out at the border over a given time period, based on a fixed probability of referral that is disclosed to stakeholders. Data collected through this process can be analysed to determine whether the arrival rate of the identified risk likely exceeds the department's tolerance for non-compliance.
2. If the tolerance is exceeded, either across the pathway as a whole or by certain countries of origin, then the department can introduce an appropriate CBIS rule – ideally with the monitoring fraction the same as the referral rate used for randomised testing or inspection in the first stage – to provide assurance that post-intervention non-compliance is managed consistent with the department's tolerance. If the current approach rate of the risk is below the pre-determined tolerance level, then the randomised testing or inspection could be discontinued.

As part of establishing suitable parameters for the two-step process, the department can use the CBIS Sensitivity Module to choose values for *CN* and *MF* for the second stage that are consistent with managing the risks below an agreed post-intervention non-compliance threshold. The value for *MF* determined in this stage can then be adopted as the referral rate for intelligence-gathering purposes in the first stage.

4.6 Options for managing hitchhiker pests on the timber pathway

As noted in Chapter 3, the data analysis of the timber pathway has shown some evidence of hitchhiker pests on a small segment of the timber pathway. However, information on the broader pathway is not available, suggesting there is a need for

[47] The two-step approach suggested here shares several similarities to the staging of measures adopted by the department in 2019 to manage the high rate of non-compliance on the cut-flower pathway.

randomised inspections to be introduced as part of an intelligence-gathering phase. Based on the discussion in earlier parts of this chapter, one approach to manage these risks would involve:

1. establishing a benchmark threshold tolerance for hitchhiker pests across the timber pathway. This assessment would draw upon knowledge of the likely consequences of post-border leakage of hitchhiker pests;
2. using the CBIS Sensitivity Module alongside other information to develop recommended *CN* and *MF* values as part of an appropriate CBIS rule to manage risks on the timber pathway to an appropriate level;
3. adopting the *MF* value selected for the CBIS rule as part of the information-gathering stage to assess whether current import conditions and onshore interventions are managing the leakage of hitchhiker pests to an acceptable level.

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Appendix A: Timber inspection data analysis

A.1. Data analysis overview

A brief exploratory analysis of timber lines under the Harmonised System four-digit tariff code 4407 is presented in this Appendix. The timber dataset does not support formal modelling methods because the lines that are inspected cannot be considered representative of the lines that are not because the latter undergo some kind of treatment.

Nonetheless, we construct simple models that suggest that an increase in overall interception rate from about 1 per cent in 2008–2011 to 4 per cent in 2015–2018. This likely reflects a concomitant change in supply from Country 1 (0.083 per cent interception rate) to Country 4 (3.8 per cent interception rate). Also, there is a statistically significant difference between the interception rates: the inspected lines from northern-hemisphere countries are approximately five times more likely to be contaminated than are those from southern-hemisphere countries, and neither is negligible. In contrast, the interception rates for inspected lines from equatorial countries is very low.

Furthermore, despite searching for statistical evidence for a seasonal effect in the interception rate, even allowing for different seasonal patterns between global hemispheres, none could be detected with these data. Finally, based on the analyses documented herein, it seems possible that compliance-based inspections could be used as a border measure to manage the biosecurity risk of timber lines, if it is applied at the supplier or importer level.

To develop a dataset that supports the kind of analysis envisioned here, it will be necessary for the department to inspect lines that are treated. We recommend the department consider taking a snapshot survey or use the Cargo Compliance Verification approach to collect a more suitable dataset if risk-based intervention on the timber pathway is of interest.

A.2. Summary statistics

This section provides summary statistics of the timber data. CEBRA was provided border records for 120 459 timber lines that arrived during the data collection period (namely, 2008 to 2018 inclusive). The lines are sourced from 79 countries and the pathway activity includes 2 289 suppliers and 1 048 importers.

A.2.1. Inspections

A small fraction of lines (5.5 per cent) have been inspected. The annual rate (percentage) of lines inspected is presented in Figure 16. This figure shows a steady increase in the inspection rate from 2008–2011, followed by a drop in 2012–2013 and a plateau thereafter. Inspection is undertaken when evidence of treatment is not available, so we infer that the changes in time simply reflect changing numbers of arriving untreated lines.

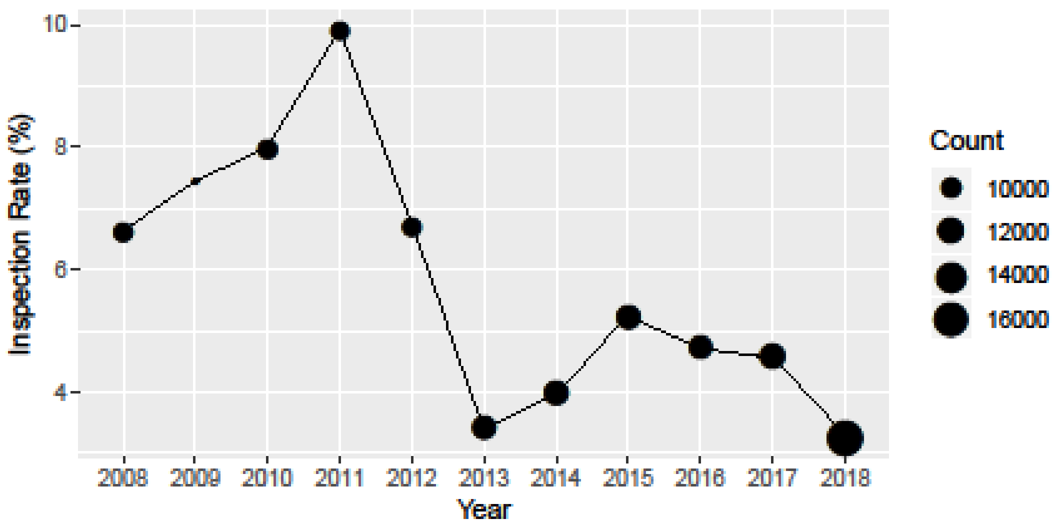

Figure 16. Inspection rate for arriving lines by year.

Note: Count refers to the number of arriving lines.

The four-digit tariff code 4407 includes a large range of products. Table 11 shows the types of products, down to the ten-digit level, under this four-digit tariff code. For the remainder of this analysis, we focus on the eight-digit tariff codes, as these codes are the ones reported systematically in the department's AIMS and Incidents databases.

Figure 17 shows the inspection rate by tariff code. The plot shows considerable variation, with only a handful of tariff codes inspected at more than 50 per cent, namely:

- 44071991, comprising wood from conifers other than pine (*Pinus spp.*), fir (*Abies spp.*) and spruce (*Picea spp.*) , including timber that is redwood (*Sequoia sempervirens*), western red cedar (*Thuja plicata*), cut to size for making staves or has a cross-sectional area of 450 cm^2 or greater;
- 4407129, which incorporates timber from fir (*Abies spp.*) and spruce (*Picea spp.*) that are not planed or sanded;
- 44072810, which includes planed or sanded (*Milicia excelsa* and *Milicia regia*);
- 44072710, comprising planed or sanded sapelli (*Entandrophragma cylindricum*); and
- 4407, the generic four-digit tariff code which does not provide more detailed information about the consignment of timber.

However, these tariff codes have comparatively few lines. The tariff codes with the largest number of consignments, namely 44071010, 44071099 and 44071110, all have inspection rates around or below 5 per cent. These tariff codes include treated and untreated wood from conifers, including radiata pine (*Pinus radiata*), Douglas fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*), with tariff code 44071110 incorporating weatherboards.

Table 11. Harmonised System (HS) Tariff Code List, Down to Ten-Digit Level, Comprising the Four-Digit Code 4407 (Wood Sawn or Chipped Lengthwise, Sliced or Peeled, Whether or not Planed, Sanded or End-Jointed, of a Thickness Exceeding 6 mm).

Tariff code					
Five-digit	Six-digit	Seven-digit	Eight-digit	Ten-digit (Last two digits)	Description
4407.0			**4407.00.00**		**Wood Sawn or Chipped Lengthwise, Sliced or Peeled, Whether or not Planed, Sanded or End-Jointed, of a Thickness Exceeding 6 mm**
4407.1					**- Coniferous**
	4407.10		4407.10.10	24	Other - Radiata pine - Treated – Other
				33	Other – Other
			4407.10.91	01	Cut to size for making staves
				02	Other – Redwood
				03	Other - Western red cedar - Having a cross-sectional area of less than 120 cm^2
				04	Other - Western red cedar - Having a cross-sectional area of 120 cm^2 of greater
				19	Other - Other species having a cross-sectional area of 450 cm^2 or greater
			4407.10.99	11	Having a cross-sectional area of less than 120 cm^2 - Radiata pine - Treated Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Radiata pine – Untreated
				14	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Douglas fir
				15	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Radiata pine – Treated
				16	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Radiata pine – Untreated
				20	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Other

Tariff code					
Five-digit	**Six-digit**	**Seven-digit**	**Eight-digit**	**Ten-digit (Last two digits)**	**Description**
4407.1	4407.11				-- Of pine (Pinus spp.)
			4407.11.10		--- Planed or sanded
				23	Weatherboards
				30	Other - Radiata pine - Treated, with waterborne preservatives
				31	Other - Radiata pine - Other treated
				32	Other - Radiata pine – Untreated
				40	Other
		4407.11.9			--- Other
			4407.11.91	41	---- Wood that (a) is cut to size for making staves; or (b) has a cross-sectional area of 450cm2 or greater
			4407.11.99		---- Other
				01	Having a cross-sectional area of less than 120 cm^2 - Radiata pine - Treated - With waterborne preservatives
				02	Having a cross-sectional area of less than 120 cm^2 - Radiata pine - Treated - Other
				03	Having a cross-sectional area of less than 120 cm^2 - Radiata pine - Treated - Untreated
				04	Having a cross-sectional area of less than 120 cm^2 - Radiata pine - Treated - Other
				10	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Radiata pine - Treated
				11	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Radiata pine - Untreated
				12	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2 - Radiata pine - Other

Tariff code					
Five-digit	Six-digit	Seven-digit	Eight-digit	Ten-digit (Last two digits)	Description
4407.1	4407.12				-- Of fir (Abies spp.) and spruce (Picea spp.)
			4407.12.10	13	--- Planed or sanded
		4407.12.9			--- Other
			4407.12.91	14	---- Wood that (a) is cut to size for making staves; or (b) has a cross-sectional area of 450cm^2 or greater
			4407.12.99		---- Other
				15	Having a cross-sectional area of less than 120 cm^2
				16	Having a cross-sectional area of 120 cm^2 or greater but less than 450 cm^2
	4407.19				-- Other
			4407.19.10	17	--- Planed or sanded
		4407.19.9			--- Other
			4407.19.91	90	---- Wood that (a) is redwood (*Sequoia sempervirens*); or (b) is western red cedar (*Thuja plicata*); or (c) is cut to size for making staves; or (d) has a cross-sectional area of 450 cm^2 or greater
			4407.19.99	91	---- Other
4407.2$^\sharp$					**- Of tropical wood**
	4407.21		4407.21.00	10	--Mahogany (Swietenia spp.)
	4407.22		4407.22.00	20	--Virola, Imbuia and Balsa
	4407.25				--Dark Red Meranti, Light Red Meranti and Meranti Bakau
			4407.25.10	04	---Planed or sanded
			4407.25.90	05	---Other

Tariff code					
Five-digit	**Six-digit**	**Seven-digit**	**Eight-digit**	**Ten-digit (Last two digits)**	**Description**
4407.2♯	4407.26		4407.26.00	01	--White Lauan, White Meranti, White Seraya, Yellow Meranti and Alan
	4407.27				--Sapelli
			4407.27.10	40	---Planed or sanded
			4407.27.90	45	---Other
	4407.28				--Iroko
			4407.28.10	50	---Planed or sanded
			4407.28.90	55	---Other
	4407.29				-- Other
			4407.29.10		--- Planed or sanded
				14	Merbau
				16	Other
		4407.29.9			--- Other
			4407.29.91	24	---- Mandio-queira, Pau amarelo, Quaruba and Tauari
			4407.29.92†	25	---- Tropical wood specified in note marked with †, other than goods of 4407.21.00, 4407.22.00, 4407.25, 4407.26.00, 4407.27, 4407.28 or 4407.29.91
			4407.29.93	26	---- Other
			4407.29.99	38	Other
4407.9					**-Other**
	4407.91				--Of oak (Quercus spp.)
			4407.91.10	08	---Planed or sanded
			4407.91.90	09	---Other
	4407.92		4407.92.00	01	--Of beech (Fagus spp.)

Tariff code					
Five-digit	**Six-digit**	**Seven-digit**	**Eight-digit**	**Ten-digit (Last two digits)**	**Description**
4407.9	4407.93				--Of maple (Acer spp.)
			4407.93.10	11	---Planed or sanded
			4407.93.90	15	---Other
	4407.94				--Of cherry (Prunus spp.)
			4407.94.10	12	---Planed or sanded
			4407.94.90	16	---Other
	4407.95				--Of ash (Fraxinus spp.)
			4407.95.10	20	---Planed or sanded
			4407.95.90	25	---Other
	4407.96		4407.96.00*	30	-- Of birch (Betula spp.)
	4407.97		4407.97.00	31	-- Of poplar and aspen (Populus spp.)
	4407.99				-- Other
			4407.99.10	32	--- Planed or sanded
		4407.99.9			---Other
			4407.99.91	13	----Ebony (Diospyros spp.)
			4407.99.99	33	---- Other

Source: Commonwealth Government Department of Agriculture, Water and Environment Australian Biosecurity Import Conditions (BICON) database. Available from: https://bicon.agriculture.gov.au/BiconWeb4.0. Notes ♯ and † taken from the Australian Border Force website (https://www.abf.gov.au/importing-exporting-and-manufacturing/tariff-classification/current-tariff/schedule-3/section-ix/chapter-44) that is the online version of Schedule 3 of the Department of Home Affairs' Combined Australian Customs Tariff Nomenclature and Statistical Classification.

Notes:

♯ For the purposes of tariff code 4407.2, "tropical wood" means one of the following types of wood:Abarco, Abura, Acacia, Acajou d'Afrique, Adjouaba, Afina, Afrormosia, Aielé, Aiéouéko, Akak, Ako, Akossika, Alan, Alep, Almácigo, Almendrillo, Alumbi, Amapa, Amapola, Amberoi, Amourette, Andira, Andiroba, Andoung, Angelim, Angelim rajado, Angelim vermelho, Angueuk, Aniégré (Aningré), Apobeaou, Araribà, Arisauro, Aromata, Assacù, Assas, Avodiré, Awoura, Ayous (Obéché), Azobé, Balata pomme, Balau red, Balau yellow, Balsa, Balsamo, Banga-wanga, Baromalli, Basralocus, Batai, Batibatra, Benuang, Bété (Mansonia), Bilinga, Billian, Bintangor, Bitis, Bodioa, Bois rose femelle, Bomanga, Bossé clair, Bossé foncé, Botong, Breu-sucuruba, Bubinga, Burada, Burmese Ebony, Burmese Rosewood, Busehi, Cabreùva, Cachimbo, Cambara (Jaboty), Canalete, Canelo, Canelón, Capomo, Caracoli,Castanheiro Para, Castanopsis, Catiguà, Cativo, Cedro, Cedroi, Celtis d'Afrique (Diania, Ohia), Cerejeira, Champak, Checham, Chengal, Chicha/Xixa, Cocobolo, Comino Crespo, Congotali, Copaiba, Cordia d'Afrique, Coula, Crabwood d'Afrique, Cristobal granadillo, Cumaru, Cupiuba, Curupay, Dabéma, Dibétou, Difou, Divida, Djohar, Douka (Makoré), Doussié, Drago, Duabanga, Dukali, Durian, Ebène d'Afrique (Ebène Madagascar), Ebène noire d'Asie, Ebène veinée d'Asie, Ebiara, Ekaba, Ekoune, Emien, Essessang, Essia, Essoula, Etimoé, Eveuss, Evino, Eyek, Eyong, Eyoum, Faro, Faveira, Faveira Amargosa, Fijian Sterculia, Framiré, Formigueiro, Freijo, Fuma (Fromager), Gaiac, Galacwood, Gale Silverballi, Gavilan, Gavilán Blanco, Geronggang, Gerutu, Gheombi, Goiabao, Gombé, Greenheart, Grenadille d'Afrique, Grigri, Guágara, Guariuba, Haiari, Haldu, Hard Alstonia (Pulaï), Hevea, Higuerilla, Huruasa, Iatandza, Ibirà Pytâ, Idewa, Igaganga, Ilomba, Imbuia, Inga, Ingyin, Inyak, Ipé, Iroko, Itaùba, Izombé, Jacareuba, Jatoba, Jelutong, Jequitiba, Jito, Jongkong, Jorori, Jùraco, Kabok, Kadam, Kanda (Kanda brun, Kanda rose), Kapokier, Kapur, Karité, Kasai, Kaudamu, Kedondong, Kekatong, Kékélé, Kelat, Keledang (Terap), Kembang semangkok, Kempas, Keranji, Keriti Silverballi, Keruing, Kiasose, Kibakoko, Kikenzi, Kokko, Kondroti, Kosipo, Kotibé, Koto, Kulim, Kumbi, Kungkur, Kurokaï, Landa, Lati, Laurel (Indian), Limba, Limbali, Limonaballi, Loliondo, Longhi, Lotofa, Louro vermelho, Lupuna, Lusambya, Maçaran-duba, Machang, Machiche, Mafu, Mafumati, Mahogany, Malagangai, Malas, Manbodé, Mandio-queira, Manil, Manil Montagne, Marupa, Mata-Mata, Mata Ulat, Mecrussé, Medang, Melunak, Mempening, Mengkulang, Mepepe, Meransi, Meranti (Dark red), Meranti (Light red), Meranti (White), Meranti (Yellow), Meranti Bakau, Merawan, Merbau, Merpauh, Mersawa, Messassa, Metondo, Mirindiba-Doce, Mjombo, Moabi, Moambé jaune, Molave, Momoqui, Monghinza, Mopaani, Mopé, Mora, Moral, Morototo, Movingui, Mtambara, Mtandarusi, Mubala, Mueri, Mugaita, Mugonha, Muhimbi, Mühühü, Muira-piranga, Muiratinga, Mukarati, Mukulungu, Muninga, Muniridan, Musharagi, Musine, Mussibi (Mutenyé), Mutaco, Mutondo, Muziga, N'téné, Naga, Nargusta, Nganga, Niangon, Nieuk, Niové, Nyatoh, Obéro, Odzikouna, Okan, Okoué, Okoumé, Olon, Olonvogo, Onzabili, Orey, Osanga, Ossimiale, Ossoko, Ovengkol, Ovoga, Ozigo, Ozouga, Paco, Padauk Amboyna, Padouk d'Afrique, Paldao, Palissandre d'Asie, Palissandre de Guatemala, Palissandre de Madagascar, Palissandre de Rose, Palissandre de Santos, Palissandre Honduras, Palissandre Panama, Palissandre Para, Palissandre Rio, Panacoco, Pao rosa, Parapara, Parcouri, Pashaco, Pau amarelo, Pau marfim (Peroba rosa), Pau mulato, Pau rosapau, Pau Roxo, Penaga, Pernambouc, Peruvian Pepper, Pillarwood, Pilon, Piquia, Platano, Pombeira, Primavera, Punah, Pyinkado, Quaruba, Ramin, Rengas, Resak, Rikio, Rosawa, Rose of the Mountain, Sabicu, Saboarana, Safukala, Sal, Sali, Sandalwood, Sapelli, Sapucaia, Saqui-Saqui, Satin Ceylan, Sepetir, Seraya (white) (White Lauan), Sesendok, Simpoh, Sipo, Slangehout, Sobu, Sougué, Sucupira, Sumauma, Suren, Suya, Tali, Tamboti, Tani, Tanimbuca, Tapiá, Tasua, Tatajuba, Tauari, Tchitola, Teak, Tembusu, Tento, Terminalia (brown), Terminalia (yellow), Thinwin, Tiama, Timbo, Tipa, Tola (Oduma), Toubaouaté, Trebol, Tsanya, Tualang, Umgusi, Umiri, Urunday, Vene, Vésàmbata, Virola, Wacapou, Walaba, Wamara, Wamba, Wengé, Xoan, Yemane, Yungu, Zingana.

† For the purposes of tariff code 4407.29.92, "tropical wood" means one of the following types of wood: Abura, Acajou d'Afrique, Afrormosia, Ako, Alan, Andiroba, Aniégré (Aningré), Avodiré, Ayous (Obéché), Azobé, Balau red, Balau yellow, Balsa, Bété (Mansonia), Bossé clair, Bossé foncé, Cambara (Jaboty), Cativo, Cedro, Dabéma, Dibétou, Doussié, Douka (Makoré), Framiré, Freijo, Fuma (Fromager), Geronggang, Hard Alstonia (Pulaï), Ilomba, Imbuia, Ipé, Iroko, Jelutong, Jequitiba, Jongkong, Kapur, Kempas, Keruing, Kosipo, Kotibé, Koto, Limba, Louro vermelho, Maçaran-duba, Mahogany, Mandio-queira, Mengkulang, Meranti (Dark red), Meranti (Light red), Meranti (White), Meranti (Yellow), Meranti Bakau, Merawan, Merbau, Merpauh, Mersawa, Moabi, Niangon, Nyatoh, Okoumé, Onzabili, Orey, Ovengkol, Ozigo, Padauk Amboyna, Paldao, Palissandre de Guatemala, Palissandre de Rose, Palissandre Para, Palissandre Rio, Pau amarelo, Pau marfim (Peroba rosa), Punah, Quaruba, Ramin, Sapelli, Saqui-Saqui, Sepetir, Seraya (white) (White Lauan), Sipo, Sucupira, Suren, Tauari, Teak, Tiama, Tola (Oduma), Virola.

* Tariff code 4407.96.00 did not appear in the inspection data provided by the department.

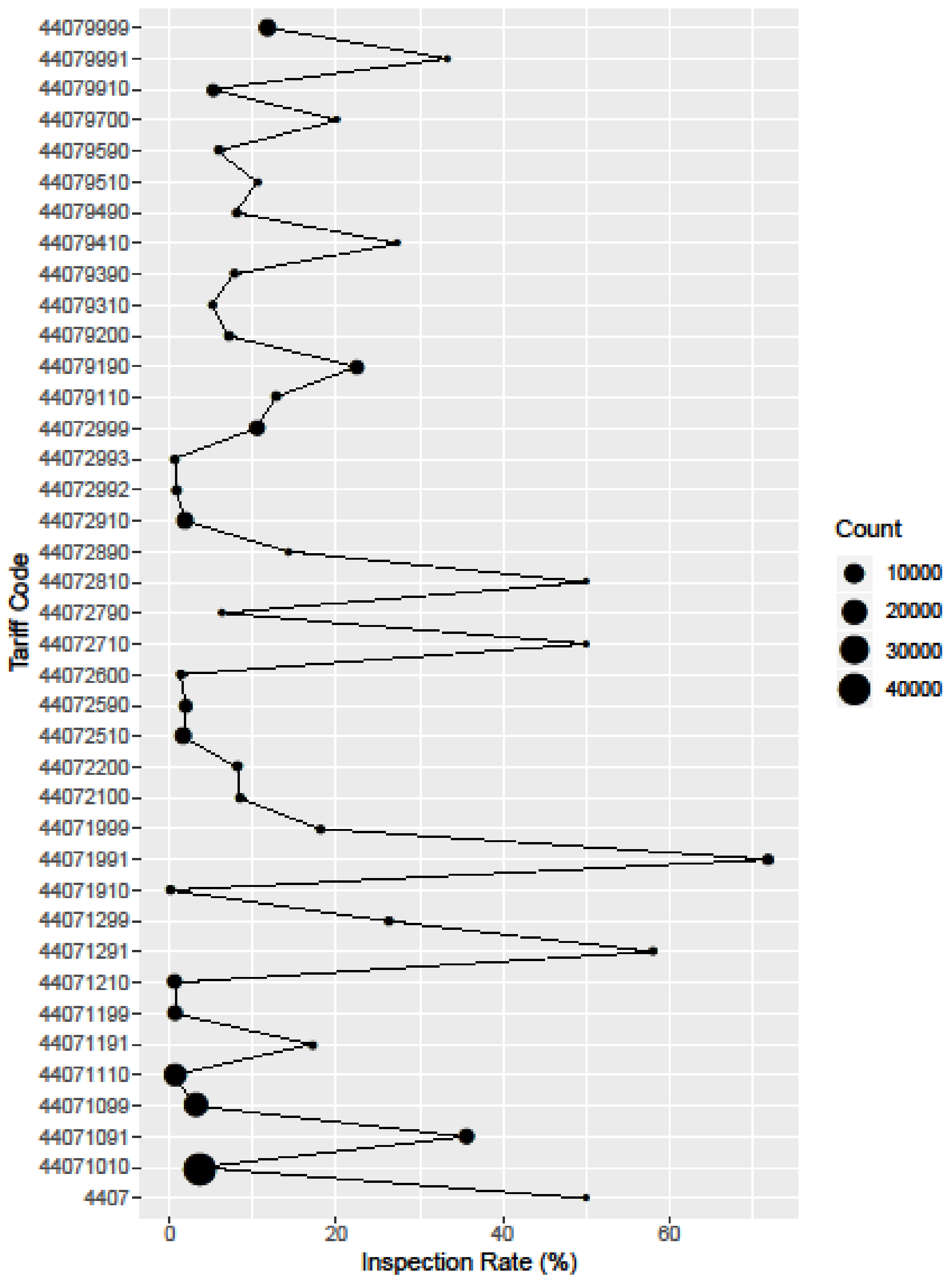

Figure 17. Inspection rate for arriving lines by tariff code.

Note: Count refers to the number of arriving lines.

Likewise, Figure 18 shows that a handful of export countries are inspected at 100 per cent, namely country codes 44, 59, 61, 62, 65, 67, 69, and 76. As with the most heavily inspected tariff codes, these countries correspond to small line counts. The most substantial countries in terms of line counts, namely 8, 2, 3, and 11, all have inspection rates at or below 5 per cent.

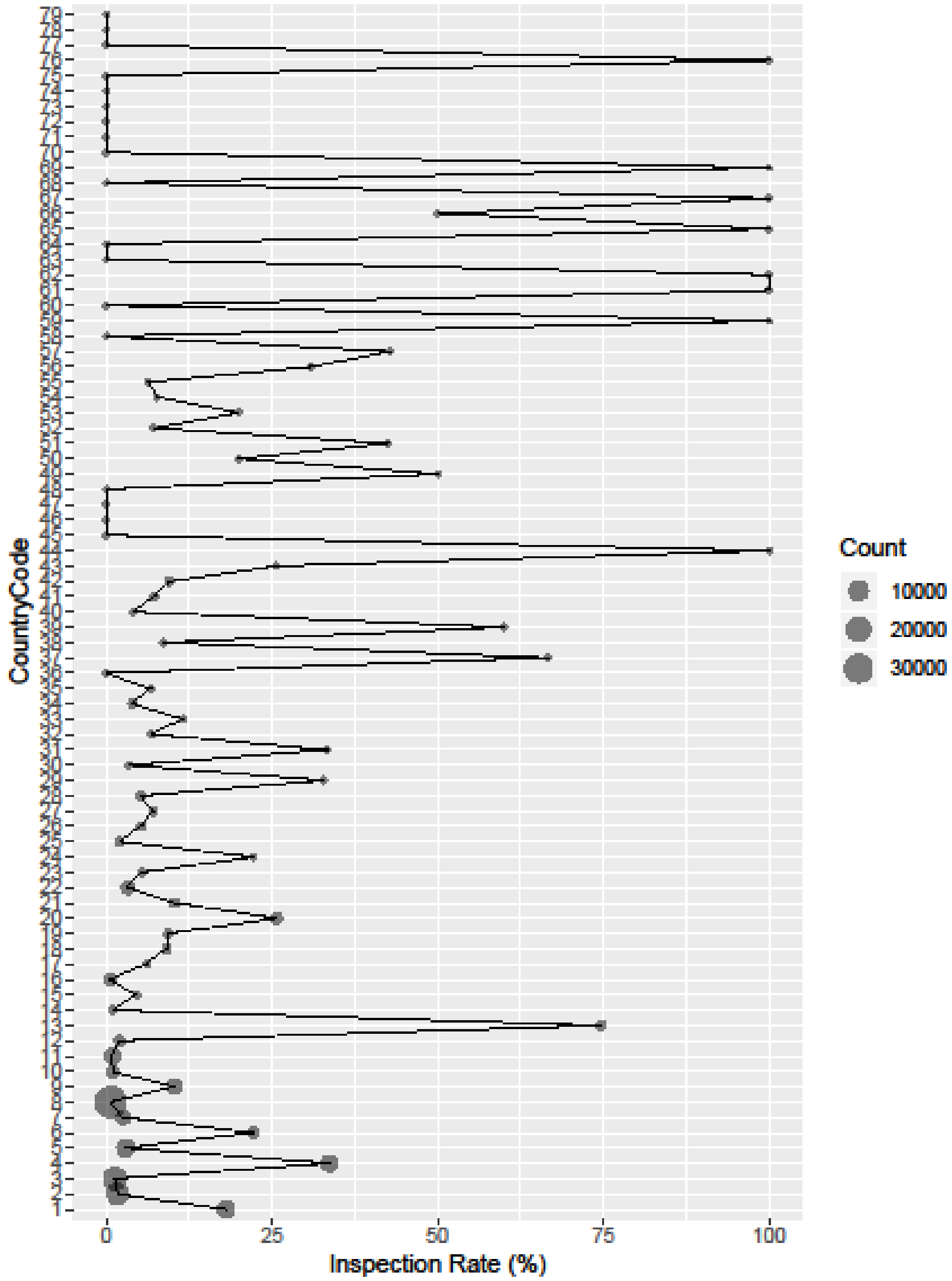

Figure 18. Inspection rate for arriving lines by exporting country.

Note: Count refers to the number of arriving lines.

We also investigated whether there is significant nesting of importers or suppliers within countries; that is, whether the preponderance of importer or supplier activity is from single or multiple countries. Such nesting may provide insight as to the within-country risk landscape and provide useful feedback to competent authorities.

Table 12 shows that more than 85 per cent of the suppliers supplied the lines from only one country, but that this single-country supplier activity represented only about half of the arriving lines.

Table 12. Count of suppliers by the number of countries from which they export and count of corresponding lines from suppliers.

Countries	Suppliers	Lines
1	1 980	62 995
2	211	17 911
3	66	13 995
4	16	5 628
5	9	6 024
6	2	5 616
7	2	4 227
8	1	287
9	1	2 311
12	1	1 465

Table 13 shows that nearly 75 per cent of the importers imported the lines from only one country, but this was barely 5 per cent of the pathway volume in terms of line count. These results suggest that the supplier/country system is reasonably hierarchical, but the importer/country system is not.

Table 13. Count of importers by the number of countries from which they import and count of corresponding lines from importers.

Countries	Suppliers	Lines
1	776	5 675
2	109	5 951
3	50	9 158
4	35	5 125
5	18	7 191
6	17	3 371
7	6	6 654
8	5	2 500
9	8	19 699
10	6	5 007
11	4	2 102
12	4	1 930
13	3	12 544
14	2	5 636
15	1	4 325
16	2	5 881
22	1	15 467
23	1	2 243

A.2.2. Interceptions

For this analysis, *interception* refers to the inspection and discovery of at least one hitchhiker pest of interest, as identified from a list of species provided by the department. This use of the term differs slightly from the IPPC definition that relates to "the detection of a pest during inspection or testing of an imported consignment" (FAO, 2007).

Lines that have been inspected are sourced from 60 countries. The inspected pathway includes 780 suppliers and 453 importers. For the 6 664 timber lines inspected during the data collection period, only a small fraction of inspections (2.3 per cent) have resulted in detections of hitchhiker pests of interest. Figure 19 shows that higher interception rates have been experienced in the most recent four years than the years preceding — the recent rate is approximately double the earlier rate. This observation is explored further in the next section.

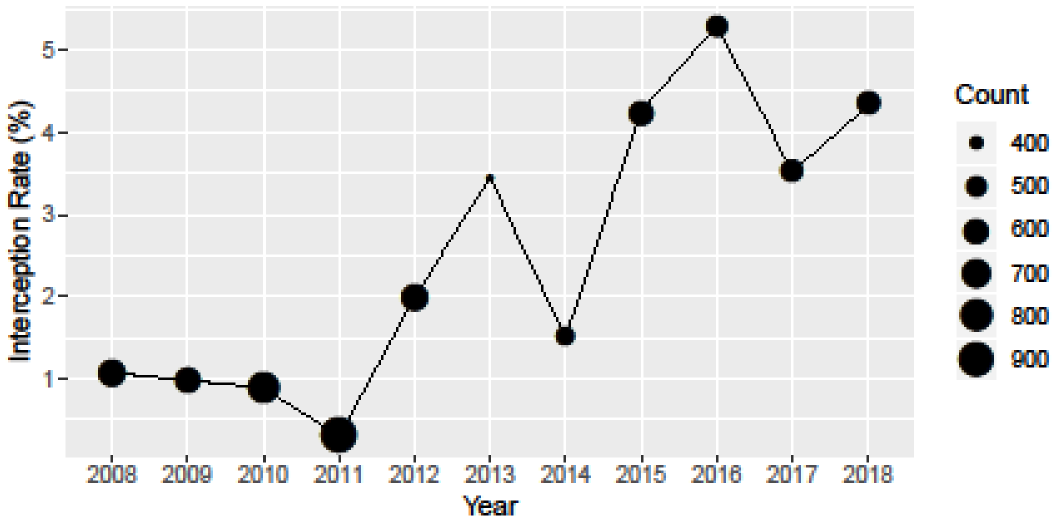

Figure 19. Interception rate for inspected lines by calendar year.

Note: Count refers to the number of arriving lines.

Figure 20 shows the interception rate for inspected lines by tariff. The most inspected tariff code – 44071010 – which includes coniferous timber imports, has a low interception rate. In contrast, the interception rates for tariff codes:

- 44071091, which features a range of coniferous timber products, including those cut for staves;
- 44071991, comprising wood from conifers other than pine (*Pinus spp.*), fir (*Abies spp.*) and spruce (*Picea spp.*), including timber that is redwood (*Sequoia sempervirens*), western red cedar (*Thuja plicata*), cut to size for making staves or has a cross-sectional area of 450 cm^2 or greater;
- 44079190, which features oak (*Quercus spp.*) timber products that are not planed or sanded,

are 4 per cent or higher.

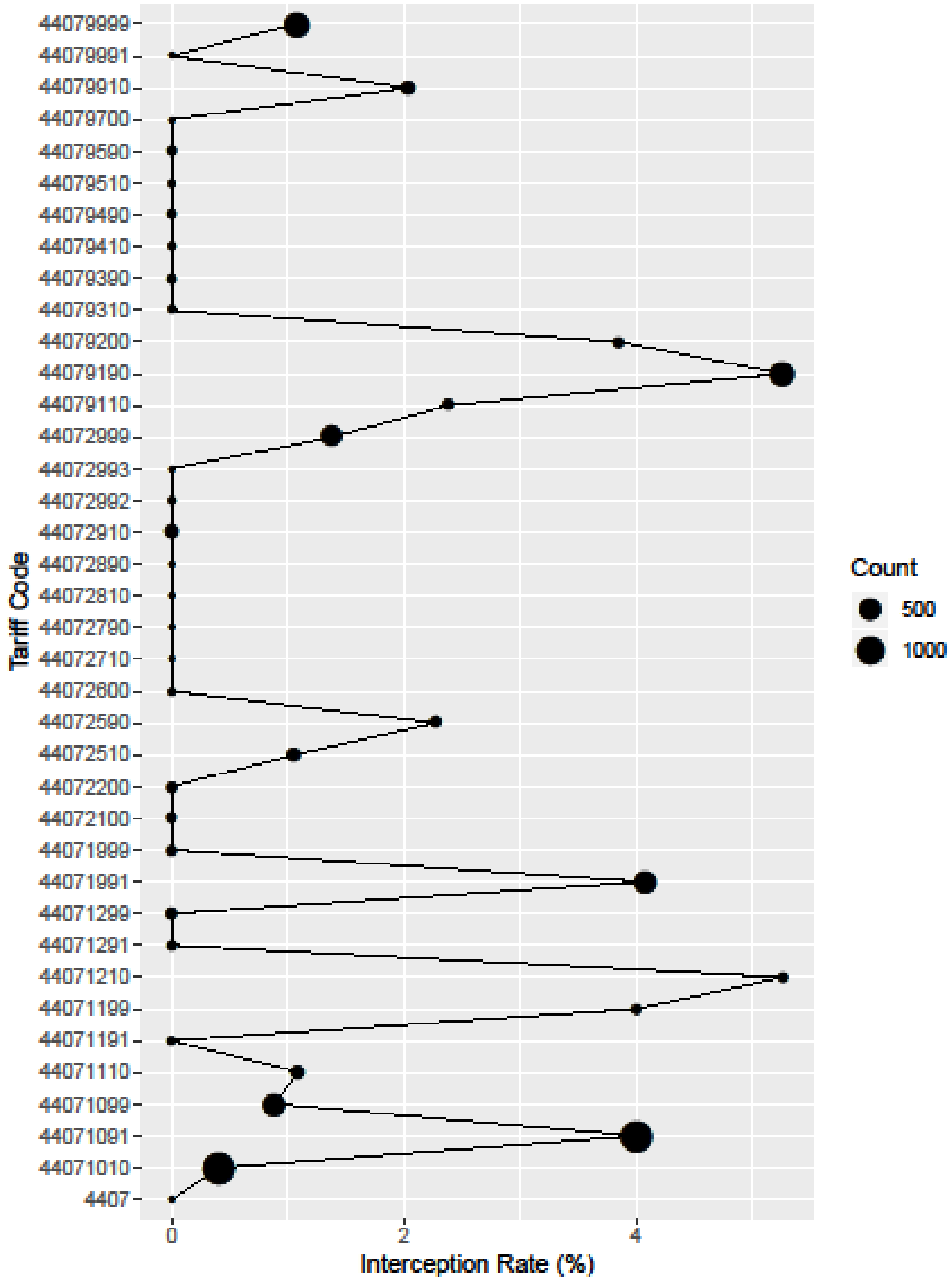

Figure 20. Interception rate for inspected lines by tariff code.

Note: Count refers to the number of arriving lines.

Figure 21 provides the interception rate for inspected lines by exporting country. Country 4 dominates in terms of inspections, but the interception rate is low at about 4 per cent. On the other hand, countries 44 and 17 have much higher interception rates but lower counts of inspected lines.

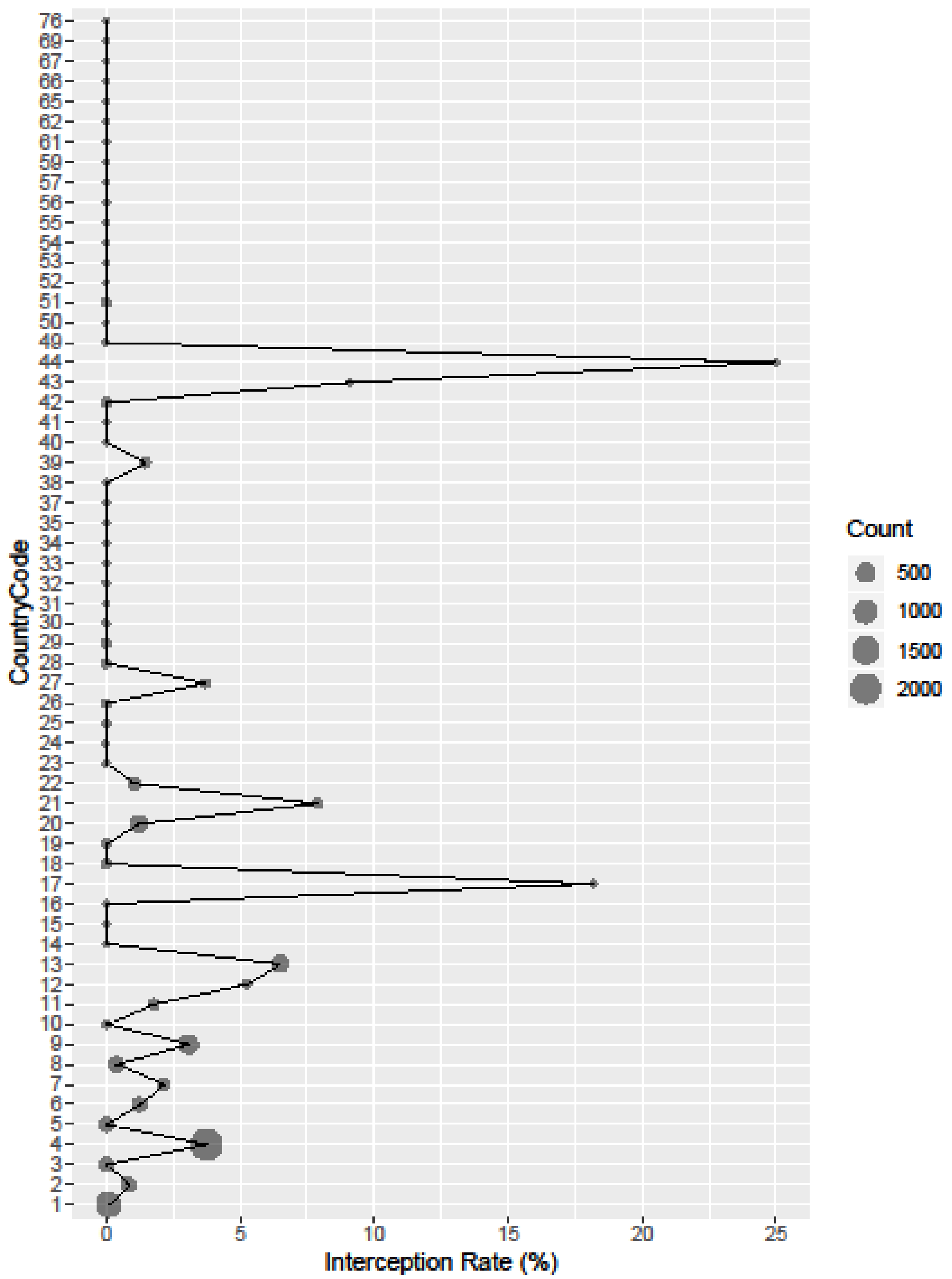

Figure 21. Interception rate for inspected line by exporting country.

Note: Count refers to the number of arriving lines.

Finally, the interception rate is plotted against the inspection rate by country in Figure 22. This shows the high inspection and interception rate for country 44, and the high interception rate but low inspection rate for country 17.

It is tempting to conclude that the biosecurity risk of lines from country 17 should be managed differently: few lines are inspected, and those that are inspected show high contamination rates. However, these data do not support this conclusion. It is important to keep in mind that the inspected lines cannot be assumed to represent the lines, in the usual statistical sense, because we know uninspected lines are accompanied by evidence of treatment, unlike the inspected lines.

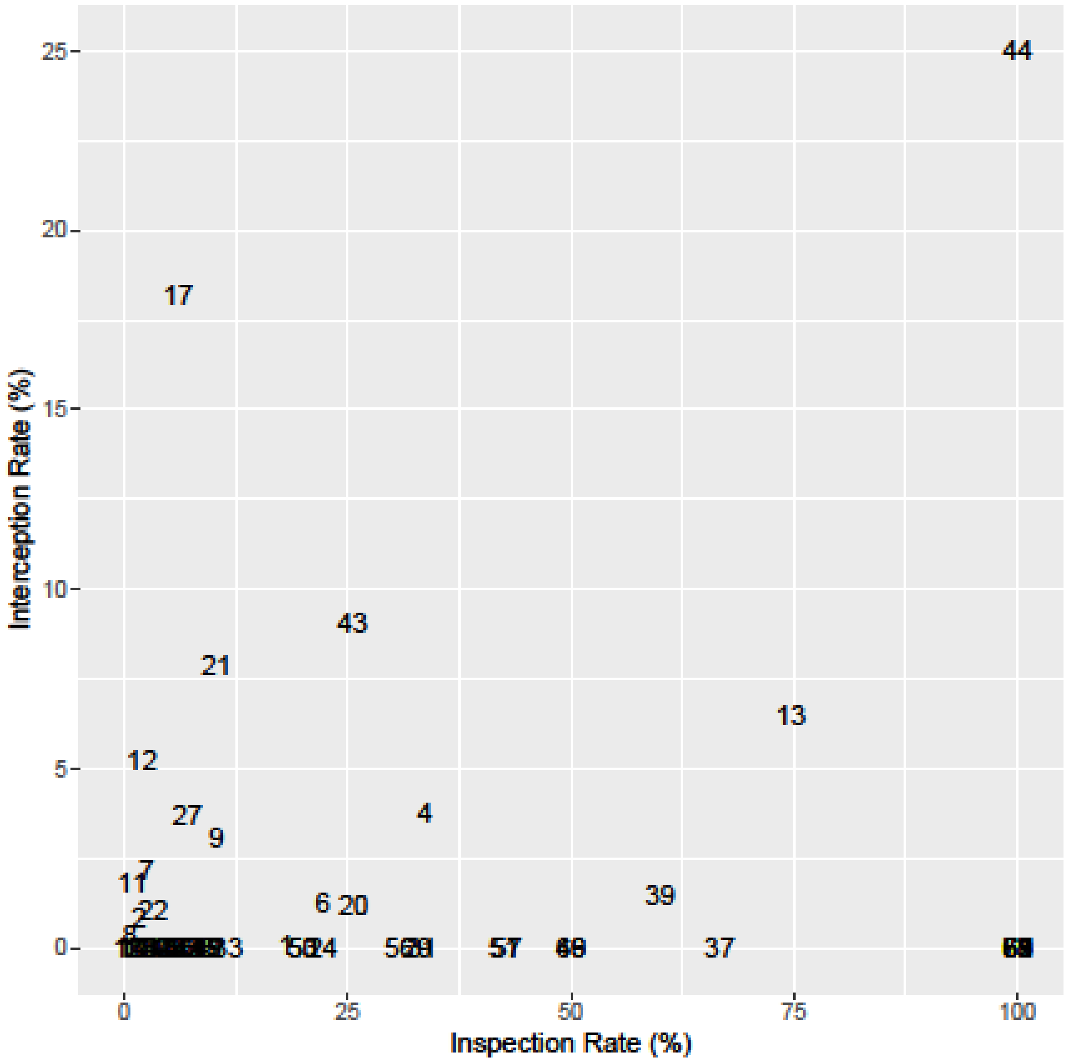

Figure 22. Interception rate for inspected lines, plotted against inspection rate, by country.

Note: The plotted label represents the country code.

Of course, it is possible that some documentary evidence of treatment is incorrect or misleading, and that a portion of the lines not inspected are also untreated. The only way to determine whether this conjecture is true, or even material, is to inspect a sample of lines that arrive with documentation that would otherwise be cleared without further intervention. A program similar to the department's Cargo Compliance Verification exercise, or a snapshot survey comprising a few hundred randomly selected lines, should suffice.

It is also reasonable to ask whether there is significant nesting of importers or suppliers within countries for the inspected lines only. Table 14 shows that more than 90 per cent of the suppliers that had lines inspected between 2008 and 2018 supply the inspected lines from only one country; however, this represents two-thirds of the pathway's inspection activity. Further details for a subset of the suppliers are shown in Figure 23.

Table 14. Count of suppliers of inspected lines by the number of countries from which they export, and count of corresponding inspected lines from suppliers.

Countries	Suppliers	Lines
1	722	4 405
2	47	1 388
3	8	373
5	2	374
8	1	124

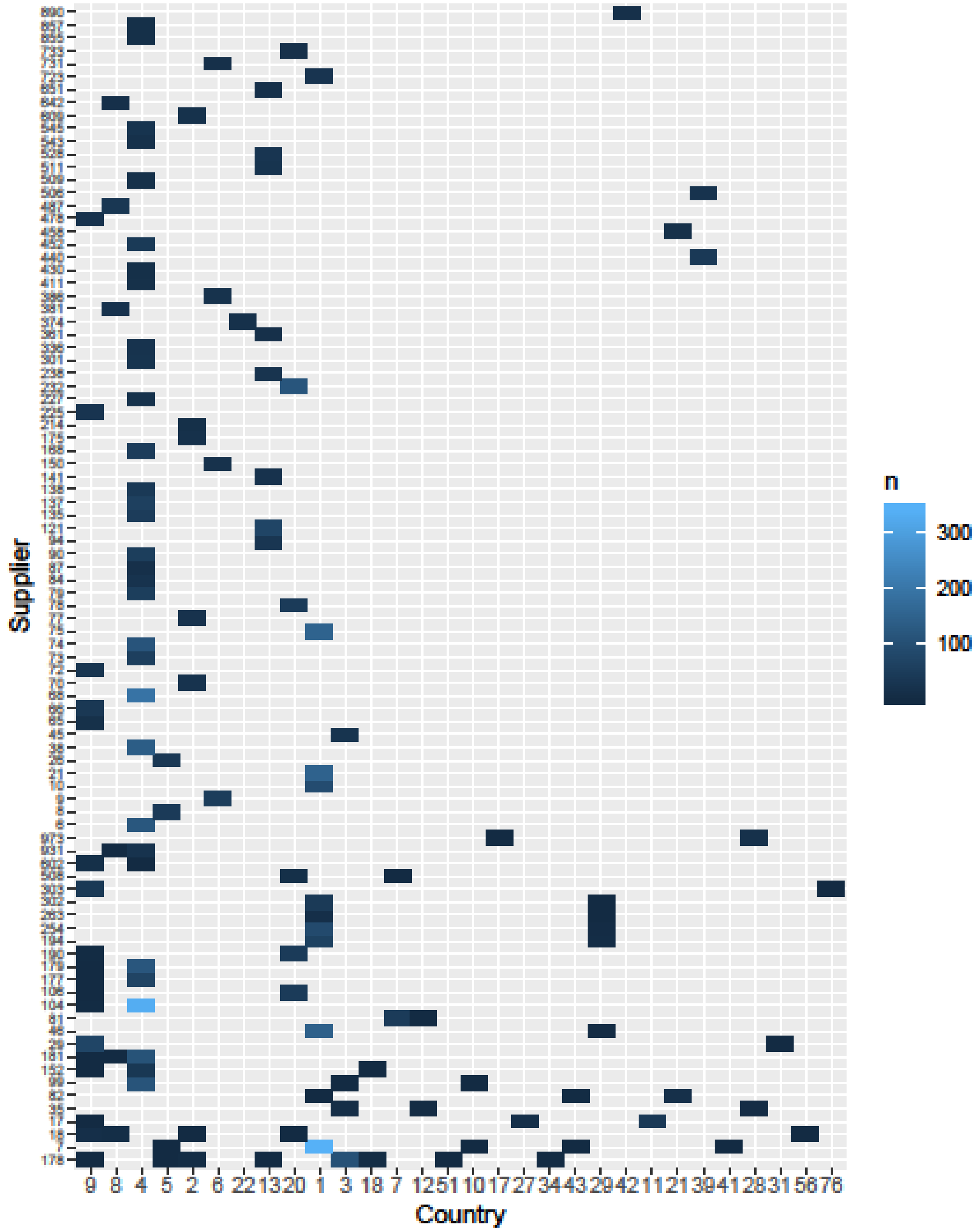

Figure 23. Heatmap of supplier and country activity for suppliers with at least 15 inspected lines.

Notes: The levels of “Supplier” are sorted according to the number of countries from which they export, as shown in Table 10, with the levels of “Country” are sorted by the number of suppliers exporting from them. The swatch colour reflects the number of inspected lines from each country and supplier combination.

Table 15 shows that more than 75 per cent of the importers that had lines inspected between 2008 and 2018 import the inspected lines from only one country, representing 18 per cent of the pathway activity. Further details for a subset of the importers are available in Figure 24. The results shown across Tables 14 and 15 and Figures 23 and 24 suggest there is reasonable hierarchical structure in the importer/country and supplier/country activity for inspected lines.

Table 15. Count of importers of inspected lines by the number of countries from which they import, and count of corresponding inspected lines from the importers.

Countries	Suppliers	Lines
1	351	1 199
2	48	1 809
3	24	781
4	11	577
5	6	332
6	6	890
7	4	344
8	1	297
10	2	435

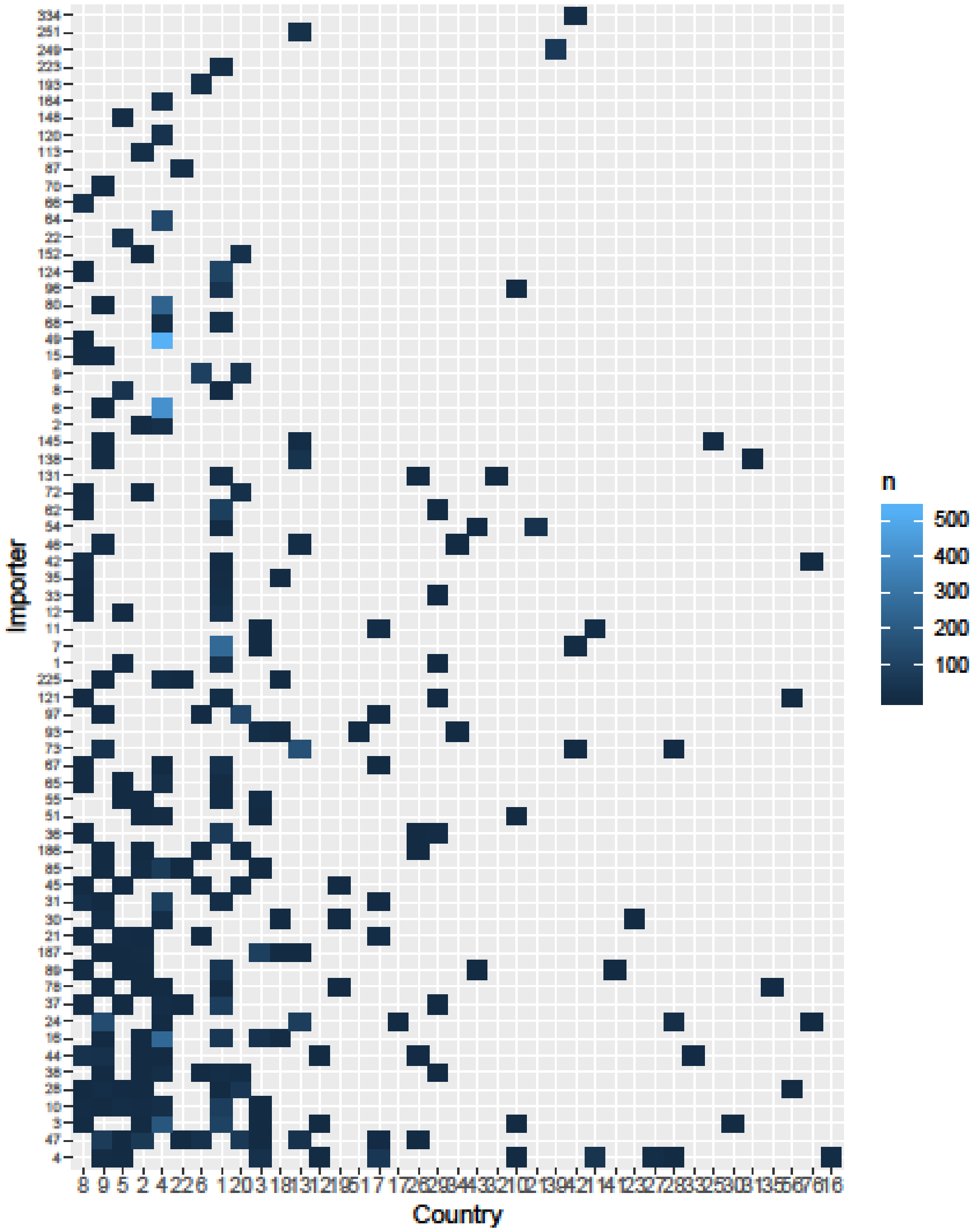

Figure 24. Heatmap of importer and country activity for importers with at least 15 inspected lines.

Notes: The levels of "Importer" are sorted according to the number of countries from which they import, as shown in Table 11, while the levels of "Country" are sorted by the number of importers importing from them. The swatch colour reflects the number of inspected lines from each country and importer combination.

A.3. Model fitting

Although it is tempting to try to fit statistical models to the timber line inspection data, there are recognised shortcomings of the dataset from a modelling point of view that hamper our ability to draw higher-level conclusions. Specifically, the selection of lines for inspection is not random nor representative; rather, it is based on whether treatment information is available. It is unlikely that the pattern of biosecurity contamination will be the same for the uninspected lines as for the inspected lines, because the lines that are not inspected all have evidence of some kind of risk-mitigating treatment. Even informal summaries, such as Figure 16, have the potential to mislead. For example, it might seem that country 17 bears further scrutiny because it is rarely inspected, but when it is inspected, it has a high interception rate. Again, all the lines from country 17 are either inspected or treated. It is very unlikely that the inspected lines can be treated as being representative of the uninspected lines.

Notwithstanding these caveats, the remainder of this section fits statistical models to assess whether the interception rate has changed over time and whether there are spatial or other differences that may help explain patterns in the interception rate.

A.3.1. Why does the interception rate change over time?

The first aspect of interest is to determine whether the change in interception rate displayed in Figure 19 might be explained by some change in the environment, such as a change in the volumes arriving from different countries. Here we construct some statistical models to try to identify relevant patterns of interceptions among the inspected lines.[48] The point of the fitting exercise is to be suggestive rather than definitive, so rather than an exhaustive modelling exercise we fit and report simple models that should provide useful insights.

Table 16 summarises a key outcome, namely that when the identity of the exporting country is taken into account, there is very little temporal pattern left. This observation is supported from the point of view that the far-right value in the bottom row is comparatively high.

Table 16. Analysis of deviance of country and time for predicting the interception of biosecurity risk from inspected lines.

	df	Deviance	Residual df	Residual deviance	Prob (>Chi)*
NULL			6 663	1 442.29	
CountryCode	59	149.18	6 604	1 293.11	0.0000
bs(CreationDate,3)	3	10.90	6 601	1 282.21	0.0123

Notes: The second row corresponds to Country and the third row to a flexible function of time.
* This column reports a measure of the statistical assurance that the purported relationship is real, as opposed to confected by randomness. It is referred to as the *p-value* and defined as “the probability that a random outcome would be as or more extreme than the observed outcome if there really were no relationship”. The strength of the assurance is inferred from the smallness of the number; for example, less than 0.01 would indicate a very low likelihood that the result is only due to random chance.

Figure 25 provides further context: it shows that the inspection rates of countries 1 and 4 vary considerably across time. If the interception rates differ between the countries, as suggested in Figure 15, then the relative change in volumes can explain the overall change in interceptions. Hence it is very possible that the apparent change in the interception rate over time observed in Figure 19 is a change in space; that is, it reflects a change in the pathway from being dominated by Country 1 (0.083 per cent interception rate) to being dominated by Country 4 (3.8 per cent interception rate). As noted earlier, this observation does not generalise to the uninspected lines for

[48] The model fitted is a generalised linear model, with binary response variable (contamination detected, or no contamination detected) and logit link function. Testing is based on whole-model tests using the chi-squared distribution. Only inspected lines are included in the fitting data.

Country 1 or 4, because the inspected lines are not a representative sample of the pathway as a whole.

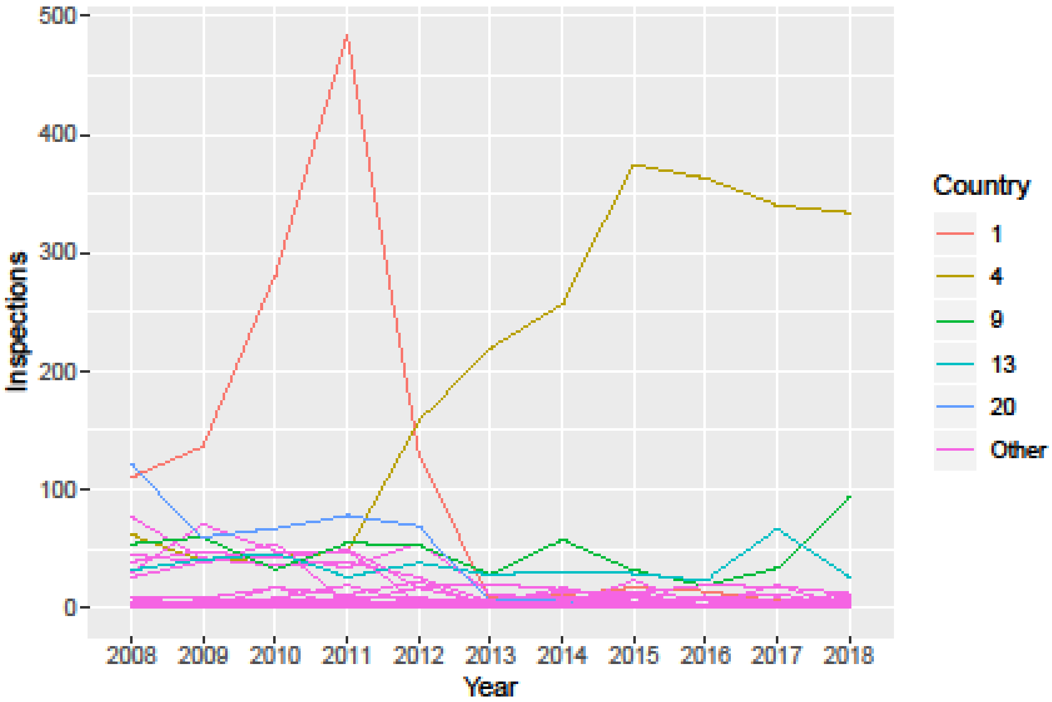

Figure 25. Annual inspection count by country.

A final small verification can be found in Table 17, which presents a statistical test for any temporal variation in the interception rate of inspected lines from Country 4. the high value in the right-most column suggests that there is none.

Table 17. Analysis of deviance of time for predicting the interception of biosecurity risk from inspected lines for Country 4.

	df	Deviance	Residual df	Residual deviance	Prob (>Chi)
NULL			2 237	716.27	
bs(CreationDate,3)	3	3.31	2 234	712.96	0.3469

Notes: The second row corresponds to a flexible function of time. The last column reports the *p-value* of the statistical test; see the notes to Table 16 for a definition of this concept.

A.3.2. Are there spatial differences in interception rates?

The second question of interest is whether there is strong evidence to suggest variation between the various countries, suppliers, and importers. We can check this by fitting and testing a model and the obtaining relevant estimates.[49]

[49] The fitted model is a generalised linear mixed-effects model, with binary response variable (contamination detected, or no contamination detected) and logit link function. Country, Supplier, and Importer each enter the model as special kinds of effects called *random effects*, which is a useful approach to handling categories that have many levels and are unbalanced. Only inspected lines are included in the fitting data.

The first two sections of Table 18 show that the identity of the supplier and the importer, respectively, show strong statistical patterns; however, there is a much weaker signal around the country of origin, as shown in the last section of the table. This can be explained by observing that the great majority of suppliers and importers are single-country operations, so much important country-to-country variation can also be explained by importer-to-importer variation or supplier-to-supplier variation, as suggested in Tables 14 and 15.

Table 18. Analysis of deviance to compare models with country, supplier and importer (glmm.cis) against models with two of these components, hence testing the statistical importance of the third component.

	df	AIC	BIC	Log likelihood	Deviance	Chi-squared test statistic	Chi-squared df	p-value
Testing the statistical importance of *supplier* (model glmm.ci includes country and importer)								
glmm.ci	3	1 298.72	1 319.14	-646.36	1 292.72			
glmm.cis	4	1 288.46	1 315.68	-640.23	1 280.46	12.26	1	0.0005
Testing the statistical importance of *importer* (model glmm.cs includes country and supplier)								
glmm.cs	3	1 321.46	1 341.88	-657.73	1 315.46			
glmm.cis	4	1 288.46	1 315.68	-640.23	1 280.46	35.01	1	0.0000
Testing the statistical importance of *country* (model glmm.is includes importer and supplier)								
glmm.is	3	1 287.79	1 308.20	-640.89	1 281.79			
glmm.cis	4	1 288.46	1 315.68	-640.23	1 280.46	1.33	1	0.2488

Note: The last column reports the *p-value* of the statistical test; see the notes to Table 16 for a definition of this concept.

Predicted relative odds ratios for contamination are presented along with approximate 95 per cent coverage intervals for selected importers, suppliers, and country of origin in Figures 26, 27 and 28 respectively. Levels with fewer than 10 lines are omitted. These figures may be interpreted as follows. The levels are sorted by increasing predicted relative odds ratios and labelled in the y-axis. The predicted relative odds ratio is indicated by the black dot, and an approximate 95 per cent coverage interval is captured by the black lines. A grey vertical line is added at Odds = 1 for reference. If the interval intersects this line, then we should treat the corresponding level as though it is not different from the 'average'.

Figure 26 identifies importers 73, 54, 49, 97, 6, 64, and 24 as being above the line — these importers all have a higher predicted odds ratio of contamination being detected when their lines are inspected. Similarly, Figure 27 identifies suppliers 545, 303 and 68, and Figure 28 identifies Country 4 as being of particular interest in this context.

Overall, this analysis, which comes with heavy qualifications, suggests there is some difference in interception rates between different suppliers and importers. There appears to be no systematic evidence of differences between countries, although Country 4 may have a higher interception rate than the others.

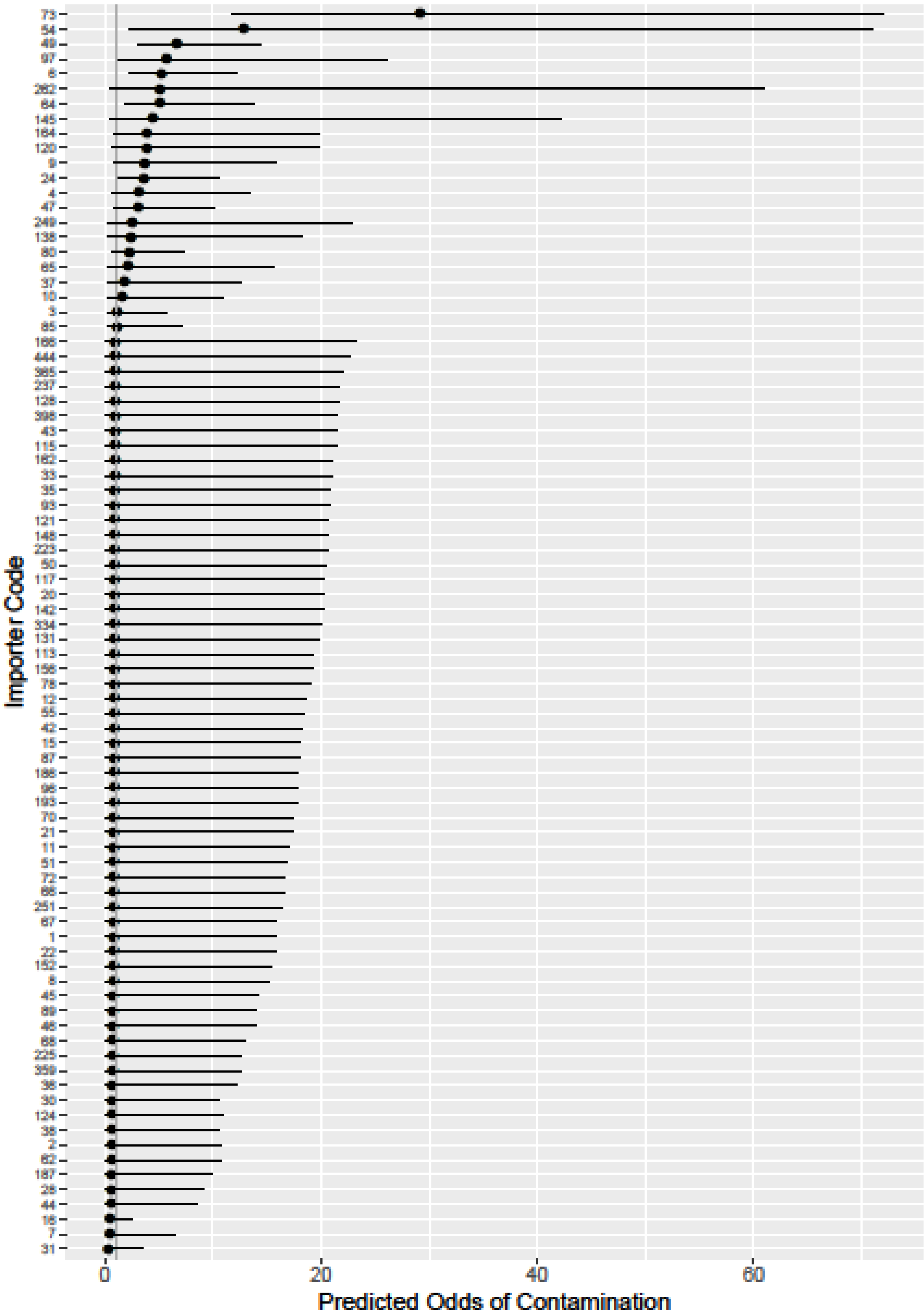

Figure 26. Dotplot of selected predicted contamination odds for importers.

Notes: The intervals are approximate 95 per cent coverage intervals. Importers with fewer than 10 lines are omitted. A grey vertical line is added at Odds = 1 for reference.

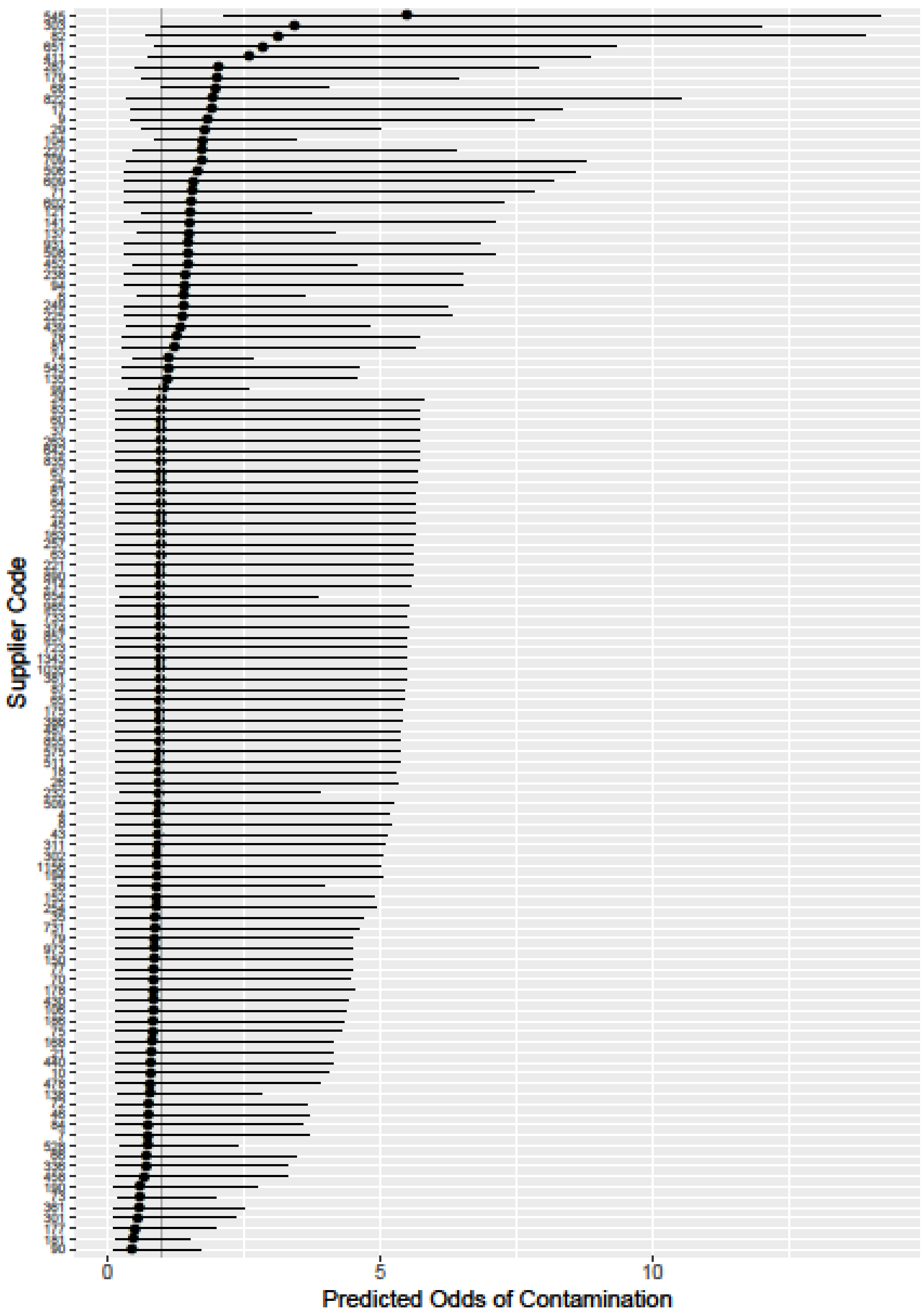

Figure 27. Dotplot of selected predicted contamination odds for suppliers.

Notes: The intervals are approximate 95 per cent coverage intervals. Suppliers with fewer than 10 lines are omitted. A grey vertical line is added at Odds = 1 for reference.

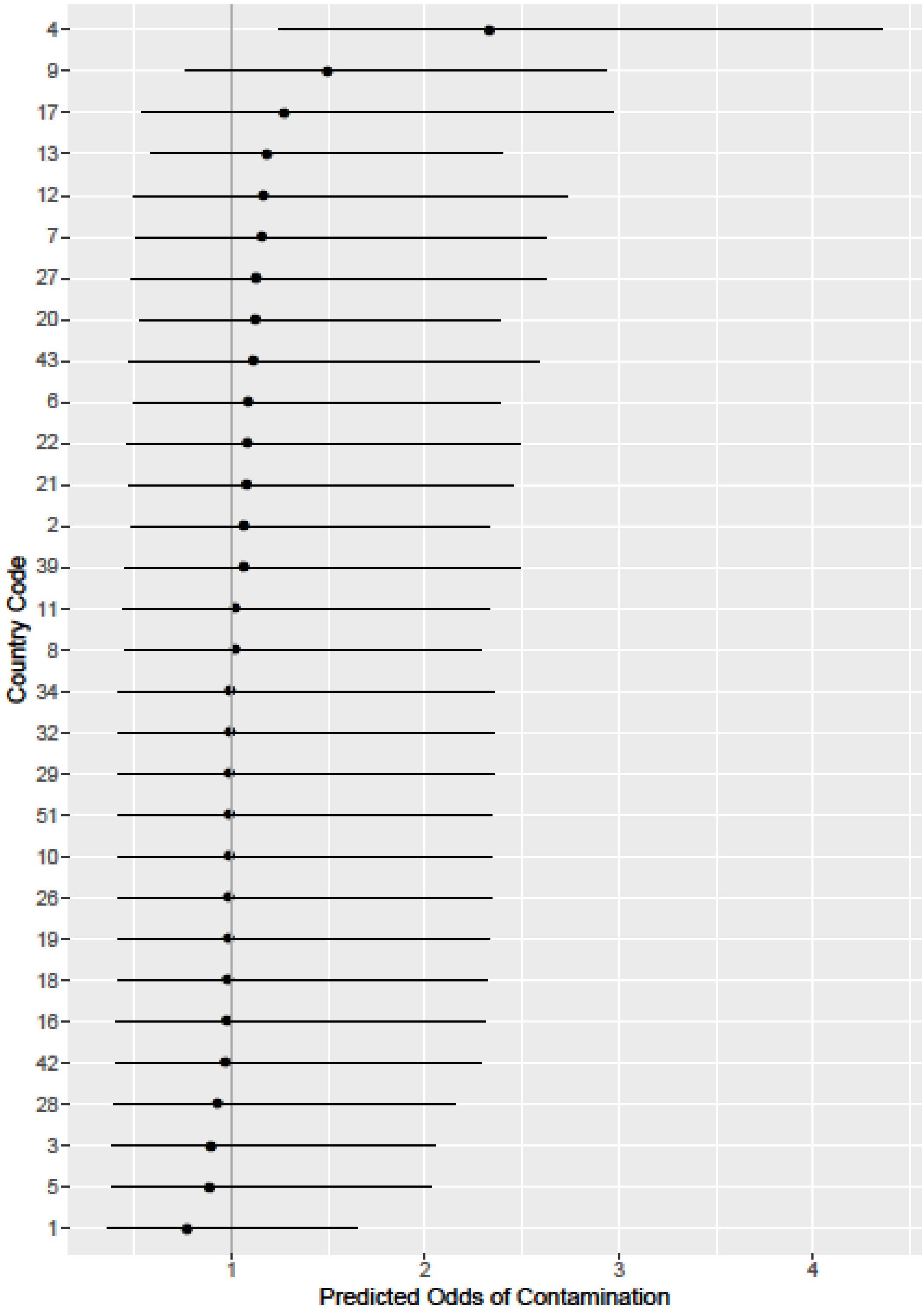

Figure 28. Dotplot of selected predicted contamination odds for countries of origin.

Notes: The intervals are approximate 95 per cent coverage intervals. Countries with fewer than 10 lines are omitted. A grey vertical line is added at Odds = 1 for reference.

A.3.3. Are there other differences in interception rates?

We now test whether there are within-year effects for interception rates, searching for seasonal differences and the like. To construct a test that provides biological realism, we distinguish between exporting countries situated in the northern hemisphere, southern hemisphere and equatorial zone.

Based on the differences shown in Table 2 in Chapter 3, a statistical model was fitted to assess the strength of the hemispherical and day-within-year signals, omitting the equatorial zone data.[50] The results in Table 19 show some evidence of a difference between the interception rates for lines arriving from exporting countries within the different global regions (first row), consistent with the commentary accompanying Table 2. Although it is conceptually attractive to expect a seasonal effect on the arrival rates of pests, there is no such statistically detectable signal in the data shown in the second row of Table 19. This lack of signal persists even when the countries from the different hemispheres are analysed separately (third row).

Table 19. Analysis of variance to test the statistical importance of hemisphere and a periodic smooth of Julian day.

	df	Sum of squares	Mean squares	F-value
ExporterCountryHemisphere	1	3.74	3.74	3.74
pbs(Julian.Day, df = 3)	3	4.32	1.44	1.44
ExporterCountryHemisphere:pbs(Julian.Day, df = 3)	3	1.70	0.57	0.57

Notes: For a statistically significant difference, the F-value should exceed 3 in this instance. The first row represents hemisphere, pointing to some difference in interception rates on this dimension, while the second represents the Julian Day (with a periodic smooth). The third row represents the interaction between the first two, which allows the different hemispheres to have different periodic behaviour. Model incorporates inspection data from timber imported from countries in the northern and southern hemispheres only.

The equatorial data were omitted from the model underpinning Table 19, because the inspection rate was low and the failure rate extremely low. Such data would introduce considerable unjustified uncertainty; furthermore, there are biological reasons to expect there should not be seasonality in equatorial country interception rates.

Figure 29 shows a within-year smoothed mean interception rate by region. The northern and southern hemispheres show statistically negligible cycles that are not particularly dissimilar, although the base rates are clearly different. One potential contributor to this lack of signal is the variable travel time. Some lines take seven to eight weeks to travel from the export country to Australia, such that these delays would considerably muddy seasonal signals.

[50] This model is a generalised linear mixed-effects model, with binary response variable (contamination detected, or no contamination detected) and logit link function. *Supplier* and *Importer* each enter the model as random effects. Only inspected lines are included in the fitting data. We fitted a special periodic smooth to the Julian Day predictor, which enforce continuity at the edges and recognises that day 1 is equally close to days 2 and 365 (except during a leap year).

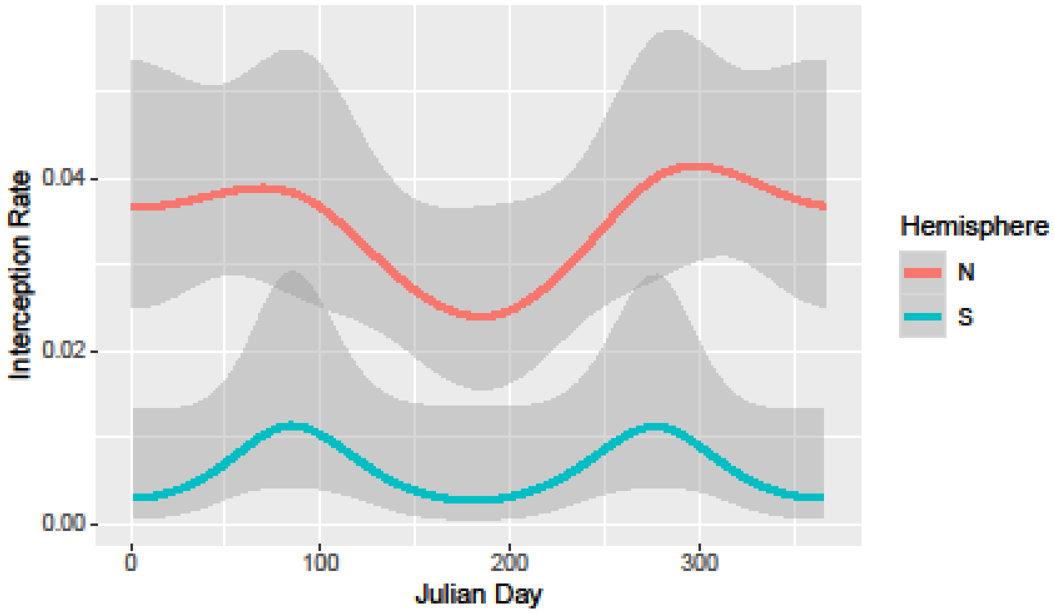

Figure 29. Within-year smoothed mean interception rate by global region – (N)orthern and (S)outhern hemisphere.

Notes: Excludes equatorial exporting countries because of their very low interception rates and small number of interceptions.

A.4. Suitability for including timber on the CBIS

The motivation for this analysis was to determine whether the border biosecurity interventions for the timber pathway could be managed using the department's Compliance-Based Intervention Scheme (CBIS). The conditions under which CBIS might be suitable for a pathway include:

- the possibility of leakage must be tolerable;
- the approach rate of the whole pathway *or identifiable sub-pathways* must be reliably low; and
- the pathway's inspection history must be made readily available so that the pathway mode can be determined and the appropriate measures taken as lines arrive.

This report focuses on the second of the conditions. Presently, border biosecurity risk management on the timber pathway comprises a documentation check for suitable treatment and inspection if the documentation check is rejected.

All lines that lack suitable documentation are inspected, but the failure rate is low, with notable exceptions. Most inspections are performed on lines from Country 4 (Figure 25), for which the failure rate is about 4 per cent (Figure 21). CBIS by country does not seem particularly useful based on this outcome.

It is possible that better discrimination would be established if the CBIS program were to manage risk by supplier or importer than by country, as suggested by the analysis in Table 18. There seems to be a better differentiation for importers (Figure 26) and suppliers (Figure 27) than for countries (Figure 28). We tentatively conclude that it could be feasible to add the timber pathway to the CBIS with appropriate parameters, applied on the inspection history of individual importers or suppliers.

Appendix B: Exploratory analysis of timber inspection data

B.1. Dataset

Data from the department's Agricultural Import Management System (AIMS) and Incidents databases comprised border inspection records for 120 459 timber lines that arrived from 79 source countries during the period 2008-2018 inclusive. There were 520 unique Incident identifiers and 511 contaminating pests found, of which there were 227 unique genus-species combinations.[51,52] Of the 227 identified contaminating pests, 199 (about 88 per cent) were identified as hitchhikers. The following analysis uses all 227 identified pests.

B.2. Analysis

Taken as a whole, the data do not suggest seasonality in pest arrivals (Figure 30). In the plot below, each dot corresponds to a contaminating pest which has a unique numerical identifier (the numbers form the y-axis). Cumulatively, over the 11 years, a slight increase of incidents is observed in spring.

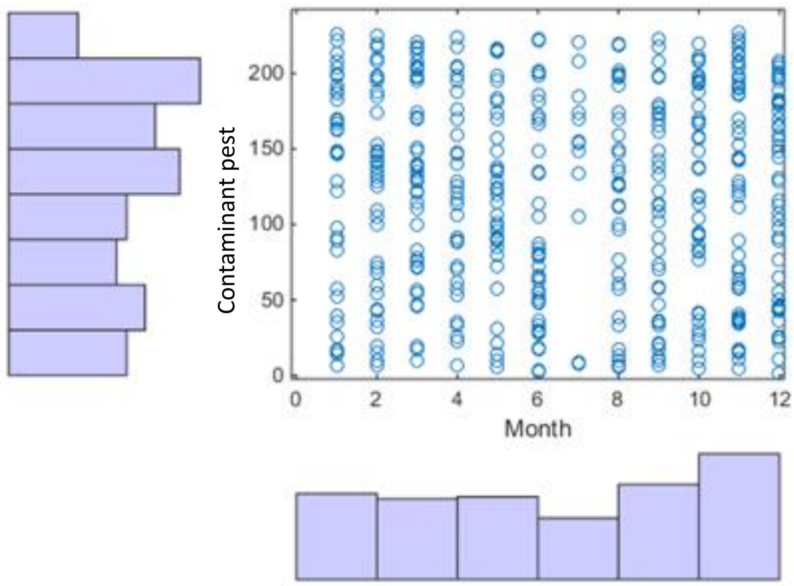

Figure 30. Contaminating pest count per month, 2008 -2018.

To see if these patterns are consistent across years, Table 20 shows the counts (and percentages relative to total numbers per year) of identified contaminating pests per year. The season with the highest count per year is highlighted in yellow; if two seasons have similar counts in a given year, both are highlighted in green.

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[51] There are 192 NA&NA, the majority of which got redistributed according to the combination of Order and Family instead—there are still 12 NA&NA combinations left.

[52] This descriptive analysis focused on contaminating pests at the species level for clarity. We note many other studies analyse interceptions data at higher taxonomic levels, such as the Order (for example, Coleoptera and Lepidoptera) or Family.

Table 20. Contaminating pest counts per year per season

Number of contaminating pests									
Year	**Summer**		**Autumn**		**Winter**		**Spring**		**Year**
2008	2	0.100	5	0.250	4	0.200	9	0.450	20
2009	10	0.435	4	0.174	5	0.217	4	0.174	23
2010	14	0.438	11	0.344	3	0.094	4	0.125	32
2011	12	0.750	2	0.125	0	0	2	0.125	16
2012	1	0.029	4	0.114	14	0.400	16	0.457	35
2013	11	0.333	10	0.303	4	0.121	8	0.242	33
2014	13	0.361	4	0.111	1	0.028	18	0.500	36
2015	24	0.300	20	0.250	15	0.188	21	0.263	80
2016	27	0.243	23	0.207	30	0.270	31	0.280	111
2017	7	0.121	7	0.121	16	0.276	28	0.483	58
2018	11	0.164	28	0.418	10	0.149	18	0.269	67
Total	132	0.258	118	0.231	102	0.2	159	0.311	511

In most years, the number of contaminating pest interceptions in spring or summer are larger than in autumn and winter. However, trying to explain this variation in terms of more than one variable at a time is not reliable because of the low number of interception events. The analysis above does not consider the variation in the number of consignments per year or per season. To understand the trade patterns of the tariff codes corresponding to incidents, the number of imports under each tariff code per season was investigated. There are 17 identified tariffs, but the largest number of imports are under tariff number 44071010 (Table 21).

Table 21. Number of imports by tariff code where contaminating pests have been found.

Tariff number	No. of imports per tariff code	Share of total (%)
44071010	41540	35
44071091	3991	3
44071099	18253	15
44071110	15639	13
44071199	3943	3
44071210	3291	3
44071991	784	0.7
44072200	467	0.4
44072510	5867	5
44072590	2253	2
44072910	5917	5
44072999	4160	4
44079110	329	0.3
44079190	3128	3
44079200	368	0.3
44079910	1888	1.5
44079999	6340	5

Information from Table 21 is plotted in Figure 31 where each dot corresponds to an import of the product, identified by the tariff code. The tariff code form the vertical axis in Figure 31; the majority of dots correspond to multiple imports. Cumulatively, over the 11 years, no seasonality is observed; neither do we see any seasonality within the year.

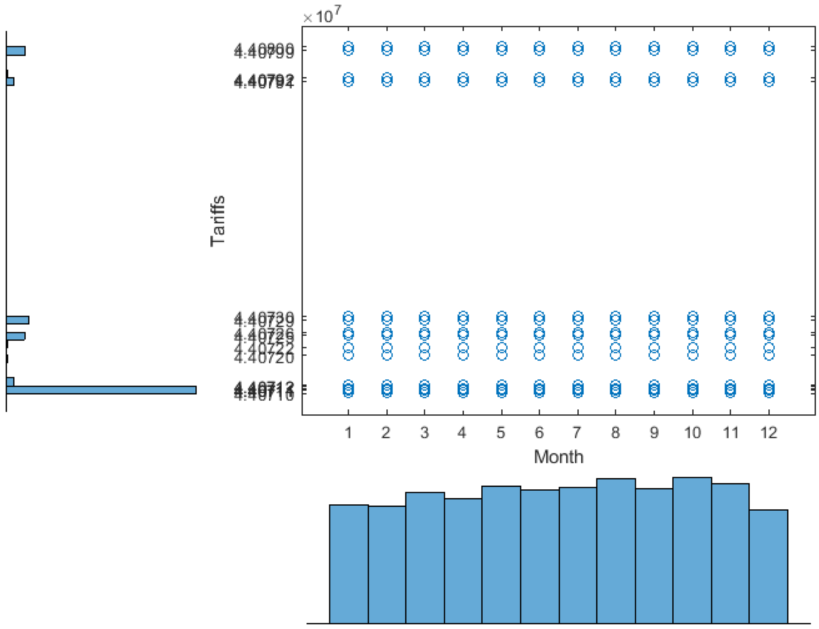

Figure 31. Imports count per month, 2008-2018.

Incidents of contaminating pest arrivals for 2016, the year with most data, are shown in Figure 32 as number of pests identified per month. The differing arrival rate during 2016, however, is not explained by a larger number of imports in that year.

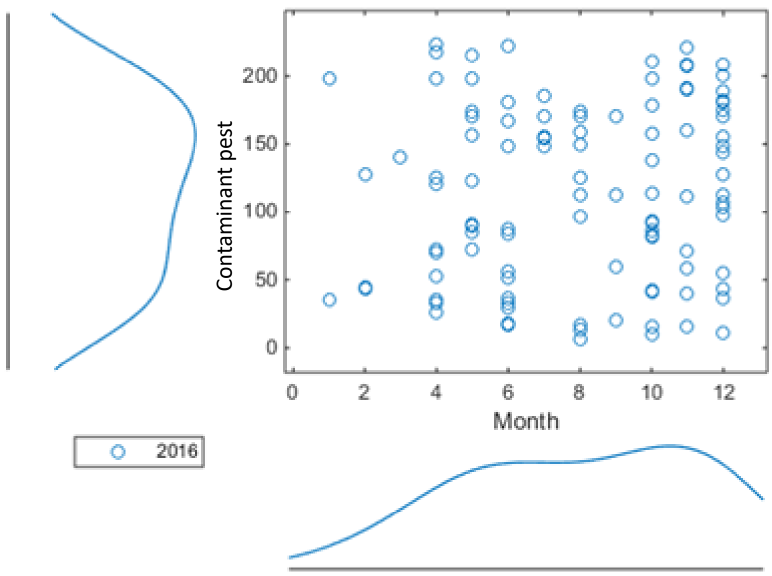

Figure 32. Contaminating pest count per month in 2016.

Table 22 shows a count of the tariff imports associated with incidents per year, with the year 2016 highlighted.

Table 22. Number of total imports per year of the 13 tariffs associated with recorded incidents.

Year	Number of total imports of the 13 tariff codes associated with recorded incidents
2008	9661
2009	8101
2010	9656
2011	9441
2012	9578
2013	11059
2014	11366
2015	11181
2016	10773
2017	11244
2018	16098

The split of imports per tariffs reveals 13 different tariff codes, with most imports corresponding to tariff number 44071010 (Table 23).

Table 23. Number of imports per tariff number (for tariff codes associated with incidents).

Tariff number	Number of of imports per tariff code	Share of total (%)
44071010	6095	57
44071091	454	4
44071099	1866	17
44072200	36	0.3
44072510	385	4
44072590	188	2
44072910	166	2
44072999	338	3
44079110	30	0.3
44079190	341	3
44079200	45	0.4
44079910	252	2
44079999	577	5

The trade pattern for 2016 for the above tariff codes listed above is not seasonal (Figure 33).

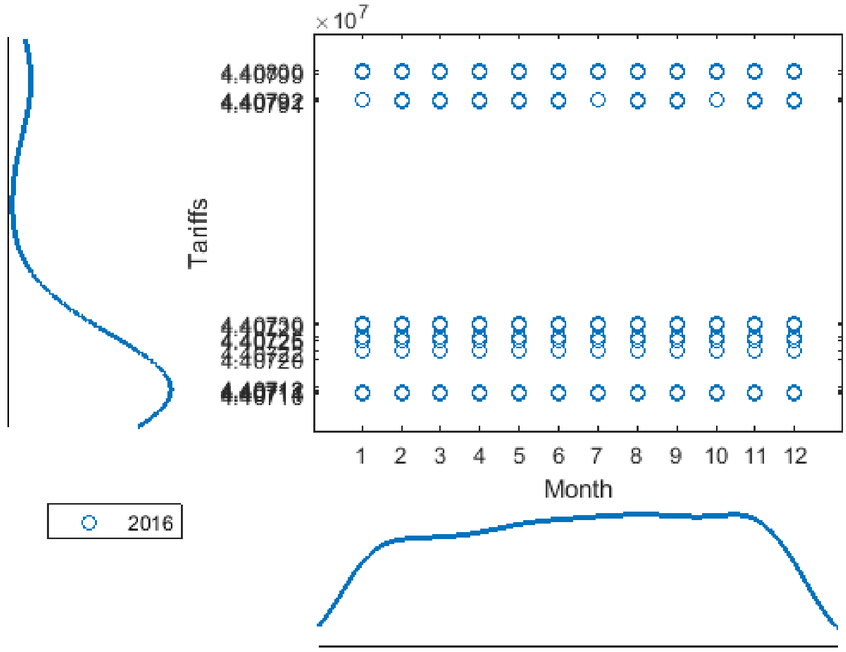

Figure 33. Imports count per month in 2016.

Notes: Each dot corresponds to imports identified by the tariff code. The tariff codes form the y-axis and the majority of dots correspond to multiple imports.

Further analysis of seasonality of contaminating pest arrivals was undertaken by isolating the number of arrivals per year, with two or three years plotted per panel (Figure 34).

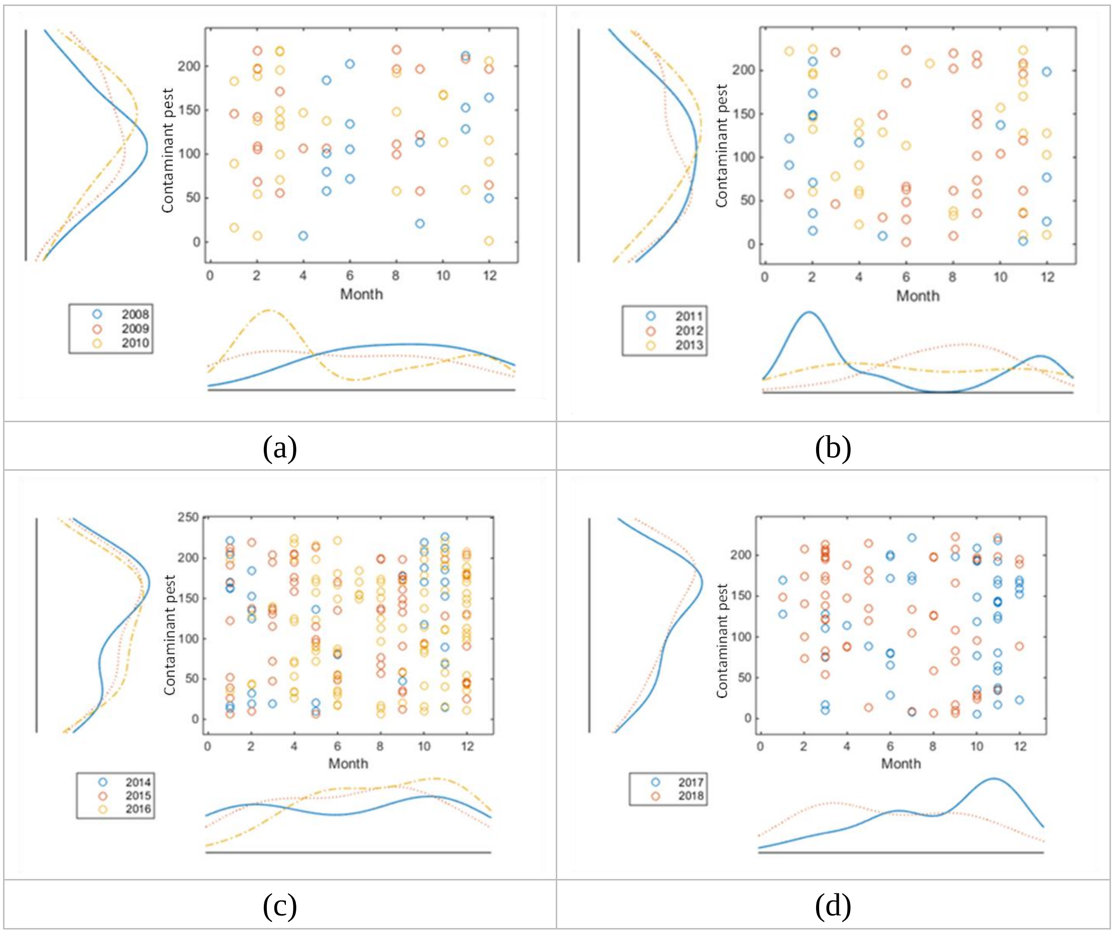

Figure 34. Contaminating pest count per month in 2008-2010 (panel a), 2011-2013 (panel b), 2014-2016 (panel c) and 2017-2018 (panel d).

While Figure 34 shows there is some increase in pest arrivals in 2009, 2010 and 2011 during summer and autumn, the seasonality during the other years is negligible. Interestingly, Table 24 suggests the number of imports per month for tariff codes associated with incidents over 2009 to 2011 shows no matching variation. This may indicate some seasonal patterns in contaminating pest arrivals.

Table 24. Cumulative number of imports in each month for tariff codes associated with incidents (2009 -2011, Australian summer and autumn months highlighted).

Month	Imports of the tariff codes associated with incidents
January	1985
February	2017
March	2388
April	2150
May	2280
June	2238
July	2301
August	2362
September	2384
October	2513
November	2513
December	2067

B.3. Contaminating pest analysis

B.3.1. Genus-species occurrences

Most contaminating pests identified to the species level occur fewer than 12 times in the 11 years dataset; for example, 134 of them occur once, 39 twice and 22 occur four times. Four different contaminating pests identified by the genus-species combination occur 13, 15, 18 and 25 times, respectively. The four panels in Figure 35 correspond to these four pests in increasing order of number of occurrences. All but one of these pests – the flat bark beetle (*Silvanus bidentatus*) in panel c – is classified as a hitchhiker pest by the department.

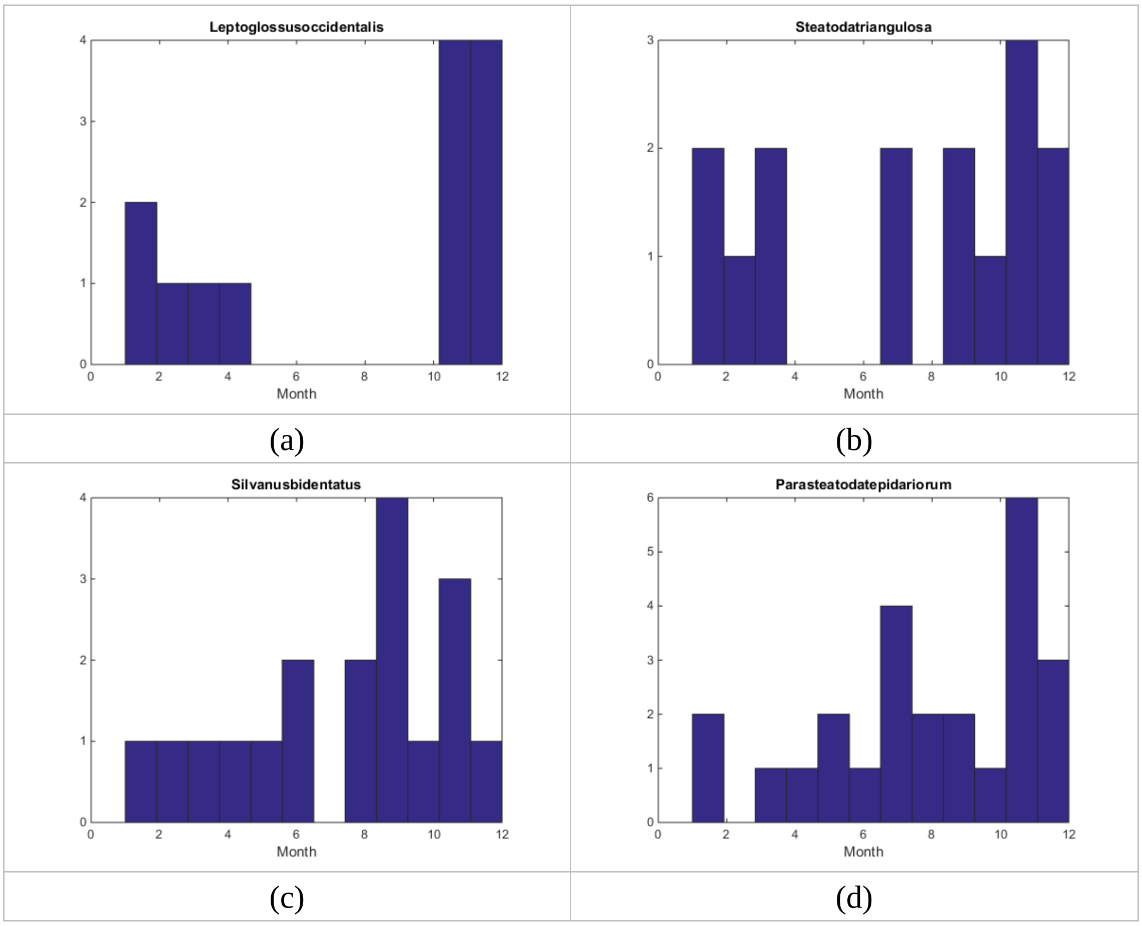

Figure 35. Occurrences by calendar month of the western conifer seed bug (*Leptoglossus occidentalis*) (N=13) (panel a), the triangulate cobweb spider (Steatoda triangulosa) (N=15) (panel b), the flat bark beetle (*Silvanus bidentatus*) (N=18) (panel c) and the common house spider (*Parasteatoda tepidariorum*) (N=25) (panel d).

B.3.2. Exporting country analysis

The Incident data were also analysed by exporting country. In total, 23 exporting countries were responsible for the contaminating pest arrivals (Figure 36). Most contaminating pest occurrences (267) came on consignments exported from Country 4.

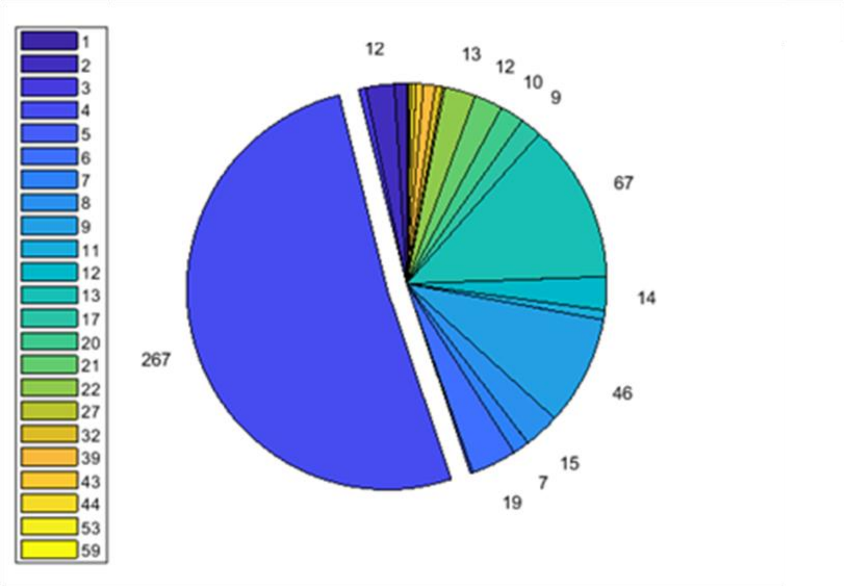

Figure 36. Distribution of contaminating pest occurrences by country of export.

Notes: The legend gives numerical identifiers for each exporting country. The numbers associated with the pie chart slices represent the number of contaminating pest occurrences per exporting country. If no number is associated with a given slice, it means that the number of contaminating pest occurrences is less than or equal to five.

Table 25 and Figure 37 present the number of exports per year and per season for Country 4. A seasonal pattern in exports pattern may be evident, with a slight increase in the number of incidents in spring.

Table 25. Number of exports per year per season for Country 4.

	Summer	Autumn	Winter	Spring
2008	164	238	218	141
2009	124	129	108	200
2010	163	162	100	119
2011	136	187	114	143
2012	96	124	134	147
2013	109	169	153	114
2014	108	96	147	130
2015	109	174	151	187
2016	132	161	190	202
2017	133	171	160	174
2018	127	198	237	163

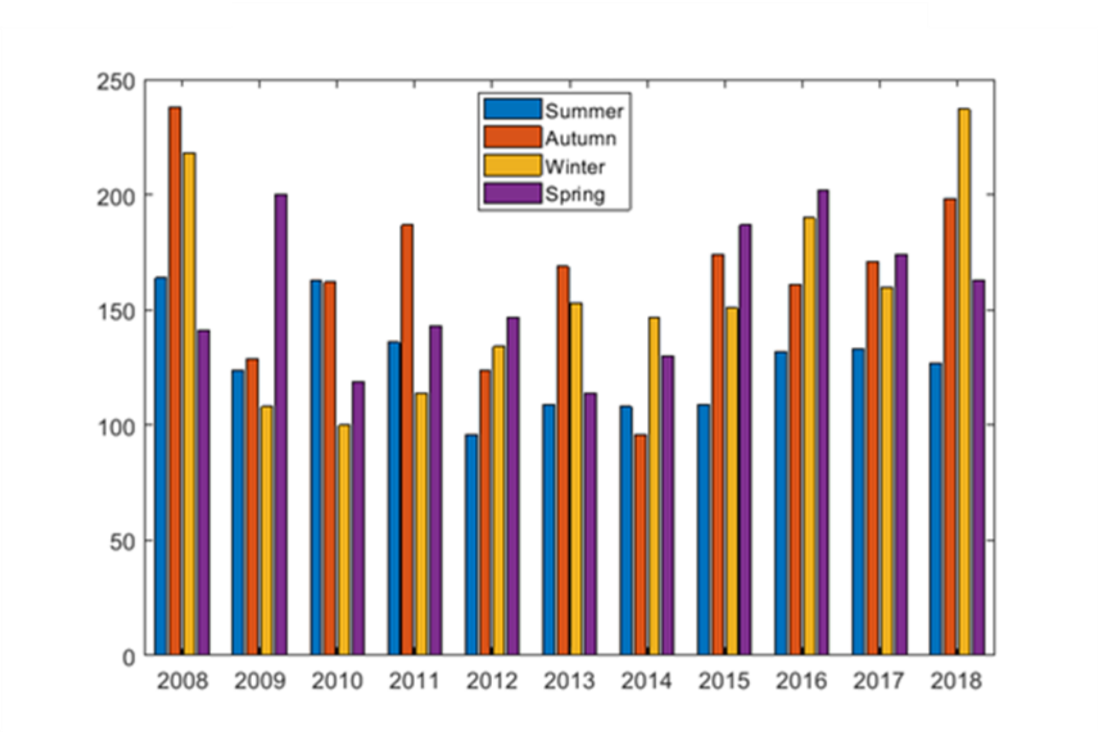

Figure 37. The number of exports per year per season for Country 4.

Figure 38 and Table 26 present the number of exports per year per season for all the countries with recorded incidents.

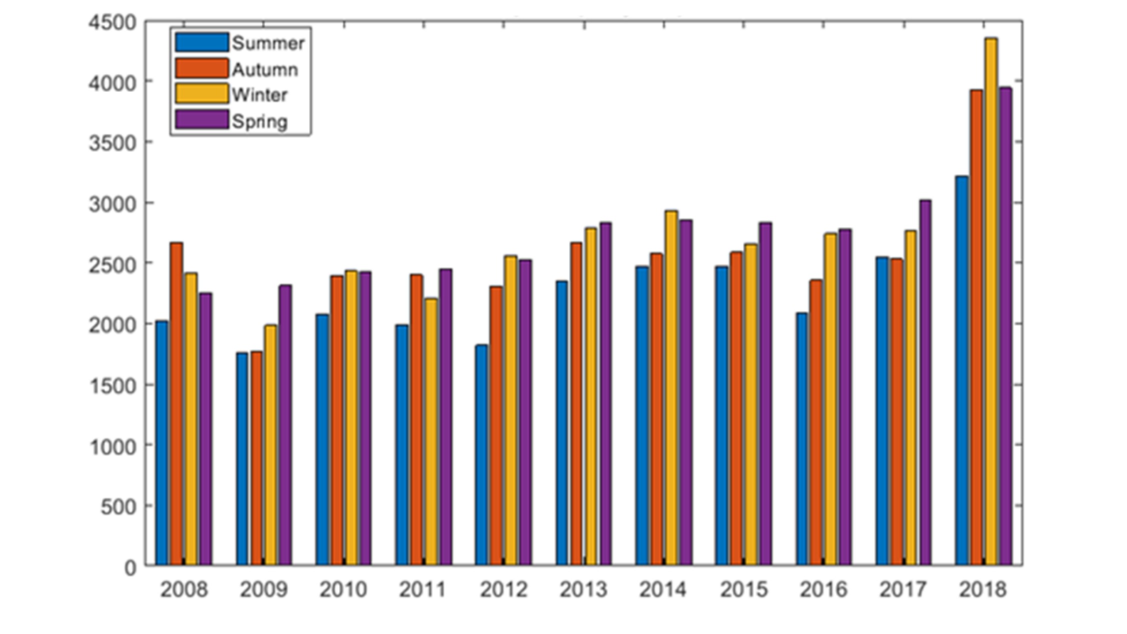

Figure 38. The number of exports per year per season for all countries with recorded incidents.

Table 26. The number of exports per year per season for all countries with recorded incidents.

	Summer	Autumn	Winter	Spring
2008	2024	2666	2411	2250
2009	1754	1770	1984	2312
2010	2080	2393	2431	2421
2011	1989	2399	2207	2449
2012	1819	2304	2559	2524
2013	2352	2668	2784	2831
2014	2467	2576	2933	2856
2015	2470	2586	2659	2834
2016	2085	2358	2740	2779
2017	2546	2530	2760	3019
2018	3219	3923	4354	3944

B.3.3. Contaminating pest occurrences of importer-supplier pairs

There are 119 unique pairs of importer–supplier combinations. Looking at the distribution of contaminating pest occurrences by importer–supplier pairs, the majority of such pairs are associated with fewer than 10 occurrences in the entire data set (that is less than 10 over the 11 years covered by the inspection data). There are 100 unique suppliers corresponding to these pairs. The most common one – supplier 104 – occurs in seven of the pairs shown in Figure 39. Importer–supplier pairs for which more than 10 incidents were recorded in the 11 years are included in Figure 39.

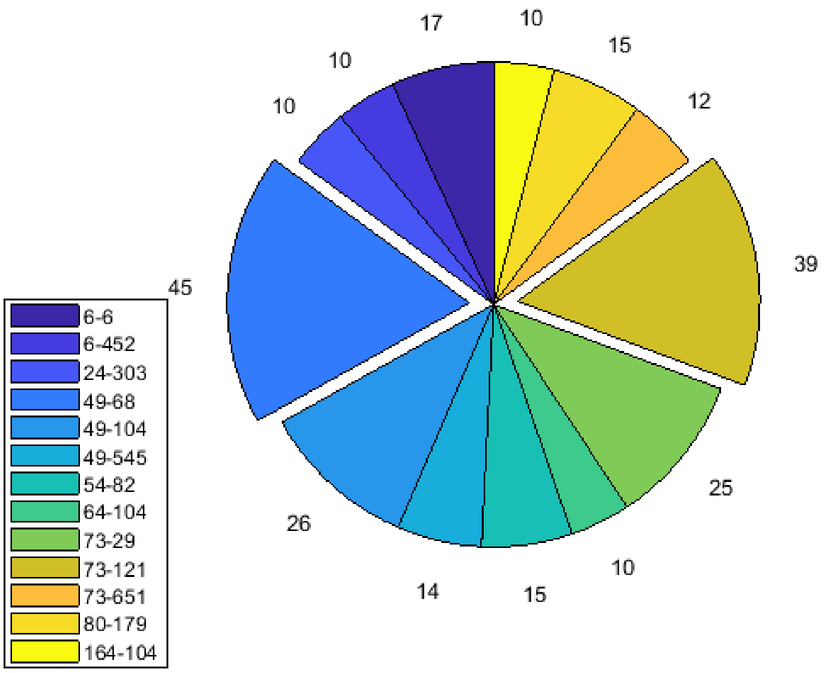

Figure 39. Distribution of contaminating pest occurrences per importer-supplier pair, for pairs with more than 10 recorded incidents.

Notes: The number of contaminating pest occurrences found per pair are listed next to each slice, and the legend corresponds to codes for the importers (first identifier) and suppliers (second identifier).

Importer-supplier combinations that appear to have consistently different contaminating pest counts were identified by fitting a generalised linear mixed effects model with importer and supplier main effects and an interaction term. If the interaction term was statistically significant, then combinations that seem different may be important.

Because the importer–supplier counts are calculated from the entire dataset, the number of incidents per year may reflect sampling fluctuations. The distribution of the 45 contaminating pest occurrences for the importer–supplier pair 49-104 – the pair with the largest count in Figure 39 – is shown in Figure 40.

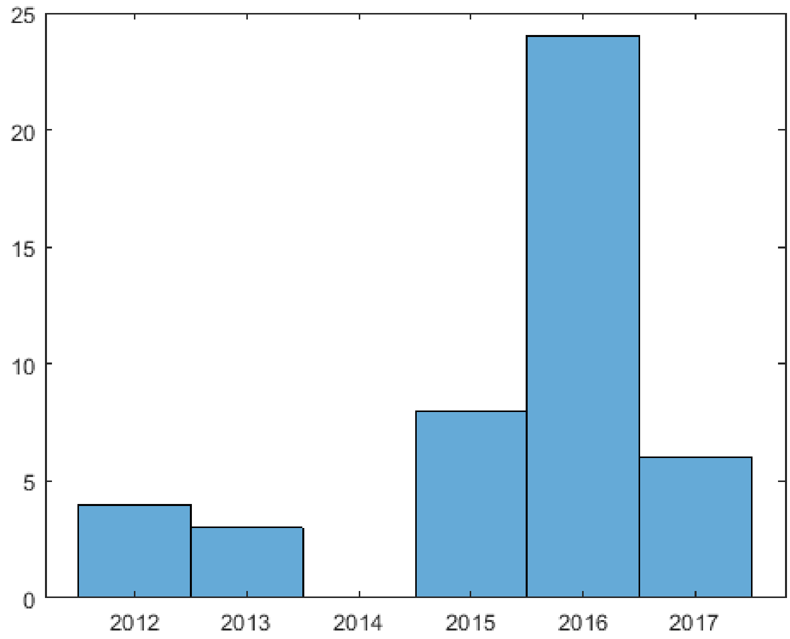

Figure 40. Distribution of the 45 contaminating pest occurrences per year for the importer-supplier pair 49-104.

Appendix C: Computing Markov chain stationary distributions for CSP algorithms

C.1. Representation of transition matrices

Modelling the CSP-1 and CSP-3 algorithms as Markov chains and using their stationary distributions to inform key measures of trade-offs associated with these rules requires specifying the *transition matrices* for the respective chains. These square matrices summarise how the Markov chain evolves from the previous state, represented in the rows of the matrix, to the current state, shown in the columns of the matrix. Each row represents the conditional probability distribution from moving to the previous state to the current state in the Markov chain and therefore sums to one. In subsequent parts of this appendix, we document the transition matrices for the CSP-1 and CSP-3 algorithms.

The *stationary distribution* of the Markov chain is defined as the probability distribution, represented by a row vector π, that satisfies:

$$\pi P = \pi,$$

where P is the Markov chain's transition matrix.[53] This means the marginal distribution of states remains the same when the Markov chain is "moved forward" one step when starting with the Markov chain's stationary distribution. Equivalently, this condition for the stationary distribution can be represented as:

$$\pi(P - I) = 0.$$

From a computational perspective, tools from linear algebra can be used to solve for the stationary distribution, in that the stationary distribution is the *left eigenvector*, whose elements are scaled to sum to one,[54] associated with the *(left) eigenvalue* one for the matrix P.

For computational ease, we will instead compute the eigen decomposition of the transpose of P, given this allows us to use in-built functions for computing *right* eigenvalues and eigenvectors in popular software packages. There is no loss in generality in using this approach, albeit that π is instead a column vector, and this approach is shown in the MATLAB code at the end of this appendix.

Because it is possible to get from any state to any other state in the Markov chains for the CSP-1 and CSP-3 algorithms when the probability of failing inspection is strictly between zero and one, the stationary distribution will be unique and always exists.[55]

[53] For more information about Markov chains and their properties, see Grimmett and Stirzaker (2001).

[54] As the stationary distribution is a (proper) probability distribution, the elements of column vector must add to one.

[55] More formally, these properties follow from all states in the Markov chain being *irreducible* and *positive recurrent*.

C.1.1. CSP-1 algorithm

For the CSP-1 algorithm, representing the time-homogeneous[56] Markov chain is relatively straightforward as a (*CN*+1)×(*CN*+1) transition matrix. If an importer has previously passed between 0 and *CN*-1 consecutive inspection, the probability of failing inspection (denoted p) is also the probability of returning to the state with zero passes; consequently, the probability of increasing the number of consecutive passes by one is 1-*p*.

Once *CN* consecutive passes have been reached and the importer attains monitoring mode, the probability of being inspected falls to *MF*. Assuming the events of a line[57] being selected for inspection and a line having attributes meaning it would fail an inspection are independent, the probability of returning to census mode and having to requalify for monitoring mode is *p.MF*. In turn, this means the probability of remaining in monitoring mode through either not being inspected or passing an inspection is 1-*p.MF*.

Combining these aspects of the rule results in a transition matrix for the Markov chain given by:

$$P(p) = \begin{bmatrix} p & 1-p & 0 & \cdots & 0 & 0 \\ p & 0 & 1-p & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots & \vdots \\ p & \vdots & \cdots & 0 & 1-p & 0 \\ p.MF & 0 & \cdots & \cdots & 0 & 1-p.MF \end{bmatrix}$$

$$\underbrace{\hspace{12em}}_{CN}$$

Using the other assumptions described in Chapter 4, one can use components of the stationary distribution, π, to obtain the key performance measures for the algorithm for a given approach rate. In particular:

- the modelled long-run proportion of saved inspections is
  $$(1-MF).\pi_{CN+1},$$
  where π_j is the jth element of the stationary distribution vector; and
- the modelled long-run post-intervention non-compliance rate is
  $$q.(1-MF).\pi_{CN+1},$$
  where q is the quarantine failure rate. This would the same as p if the rule uses the quarantine failure concept to define failing inspection; however, it could be lower than p if the CSP-1 algorithm adopts inspection failure for determining what constitutes a failure for the CBIS rule.

[56] As discussed in Chapter 4, this assumes there is a constant probability of failing inspection over time and in each state of the Markov chain.

[57] As discussed in Chapter 4, this modelling approach assumes CBIS is applied at the AIMS line level, rather than the AIMS quarantine entry level. This modelling approach would only be appropriate were CBIS applied at the quarantine entry level if it were assumed that the number of eligible lines per consignment were constant. This is because if the number of eligible lines per consignment were to change, the probability of at least one line in a consignment failing would also change.

C.1.2. CSP-3 algorithm

The CSP-3 algorithm's transition matrix is significantly more involved, reflecting the tight census and failure detection modes. A (2.*CN*+1)×(2.*CN*+1) matrix is required to represent the transition between states in the Markov chain, in part because the CSP-3 algorithm requires counting the number of inspections passed since the last failure.

In tight census mode, the state transitions mirror that for census mode until *TC* consecutive inspections are passed. Failing inspection during this phase means the algorithm returns to the start of census mode.

In failure detection mode, three possible transitions need to be accounted for, namely:

- a line is not selected for inspection, which has probability 1-*MF*. This means the Markov chain remains in the same state as the previous state;
- a line is selected for inspection and passes, which has probability (1-*p*).*MF*. In this situation, the algorithm moves forward by one state if this inspection pass is less than *CN* since the last failure, or moves to monitoring mode – the state labelled *CN*+1 in this representation of the algorithm – if this inspection pass is *CN* since the last failure; and
- a line is selected for inspection and fails, which has probability *p.MF*. This moves the algorithm back to census mode where *CN* consecutive passes are required to reach monitoring mode.

Taken together, this implies a transition matrix structure given by:

$$P = \begin{bmatrix} p & 1-p & 0 & \cdots & 0 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & 0 \\ p & 0 & 1-p & \cdots & 0 & 0 & \vdots & \vdots & \cdots & \cdots & \cdots & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ p & 0 & \cdots & 0 & 1-p & 0 & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & 0 & \cdots & \cdots & 0 & 1-p.MF & p.MF & 0 & \cdots & \cdots & \cdots & \cdots & \vdots \\ p & 0 & \cdots & \cdots & \cdots & \cdots & 0 & 1-p & \cdots & \cdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \ddots & \ddots & \cdots & \cdots & \cdots & \vdots \\ p & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 1-p & \cdots & \cdots & \vdots \\ p.MF & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 1-MF & (1-p).MF & 0 & \vdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \ddots & \ddots & \ddots & \ddots \\ p.MF & 0 & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & 0 & 1-MF & (1-p).MF \\ p.MF & 0 & \cdots & \cdots & 0 & (1-p).MF & 0 & \cdots & \cdots & \cdots & \cdots & 0 & p.MF \end{bmatrix}$$

$$\underbrace{\qquad\qquad\qquad\qquad}_{CN} \qquad\qquad \underbrace{\qquad\qquad\qquad}_{TC} \qquad \underbrace{\qquad\qquad\qquad\qquad}_{CN-TC}$$

The key performance measures for the algorithm based on the stationary distribution for a given value of *p* can then be computed as follows.

- The modelled long-run proportion of saved inspections is given by:
  $$(1-MF).\left[\pi_{CN+1} + \sum_{j=CN+TC+2}^{2.CN+1} \pi_j\right],$$
  where π_j is the j^{th} element of the stationary distribution vector.
- The modelled long-run post-intervention non-compliance rate is given by:
  $$q.(1-MF).\left[\pi_{CN+1} + \sum_{j=CN+TC+2}^{2.CN+1} \pi_j\right],$$
  where *q* is the quarantine failure rate.

C.1.3. Extending the CSP-1 algorithm representation to account for inspection decision-errors

We can adapt the transition matrix shown earlier in this appendix for the situation where inspection is effective only *100.(1-δ)* per cent of the time in detecting biosecurity risk material in a line where it is present. This approach therefore accounts for a type II error in the inspection process.[58] Similar to previous formulations of the transition matrix, the concept that define "failing inspection" can be either an inspection failure or a quarantine failure (i.e. where *p* equals *q*).

In this case, the transition matrix is given by:

$$P^*(p^*) = \begin{bmatrix} p^*(1-\delta) & 1-p^*(1-\delta) & 0 & \cdots & 0 & 0 \\ p^*(1-\delta) & 0 & 1-p^*(1-\delta) & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots & \vdots \\ p^*(1-\delta) & \vdots & \cdots & 0 & 1-p^*(1-\delta) & 0 \\ p^*(1-\delta).MF & 0 & \cdots & \cdots & 0 & 1-p^*(1-\delta).MF \end{bmatrix}$$

This mirror the transition matrix shown in Appendix C.1.1 with *p* replaced by *p*(1-δ)* such that *P(p(1-δ)) = P*(p*)*. The long-run post-intervention non-compliance rate can be expressed as:

$$q^*\delta.\left[\sum_{j=1}^{CN} \pi^*{}_j + \mathrm{MF}.\pi^*{}_{CN+1}\right] + q^*.(1-MF).\pi^*{}_{CN+1}$$
$$= q^*[\delta + (1-\delta)(1-MF)\pi^*{}_{CN+1}(q^*)],$$ [59]

where q^* is the quarantine failure rate associated with the pre-intervention approach rate p^* and $\pi*$ is the stationary distribution associated with the transition matrix P^*. This means the difference between post-intervention non-compliance rates under the CSP-1 algorithm and a mandatory inspection regime is:

$$q^*(1-\delta)(1-MF)\pi^*{}_{CN+1}(q^*),$$

since the long-run rate of leakage under a mandatory inspection regime is $q^*\delta$.

Because of the equivalence of the transition matrices demonstrated above and the retention of thinning assumptions, it can be shown using change of variable techniques that:

$$\arg\max q^*(1-\delta)(1-MF)\pi^*{}_{CN+1}(q^*) = \frac{1}{1-\delta}\, arg\, max\, q(1-MF)\pi_{CN+1}(q), \text{ and}$$

$$\max q^*(1-\delta)(1-MF)\pi^*{}_{CN+1}(q^*) = max\, q(1-MF)\pi_{CN+1}(q),$$

with π is the stationary distribution associated with the transition matrix P from Appendix C.1.1. This means the maximum difference in post-intervention leakage between a mandatory inspection regime and a candidate CSP algorithm is the same

[58] As highlighted in Rossiter and Hester (2017), a type I error represents an inspection failure (i.e. an "inspection not okay" finding) that would not be a quarantine failure. In these circumstances, an inspector would find material in a line that could be biosecurity risk material but later proves not to be actionable after follow-up investigation. This decision error mainly impacts importers' biosecurity-related costs and does not affect the key metrics for the department described in Chapter 4.

[59] If inspections are "perfect" (i.e. δ=0), the long-run post-intervention non-compliance rate simplifies to $q.(1-MF).\pi_{CN+1}$ – the formula reported in Appendix C.1.1.

under “perfect” inspections and when there are type II decision-errors. Furthermore, relative to the “perfect” inspection case, this maximum under inspections with decision-errors occurs at a pre-intervention approach rate a factor of $1/(1-\delta)$ times larger than the “perfect” inspection case.

In Chapter 4.4.4, we illustrate the above results using a numerical example.

C.2. MATLAB code implementation

The function coded in MATLAB below shows how to implement the grid-based assessment of key characteristics of the Markov chain stationary distributions for the CSP-1 and CSP-3 algorithms. Note that this code makes the simplifying assumption that the tight census number, *TC*, for the CSP-3 algorithm is set to four, consistent with the original Dodge and Torrey (1951) formulation of the rule.

```
function [avoidinsp, aoq, aoqlimit] = CSPsolve(rule, probgrid, CNvec,
MFvec)

% Provides a circuit through which the CSP-1 and CSP-3 algorithms
% (where CSP-3 has usual four mandatory inspections following a
failure in
% monitoring mode) to assess the curves of avoided inspections,
% average outgoing quality and the AOQ limit for different CN and MF
% combinations specified by CNvec and MFvec
% Rule specified by rule = 1 or 3
% Outcomes assessed based on probability grid generated by probgrid

% Outputs:
% avoidinsp - the percentage of the time in the long run where an
importer
% with approach rate will avoid inspection
% aoq - the average outgoing quality (percentage defective) based on
the
% percentage failing that get through monitoring mode
% aoqlimit - the maximum value of the average outgoing quality
according to
% the estimated grid (probgrid)

% Inputs:
% rule - 1 or 3 (to denote CSP rule variant)
% CNvec - vector of clearance number required to revert to monitoring
mode
% MFvec - vector of monitoring fraction parameters in monitoring mode

% Set up storage for outputs

% Avoided inspection matrix
avoidinsp = zeros(length(probgrid) + 2, length(CNvec) * length(MFvec)
+ 1);
% Set up row and column designations
% Row headers are probabilities
avoidinsp(3 : length(probgrid) + 2, 1) = probgrid;
% First column headers are clearance numbers
% Second column headers are monitoring fractions
avoidinsp(1, 2 : (length(CNvec) * length(MFvec) + 1)) = ...
    repelem(CNvec,length(MFvec));
avoidinsp(2, 2 : (length(CNvec) * length(MFvec) + 1)) = ...
    repmat(MFvec,1,length(CNvec));
```

```
% aoq matrix is the same dimensions and setup as the avoidinsp matrix
aoq = avoidinsp;

% aoqlimit matrix only has the maximum values from each column of the
% aoq matrix
aoqlimit = aoq(1:3, 2 : (length(CNvec) * length(MFvec) + 1));

% Conduct loop to get the properties for each part of the grid
for i = 1 : length(probgrid)
    for j = 1 : length(CNvec)
        for k = 1 : length(MFvec)
            if rule == 1
                transmat = zeros(CNvec(1,j) + 1);
                % In enhanced inspection mode, if fail return to
state with zero
                % successes; otherwise, continue until react CN
successes in a row
                transmat(1:CNvec(1,j), 1) = probgrid(1,i);
                transmat(1:CNvec(1,j), 2:(CNvec(1,j)+1)) =
eye(CNvec(1,j)) * (1 - probgrid(1,i));
                % In monitoring mode, stay in mode if goods not
inspected OR pass
                % inspection when inspected; revert back to 100%
inspection when a failure
                % is discovered when inspected
                transmat(CNvec(1,j)+1, CNvec(1,j)+1) = 1 - MFvec(1,k)
* probgrid(1,i);
                transmat(CNvec(1,j)+1, 1) = MFvec(1,k) *
probgrid(1,i);
            elseif rule == 3
                transmat = zeros(2 * CNvec(1,j) + 1);
                % In enhanced inspection mode, if fail return to
state with zero
                % successes; otherwise, continue until react CN
successes in a row
                transmat(1:CNvec(1,j), 1) = probgrid(1,i);
                transmat(1:CNvec(1,j), 2:(CNvec(1,j)+1)) =
eye(CNvec(1,j)) * (1 - probgrid(1,i));
                % In monitoring mode, stay in mode if goods not
inspected OR pass
                % inspection when inspected; revert back to 100%
inspection when a failure
                % is discovered when inspected
                transmat(CNvec(1,j)+1, CNvec(1,j)+1) = 1 - MFvec(1,k)
* probgrid(1,i);
                transmat(CNvec(1,j)+1, CNvec(1,j)+2) = MFvec(1,k) *
probgrid(1,i);
                % On failing go into tight census mode for next four
inspections
                transmat((CNvec(1,j)+2):(CNvec(1,j)+5),1) =
probgrid(1,i);

transmat((CNvec(1,j)+2):(CNvec(1,j)+5),(CNvec(1,j)+3):(CNvec(1,j)+6))
= ...
                    eye(4) * (1 - probgrid(1,i));
                % If no failures in next four, go into enhanced
monitoring
                % mode
                % Failing with CN inspections from previous failure
turns
```

```
                % back to start of algorithm
                transmat((CNvec(1,j)+6):(2*CNvec(1,j)+1),1) =
MFvec(1,k) * probgrid(1,i);
                % Advanced with successful inspection and returning
to
                % monitoring mode once pass CN consecutive
inspections
                if CNvec(1,j) > 5

transmat((CNvec(1,j)+6):(2*CNvec(1,j)),(CNvec(1,j)+7):(2*CNvec(1,j)+1
)) = ...

transmat((CNvec(1,j)+6):(2*CNvec(1,j)),(CNvec(1,j)+7):(2*CNvec(1,j)+1
)) + ...
                        eye(CNvec(1,j)-5)*MFvec(1,k) * (1 -
probgrid(1,i));
                end
                transmat(2*CNvec(1,j)+1, CNvec(1,j)+1) = MFvec(1,k) *
(1 - probgrid(1,i));
                % Remain at same point in algorithm if inspection not
                % performed

transmat((CNvec(1,j)+6):(2*CNvec(1,j)+1),(CNvec(1,j)+6):(2*CNvec(1,j)
+1)) = ...

transmat((CNvec(1,j)+6):(2*CNvec(1,j)+1),(CNvec(1,j)+6):(2*CNvec(1,j)
+1)) + ...
                    eye(CNvec(1,j)-4)*(1 - MFvec(1,k));
            end
            % Define the stationary distribution - calculate via
right eigenvector and
            % then transpose as required
            [V, D] = eig(transmat');
            [~, ind] = min(abs(diag(D)-1));
            statdist = V(:,ind) ./ sum(V(:,ind));
            % Compute desired metrics from vector
            if rule == 1
                % Saved inspections
                avoidinsp(2 + i, (j-1) * length(MFvec) + k + 1) = ...
                    statdist(CNvec(1,j)+1, 1) * (1 - MFvec(1,k));
                % Amount of leakage
                aoq(2 + i, (j-1) * length(MFvec) + k + 1) = ...
                    statdist(CNvec(1,j)+1, 1) * (1 - MFvec(1,k)) *
probgrid(1,i);
            elseif rule == 3
                % Saved inspections
                avoidinsp(2 + i, (j-1) * length(MFvec) + k + 1) = ...
                    (statdist(CNvec(1,j)+1,1) + ...
                    sum(statdist((CNvec(1,j)+6):(2*CNvec(1,j)+1)))) *
...
                    (1 - MFvec(1,k));
                % Amount of leakage
                aoq(2 + i, (j-1) * length(MFvec) + k + 1) = ...
                    (statdist(CNvec(1,j)+1,1) + ...
                    sum(statdist((CNvec(1,j)+6):(2*CNvec(1,j)+1)))) *
...
                    (1 - MFvec(1,k)) * probgrid(1,i);
            end
        end
    end
end
```

```
% AOQ limit calculation
aoqlimit(3,:) = max(aoq(3 : (length(probgrid)+2), 2 : (length(CNvec)
* length(MFvec) + 1)));
```

Appendix D: Pre-border phytosanitary measures

Table 27. Examples of Phytosanitary Measures applied on an export pathway (Source: PIO 2017).

Measure*	Description and objective	Stage	Verification
Pest free propagation material and production inputs	Testing and/or treatment of propagation material and production inputs (e.g. growing media and fertiliser) to verify freedom of pests.	Production	Verification of testing/treatment procedures and records.
Hygiene and sanitation	Practicing good sanitation and hygiene will help prevent the entry and movement of pests into the production and transport chain.	Production, harvest, grading and packing	Verification of procedures and records
Management of alternative hosts	Treatment and/or destruction of alternative host plants (commercial, domestic and wild) to minimise potential pest reservoirs.	Production	Verification of orchard records (including visual observation of orchards)
Rotation of crops	Applicable only to annual crops where available production sites are extensive. May serve to slow the build-up of pest pressure in production areas. Difficult to integrate in a SA.	Production	Verification of orchard records
Production timing	Production may coincide with periods of low pest prevalence (e.g. during winter or where host availability has been limited).	Production, harvest, postharvest	Verification through agreed production and export periods based on pest biology/ecology. Ongoing verification through monitoring pest populations.
Physical pest exclusion	Pest exclusion through physical protection of plants. Examples include bagging of fruit and enclosed production systems such as glasshouses and screen houses.	Production, harvest	Verification through certification and visual observation at production sites.
In-field chemical treatments	Application of sprays to hosts (targets and alternatives) to manage pest. Dependent on availability of chemicals for this application and is well suited to managing high pest pressures.	Production	Verification through ongoing monitoring and orchard records.
Biological control	The release of large numbers of parasitoids, pathogens and predators may suppress pest populations,	Production, harvest, grading, packing	Verification through pest monitoring activities
Segregation and safeguarding of product	Certified/compliant product clearly segregated from non-certified/compliant product and safeguarded to prevent re-infestation.	Harvest, postharvest	Verification through monitoring and auditing procedures and records.

Measure	Description and objective	Stage	Verification
Irradiation	Physical treatment that can be used on a broad spectrum or targeted basis.	Pre-export	Verification through treatment certification processes, auditing procedures and monitoring treatment records.
Cold disinfestation	Physical treatment to meet agreed levels of phytosanitary protection. The rigor of the treatment will depend on the level of pest risk reduction achieved by other measures of the system.	Pre-export, during export	Verification through treatment chamber certification processes, auditing procedures and monitoring treatment records.
Heat treatment	Physical treatment to meet agreed levels of phytosanitary protection. The rigor of the treatment will depend on the level of pest risk reduction achieved by other measures of the system. Typically conducted prior to packing.	Pre-export	Verification through treatment chamber certification processes, auditing procedures and monitoring treatment records.
Chemical disinfestation	Post-harvest dips, sprays and fumigation treatments. The rigor of the treatment will depend on the level of pest risk reduction achieved by other measures of the system. In the case of dips and sprays the treatment is generally conducted prior to packing. Fumigation may be conducted before or following packing.	Postharvest, Pre-export	Verification through treatment chamber/dip tank/spray equipment certification processes, auditing procedures and monitoring treatment records.
Testing	Sampling and testing for freedom from a pest (or to an agreed tolerance). Can be useful for pests that are visually hard to detect/identify.		
Inspection and reconciliation	Can be used as a risk reduction measure as well as a verification activity.	Production, harvest, postharvest, pre-export	Verification through auditing procedures and records as well as inspection at the border.
Pest free area or place of production	Establishing a pest free area of place of production.	Production site	Verification through, auditing systems in place to establish, maintain and verify freedom and monitoring of survey records.
Processing	Processing removes/reduces pest risk. e.g. cooking, pressurised air to dislodge pests on fruit, washing processes	Pre-export	Verification through auditing arrangements and processing procedures.

Notes: * Host specificity and varietal differences have also been identified as important measures.