NATIONAL PLANT PEST REFERENCE COLLECTIONS STRATEGY

2018

Ensuring biological collections support trade and biosecurity

Acknowledgements

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Subcommittee on Plant Health Diagnostics

The Subcommittee on Plant Health Diagnostics (SPHD) aims to sustain and improve the quality and reliability of plant pest diagnostics in Australia. SPHD achieves this by:

- coordinating the development of National Diagnostic Protocols for priority plant pests
- developing and implementing the National Plant Biosecurity Diagnostic Strategy within the framework of the National Plant Biosecurity Strategy and the Intergovernmental Agreement on Biosecurity
- coordinating the National Plant Biosecurity Diagnostic Network
- assisting the development of diagnostic tools and material
- facilitating and coordinating the delivery of training to diagnosticians
- facilitating the progression of laboratory accreditation and proficiency testing.

SPHD is a subcommittee of Plant Health Committee and includes representation from the Australian, state and territory governments, PHA, Plant Biosecurity CRC, CSIRO and the New Zealand Ministry of Primary Industries.

Cover image: Specimen draws (Lepidoptera) in the Australian National Insect Collection (ANIC)

Back cover image: Pinned ant specimens (CSIRO)

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Australian Government

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Plant Health AUSTRALIA

Examining specimens of fungi at the Australian National Herbarium (ANBG) collection in Canberra. Many biodiversity collections like ANBG hold material essential for plant health diagnostics. Image courtesy of Sue Pederick.

Introduction

The strategy

Biological collections are an essential part of the plant health system, facilitating plant product exports, underpinning emergency incursion responses, and ensuring exotic pests on imports do not damage local producers or the environment. This National Plant Pest Reference Collections Strategy (NPPRCS) strategy will ensure that biological collections can continue to support Australia's trade and biosecurity.

The strategy recommends a diverse, dispersed system of reference collections with a similar diverse, dispersed system of information management and transfer. This type of organisation has advantages over other ways of monitoring and organising complex networks. Systems like this are efficient, using minimum resources to deliver optimum results. They are speedy, able to maximise the rate of throughput. And they are responsive, able to change rapidly as conditions and demands change. All of these characteristics are especially important as trade and biosecurity become huge activities in a globalising world, that is rapidly changing and evolving, but often with limited resources.

Many organisations, including postal services, medical testing, diagnosis and treatment, and product retailers like Amazon™ or Walmart™ are now adopting this form of organisation and information architecture. It is already being used in national defence, but is a new way of organising biosecurity and defence against plant pests, offering great benefits for the efficient management and resilience of collections and plant health diagnostics more generally.

Diverse, dispersed collections and information management systems allow many different types of material and information to be brought together to solve a problem. They can also operate on different levels of organisation, for example, information on where and when a single specimen was collected, information on all the material in a collection, information on the contact details for all collections in Australia, or information on all material held in all Australian collections. Diverse, dispersed systems have many advantages, but they require coordination at a high level. This strategy outlines the form such coordination should take.

Unlike a lot of reviews and strategies for reference collections, both past and present, this strategy is deliberately outward looking. It actively sought input from outside the collections community, asking what collections can and should deliver for trade and biosecurity. It also asked what collections need to be able to do this, and how they should be arranged and supported to achieve the best outcomes for trade, biosecurity and plant health. This contrasts with traditional approaches which have simply asked collection managers what collections need.

The current state of collections

The current state of collections and whether they include Australia's National Priority Plant Pests (NPPPs) has recently been surveyed extensively (Hodda *et al.* 2017b). The survey found that there were no verified specimens of many of the NPPPs, which will become a major issue should there be suspected or actual incursions of any of these pests. **Recommendation 1** explicitly addresses this identified gap.

Specimens of some NPPPs are held in at least one collection, although not necessarily the right one. Identifying and locating different collections would also add value to existing collection assets. Overall, coordination of the plant health, trade and biosecurity functions of collections could be better, and this point is addressed in **Recommendation 2** of this strategy.

Prevention of specimen deterioration and obtaining the right level of support were also identified as issues. Clear standards are needed for collections to address these issues, as outlined in **Recommendation 3**.

Improving the exchange of information between collections, and enhancing communication between collections and other parts of the plant health diagnostic system were other issues identified. These are addressed in **Recommendations 4, 5** and **6** of the strategy.

The survey of collection holders highlighted that many of the issues identified are long-standing, recognised in earlier surveys going back 20 years or more, with little improvement evident (Howie 2006, 2012, Miller & Moran 1996, Moran & Muirhead 2002, Rodoni & Geering 2006). This strategy recommends that collections be valued, so that the losses and deterioration that occur if these issues are not addressed are recognised, and preventative action can be taken or the costs of inaction identified.

Support for collections is also a long-standing issue, which is recognised as a structural problem by other analyses of the system, and is addressed in the current strategy.

What's in collections

Material

Collections do not just contain dead specimens: a variety of materials supporting trade and the biosecurity system is stored within them. Collections include not only physical specimens of plant pests and their local relatives or lookalikes, but also the information on where, when and how they were collected. The specimens may be whole or partial organisms (e.g. DNA or proteins), or even virtual specimens (e.g. images or 3-dimensional reconstructions). Collections may also hold taxonomic literature which is specialised and not available elsewhere, or old identification keys which are the most comprehensive available and therefore still widely used. Frequently, collections house historical pest records as well.

Information and linkages

All of the different materials in a collection may be linked. For example, a type specimen that defines the typical individual of a species may be associated in the collection with all the variant forms and the closely related but distinct species from which it is taxonomically distinguished. Verifiable historical records detailing changes in distribution may also exist. The linkages add further value and, together with the physical specimens and information, constitute the total collection resource for a particular pest.

Combination of material

For a particular pest, a collection may hold one or multiple types of material. Within a collection, the combination of materials may vary for each pest. The type of material held may vary between collections according to the facilities available, or it may reflect particular industries, pests and stakeholders that particular collection serve.

The needs for different types of collection material will also vary among pests and situations. All types of material held by collections are potentially important, and therefore should be considered as distinct parts of the overall resources in a collection. In this strategy, collections are considered to consist of specimens, parts of specimens, DNA, information about specimens or species occurrence, and the linkages between them.

Images right show some of the types of materials stored in collections (from top): 1, Dried, pinned morphological specimen of the beetle *Notomus montorum* *(ANIC, CSIRO);*
2, genetic material stored at -80 °C (ANIC, CSIRO);
3, microscope slide mounted historic material (Agriculture Victoria);
4, freeze-dried living fungal specimens (Agriculture Victoria)

The environment for collections

Collections within plant health diagnostics

Collections are one part of the national plant health diagnostic system and must operate within the broader plant health diagnostic system. There are four components (Hodda *et al.* 2017b, Merriman 2012), each of which are necessary for the whole diagnostic system.

1. **Collections**, consisting of specimens and other material used for reference, vouchering, teaching, providing genetic material, producing images, recording variation and anchoring names to attributes of organisms (using the concept of type specimens).
2. **Human capability**, being a store of undocumented experience and expertise.
3. **Information** contained in images, diagnostic protocols, gene sequences and systematic publications, on-line keys and other taxonomic resources.
4. **Interactions and linkages** between the other three components necessary for whole system to work together.

To deliver the best performance, all these components should be coordinated and integrated to work synergistically. With coordination, the different components of the system can compensate for deficiencies in other components to some extent, however the fourth component—interactions and linkages—is critical for the others to work together (Hodda *et al.* 2017b).

Plant health, trade and biosecurity within the broader collections community

There are many biological collections in Australia with many different foci: some narrow, some broad, some directly related to plant health, and some related to other priorities such as biodiversity or scientific research. Many serve multiple national priorities, but whatever their primary focus, all collections are of value for trade, biosecurity and plant health diagnostics because they all contain at least some material of relevance. This may include:

- **exotic pests** – recognised, emerging threats and others, all directly related to trade, biosecurity and plant health diagnostics
- **common native relatives and lookalikes of exotic pests** – essential for accurate diagnosis of the pests, and to develop effective diagnostic methods
- **historical material and records** – including vouchers and evidence of surveillance or distribution
- **type specimens** –definitive scientific records of any species, and essential for taxonomic research and diagnostics
- **expertise** – techniques for curation, storage, information capture, data management and other tasks that are common to all collections , but which have been, or are being, developed or improved in particular single collections, and which should be shared to maximise value.
- **materials for teaching and demonstration** – for use by people learning to identify pests or by those teaching diagnostic methodology
- **Taxonomic resources** – such as general keys which may be needed for unfamiliar pests or taxonomic groups.

Collections not normally considered to be focused on plant health need to be coordinated and linked with those that are primarily focused on plant health. Strong links are not always necessary, but it is important to identify cases where they would be beneficial. The current linkages between collections are often rudimentary, but because of the potential value of commonalities, collaborations and synergies, they are included in this strategy.

Committees coordinating plant health diagnostics

A diverse, dispersed, flexible system of collections will best serve the parallel needs of trade, biosecurity and plant health diagnostics. However, such a system will not achieve higher-level goals if not integrated at a higher level. The reasons for this are documented in the section on properties of hierarchical complex systems (page 13). Because it is so important, a considerable portion of this strategy is dedicated to the coordination of collections within the broader plant health diagnostic and collections systems. This coordination is critical to making the strategy work. The Australian plant health diagnostic system is presently loosely coordinated by the Plant Health Committee (PHC) and its subcommittees (the Subcommittee on Plant Health Diagnostics and the Subcommittee on National Plant Health Surveillance). The members of these committees are often ex officio the same people as those in charge of the state or national diagnostic services, collections and taxonomic institutes. Hence, there is informal communication regarding plant health diagnostics and collections, although this is at a quite high and general level.

The National Plant Biosecurity Diagnostic Network (NPBDN) connects plant health diagnosticians. Current NPBDN members are the people and institutions involved in plant health, but not those associated with collections. NPBDN activities are coordinated by SPHD, and supervised by PHC. Despite the titles, these positions do not presently direct or actively manage the activities or individual elements of the network, beyond communicating on behalf of the network as a whole. Rather, they are more concerned with procedural matters and the formation and maintenance of linkages. The NPBDN was formed only in the last few years and is still developing. Overseeing the network, monitoring activities, identifying gaps and its general coordination were originally envisaged as roles for the network coordinator and supervisor, but the scope of the network and these responsibilities are still evolving. The NPBDN and its organisation is therefore very relevant to plant health collections, and has been considered and incorporated into the recommendations of this strategy.

Demands for plant health diagnostics and collections

From many industries

Altogether, there is a huge number and diversity of plants whose health is of concern. A lot of plant production industries rely on diagnostics for trade and biosecurity purposes: everything from crops such as wheat with a growing season of a few months, to trees in forests managed over decades. Plants are used in many ways: as food for human or animal consumption, fibre production, social amenity, generation of bioenergy, and the provision of ecosystem services. Plant health diagnostics and collections must also deliver to developing bioindustries, and deal with the transfer of plant materials for research. There are national security concerns as well, involving the economic security of trade, food production and potential acts of bioterrorism. In all these situations, the system must supply accurate and speedy diagnosis when plants become diseased, as well as informing measures such as quarantine to prevent disease from occurring in the first place.

From large to small

The circumstances and scale in which plant health diagnostics must deliver varies enormously: anywhere from small pot plants in homes to large-scale commercial plantings in open fields, and from agricultural industries to non-commercial environmental situations.

For many pests

Together, the different industries, plants and scales of operation mean that there is a huge number and range of pests that warrant attention in the field of plant health diagnostics. This is quite different from the situation in human or animal health where there are only a few diseases that involve a few host species.

In many, many situations

The many ways in which interactions between pests, hosts, situations and stakeholders can occur complicates the ways that plant health diagnostics and reference collections are required to deliver benefits to trade and biosecurity. Many pests attack several types of crops, with sometimes different symptoms and results. The effects of pests and diseases on plants may not be immediately apparent: they can be cryptic or have a lag or latent phase before serious consequences occur. It may be that several organisms are involved, such as a disease-causing agent and its vector, or that two different organisms may cause a plant disease synergistically. To further compound the problem, the organism(s) that cause a disease may be poorly defined and require further research.

From trade & biosecurity

In addition to many crops, pests, scales of operation and situations, trade and biosecurity involve different modes of transport, regulatory matters and geographic locations.

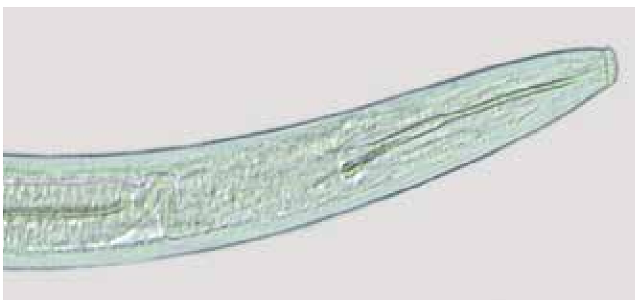
The transport of pests and disease-causing organisms may be natural or mediated by humans (accidental or deliberate) travelling by road, ship or plane, and in mail, passenger luggage or cargo.

Regulatory matters may be international (e.g. International Standards for Phytosanitary Measures (ISPM)), bilateral requirements for export certification, area freedom requirements or risk assessments. In the era of globalised trade, pests can arrive from almost anywhere in the world, and come via almost anywhere else, so the outlook needs to be global. Trade and biosecurity may be concerned with imports carrying exotic pests, or exports carrying Australian native species.

Trade in particular is a major beneficiary of the samples, information and knowledge held by collections. One of the ways collections do this is through providing evidence that growing areas are free from pests or diseases. Proof of area freedom requires vouchering of specimens and records under international standards (i.e. ISPM8), a service that is provided by Australia's collections. It is widely recognised that Australia has a competitive advantage for trade in many types of plant produce because there is no need to use pest control measures (Agricultural Competitiveness White Paper 2015). This can reduce costs and increase desirability of produce because prophylactic chemical control measures are not necessary. It is also desirable for negotiating access to new markets or to maintain access to existing markets.

The net result of all these considerations is a very complex set of demands, which must be met with a large range of resources in many different situations. These requirements are similar in many ways to those for modern systems dealing with 'big data', which means that recent developments from that field can be used to improve the design and operation of collections within the national plant health system.

Image right : The head of the nematode Xiphinema americanum. This nematode is itself a pathogen of many plants (ranging from corn to fruit and forest trees), but is also a vector for other plant pathogens (viruses), and causes restrictions to trade in many countries.



What's needed from a collections system

The right arrangement of assets

A characteristic of the defence system that is applicable to plant health diagnostics is the arrangement of the assets. Defence, like plant health diagnostics, deals with a diverse range of geographically dispersed, varied and potentially unanticipated threats. To safeguard against the threats, defence assets are deliberately dispersed and diverse. By analogy, provided there are good linkages to allow for the flow of information and material between the components, a diverse and dispersed collection system is stable and resilient to change, stresses or sudden shocks, for example when there is an incursion by a pest that is the cause of trade sensitivity.

The right general characteristics

The support provided by collections and other diagnostic resources must consider the diverse and complicated nature of the material in collections, the collections as institutions, the wider environment in which collections must operate, and the demands from trade and the biosecurity system. Complexity is intrinsic. It must be dealt with for any strategy to be effective, and this is what the current strategy explicitly does. Using the latest insights from research into complex hierarchical systems, networks and universal search capability, the strategy recommends using the characteristics of trade and plant biosecurity to deliver a system of collections that is:

- **rapid** – with multiple alternative and parallel access pathways;
- **responsive** – by having resources where they are most effective;
- **resilient** –with multiple, dispersed assets; and
- **efficient** – through heterogeneity, which is effectively coordinated and monitored.

Because of the ways in which collections support trade, biosecurity and plant health diagnostics are diverse, the ways to improve the current situation are also diverse. The diversity extends to including both simple, relatively short-term actions and larger, more complex, longer-term actions.

The strategy therefore includes recommendations that can be achieved relatively simply and quickly, as well as recommendations that will be more difficult and require a longer time frame.

Preparedness

Like other parts of the plant biosecurity system, collections need to be prepared for when threats materialise. It is too late to seek reference material from overseas during an incursion. There may be uncertainty over where to source material, and a dependence on links, that are often inadequate, between people or collections.

There are potential conflicts involving vested interests during incursions: those from whom material or information is sought may be the same as those associated with the imports on which the pest originated. Seeking material during the investigative phase of an incursion can undermine the confidence of trading partners in our plant health system. It is also too late to assemble evidence of area freedom immediately prior to initiating trade negotiations.

There are considerable benefits to having collections that are available and fit for purpose. The costs of not having them can far outweigh immediate investments to ensure they are available when needed.

Proactive nature

As with natural disaster preparedness, national defence and human health systems, there needs to be a strategy for collections, which not only addresses current needs, but also looks to the future. Otherwise, Australia's plant biosecurity system may fail when challenged by damaging pests, with serious consequences for the environment, agricultural production and exports. Such challenges are inevitable in the era of globalised trade.

If Australia is reactive rather than proactive in addressing fragility in the system biosecurity breaches will increase. Preparation is needed now to have adequate systems in place to combat the threats when they arise. The course of action must be based on close examination of the current and future requirements for collections to support trade and biosecurity. The best evidence available should then be used to construct and implement a viable strategy. Although this strategy will be reviewed and improved over time, the most pressing need is for the initial strategy.

Flexibility and responsiveness

An essential part of biosecurity is identifying threats and the risks they pose. While some threats are clear and foreseeable, others will remain surprises and arise unexpectedly: another reason why a diverse, resilient collections system is desirable.

While collections can have some input into estimating biosecurity risks, by-and-large risk analysis is another domain and not part of a collections' strategy. Even so, it is important that managers of collections are aware of the species of plant health concern, and changes in the species of concern that stem from changing trade patterns, crops or farming practices. It is equally beneficial if collections have a way to provide feedback into the estimation of plant health risks. For example, if many specimens of a pest start coming in to a collection it may indicate that there has been a change in occurrence, detection or interception of the pest. There may also be specimens of several newly-recognised local species deposited in a collection that are easily mistaken for exotic pests, indicating that the threat may have been incorrectly evaluated because the natives were mistaken for an exotic pest.

Embedding within the broader biosecurity system

The potential benefits derived from communication between managers of collections and people involved in risk assessment are great. A mechanism for the communication of emerging and newly identified risks to collections is therefore included here. The aim is to encourage and support pre-emptive acquisition of material of high-risk pests. Collections providing intelligence on potential threats and issues to those involved in risk assessment may be similarly beneficial.

Innovation and continual improvement

Merely maintaining collections will not see them improve in efficiency, expand their reach, more comprehensively cover an increasing range of organisms potentially threatening Australia, keep up with trading partners or competitors, or maintain a presence in international fora. Rather than remaining static—or even worse declining—collections should be developing and improving techniques. Innovation is possible in many areas, including digitisation, imaging, three-dimensional reconstruction, new curation techniques, novel storage methods, extraction and storage of molecular material and many others. Collections themselves should be central to this, so recommendations on an explicit innovation agenda for collections are included in this strategy.

Summary

The right collections system to support trade and biosecurity is pro-active, comprehensive, responsive, dispersed, diverse, innovative and supported in the right way. Such a system may be multifaceted, but it necessarily reflects the very complex system it is serving. Such a system is not so different from the current system. It can be achieved, and this strategy suggests ways of doing so.

What is needed for the strategy to deliver?

Timely implementation

There is some urgency for a strategy for Australia's collections. Based on the recent examination of the Australian Plant Health Diagnostic System (Hodda *et al.* 2017b), the evidence is that collections can supply less than half of the current and future demands associated with the Australian National Priority Plant Pests. An even larger proportion of High Priority Pests (HPPs) named in the biosecurity plans developed by governments and industries are missing from Australian collections.

The current funding mechanism will only see the deficiency widen. It is therefore critical that the way in which collections are funded be reformed. The costs of not doing so will be considerable as material and expertise are lost and replacement costs escalate.

Standards

Standards are an important part of the strategy. The lack of clear standards was an issue identified in the survey of collections (Hodda *et al.* 2017b). Once developed and implemented, they will give collections a clear picture of the standards to which they should aspire and deliver, and allow collections to clearly articulate their needs for support. The Intergovernmental Agreement on Biosecurity (IGAB) has explicitly agreed that governments have responsibility for implementing standards. Governments are the right entity to do this because of the issues of market failure discussed on page 14 of this document.

The right support structure

Australia's biological collections do not serve plant health diagnostics as well as they could. This is in part due to the current resourcing and support structure. Lack of resources and facilities stems from the models of funding used for many collections. Current models for collection support are not delivering the right outcomes, they need to be improved and are part of this strategy.

It would be easy to recommend that "mechanisms for sustainable funding of collections to support trade and biosecurity be investigated and implemented". However, such recommendations just pass the buck to an indefinite 'someone'. This strategy therefore recommends that funders recognise the overall value of collections, and also recognise that there are many beneficiaries using a model similar to defence or infrastructure.

Having each collection focused on achieving and maintaining standards (with support to do so) may avoid an issue identified with defence support, which is "the risk of taking our eye off the ball by squabbling over the collateral benefits of … spending rather than focusing on the main game of producing capability …" (Thomson 2017). Cost shifting is another danger in any support model involving multiple entities.

The support model for collections must account for the nature of the plant health system. As discussed above, a diverse range of pests affecting a wide range of hosts over a large environmental range exists. A range of administrative arrangements also apply. The custodians of collections currently reside with multiple jurisdictions. Any strategy for collection support needs to fit within the frameworks of the IGAB, National Plant Biosecurity Strategy (NPBS), National Plant Biosecurity Diagnostic Strategy (NPBDS) National Plant Biosecurity Surveillance Strategy, and National Plant Biosecurity Research, Development and Extension Strategy together with the Implementation Committees for these strategies. The plant health system is thus characterised by considerable complexity, but there are good reasons for this, and there are advantages in maintaining the diversity of the system.

Focus on benefits

Even with the right funding model, there is a need to articulate as clearly and comprehensively as possible the contributions of collections to supporting plant health diagnostics, biosecurity and trade. This strategy presents numerous direct, concrete examples of support for plant health diagnostics, biosecurity and trade, but also notes many more indirect linkages that are hard to quantify. Having a more systematic study of benefits will be beneficial in maintaining support, and is an essential precursor to realising an improved funding model. Further investigation of the links between collections, trade and biosecurity are recommended in this strategy, and recent audits of collections provide a good starting point for this.

Some beneficiaries of collections and plant health diagnostics are more easily identified than others. Exporters of a particular crop, for example, benefit from proof of area freedom taken from records and voucher specimens held in collections. However, even in these cases, market failure still occurs: trade in products other than the main hosts damaged by a pest can benefit from area freedom. For example, trade in carrots, ornamental bulbs and grains benefit from area freedom for potato cyst nematode, even though none of these products are hosts for the pest.

Recognition of market failure

Collections represent a clear case of market failure, where the allocation of goods and services is not efficient without intervention. This has had a major impact on the organisation and support for collections, and makes it difficult to assign specific outcomes to the contributions made by collections. For a collections strategy to be successful, it is essential to recognise this feature, and to take steps to ensure that negative effects are mitigated. Full analysis is presented in the section 'Behind the vision' on page 12.

The right time scale

A central service of collections is to link materials or descriptions from the past with material of current interest, such as specimens, images or sequences. For this reason, it is essential to consider the long-term sustainability of collections in a strategy.

Like other large, potentially long-lived assets, collections need to be managed on a large, long-term basis. However, much current scientific funding is short term and project based. This is problematic where there is market failure , long life of collection materials, multiple levels of management, and incomplete valuation of assets. Indeed, the aim of collections is to maintain material over the longest time possible. Some projects may be suitable for specific, short-term funding (e.g. training or the development of new methods), but other aspects of collections must be valued over their entire life, which is long. This is standard for all other infrastructure with substantial lifetimes.

Recognition of depreciation

The depreciation of collection assets is currently inadequately accounted for. Collections are assets of great value, which is mostly unrecognised. Furthermore, they are assets that deteriorate without maintenance. The effort to maintain collections can be substantial, but spending on maintenance is viewed as a cost, rather than as protecting the value of assets. Collection maintenance should be offset against depreciation.

In the short term, changing reporting standards to recognise depreciation which is unmatched by expenditure on upkeep may be a good way to account for the true value of collections, and stabilise spending on maintenance, which has been steadily decreasing.

Behind the vision

Heterogeneous data, distributed databases, parallel architecture and universal searches

Modern systems for digital data collection, storage and access now use models that include heterogeneous data, distributed databases, parallel architecture and universal searches to manage information. Companies like Google™ and Amazon™ that rely on information and search capability use these methods. The methods do not apply merely to digital data but are applicable to many systems. Collections would benefit from adopting many of the principles of these modern, advanced systems to allow greater efficiency in storing, searching and accessing their material and information.

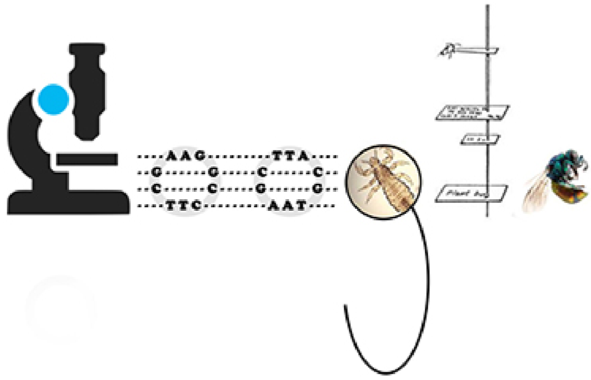
The term 'heterogeneous data' is applied to all available information from all sources, in all forms, rather than attempting to homogenise or standardise it. This allows more information from a wider variety of sources to be used in the system. Information does not require extensive analysis or processing before it can be used, nor does it need to be held in enormous, complex and potentially vulnerable central data stores. It does require extra processing or search power to information, but such extra overheads are at least partly offset by opportunities for distribution of data and parallel processing.

Distributed databases are those which are deliberately spread over multiple locations, improving the resilience and security of a system. It also avoids issues in relation to centralising data from many different places, including the choice of a location.

Distributing data also enables parallel processing, which is the ability to access and work on many parts of the data at the same time, avoiding potential bottlenecks and catastrophic overloads. It means there is a much higher potential throughput and faster response times. Together with distribution of data, parallel processing allows for a much greater range of data to be used for a particular problem, which is the essence of universal searching.

Universal searching is what enables the Google™ search engine to quickly locate information relevant to a particular search term among the enormous amount of data now on the world wide web (along with advertisements for products you are likely to buy). It brings together all of the information available from all sources for any search term.

All of the above concepts can be applied to collections. Together, Australia's biological collections have an enormous store of heterogeneous information, an analogous situation to the 'big data' for which these principles were developed. The central aim of this strategy is to produce a collections system capable of bringing together all of the available materials to bear on a problem for trade, biosecurity or plant health from wherever the material is located, as swiftly and efficiently as possible. Hence, the strategy recommends modernising the collections system to take advantage of the benefits of this approach.



Google can find more or less anything on the world wide web very efficiently. A system enabling users to find material from collections equally efficiently is the aim of this strategy.

Flexible, self-organising networks

The system of collections with the characteristics to support plant health diagnostics, trade and biosecurity described above is diverse, but needs to be linked into a complex network to operate as a coherent entity. There is a considerable amount of information on how such systems function which can inform the optimal strategy, so these are outlined very briefly in this section. This is a science theory that is applied to networks as diverse as electricity supply grids, transport networks and the spread of human, animal or plant diseases, and is well accepted.

The most efficient network is well connected, flexible, self-organising, scale-free, and small world. In the context of collections, this means that nodes (collections or users) are joined to each other by many links which can transfer material or information, such as specimens, images or locations to form a network. An efficient network will connect all nodes and maximise the flows between them. Simultaneously, all nodes will contribute to the network: there will be no unnecessary nodes, and the characteristics of nodes will reflect their different features and roles in the overall network. Likewise, the connections will reflect the flows needed between different nodes. Having the right nodes and connections is important because maintaining both nodes and connections necessarily involves a cost.

The cost of maintaining links explains why a well-connected network is much more efficient than one completely connected—with every node or collection connected directly to every other one. Completely-connected networks require an enormous number of links as they get larger to connect every possible pairwise combination of nodes. In a well-connected network each node is connected to enough others that it is possible to get to every other node via one or a few intermediary nodes. This vastly reduces the number of links that need to be maintained, while only marginally increasing the difficulty and speed of contact between any pair of nodes. The benefit is almost the same as having a completely connected network, but the cost is a small fraction.

The links in a network cannot become too sparse, or the routes and number of intermediaries between most nodes increases sharply, meaning that contacts and flows between nodes becomes much more difficult. There is also an increased chance that some nodes will become isolated from the others. A corollary of these features of sparse networks is that there is likely to be a single route of connection between any pair of nodes, rather than the multiple alternative routes that are a feature of well-connected networks. Multiple routes between nodes is important to the resilience of the network: breaking or changing some links will not affect connectivity in a well-connected network, but may disconnect or break up a sparse network.

In a flexible network, links are not fixed as might be the case with rail networks for example, but can change over time. In the context of collections, trade and biosecurity, this means that the collections system as a whole can respond to the changing circumstances that are a feature of global trade and biosecurity.

Self-organization in a network is links forming, strengthening or weakening in response to cues from the nodes themselves. In terms of collections and the plant health diagnostic system, this means that collections can contact (link) with the other parts of the system that they need when they need it. This property of networks also promotes resilience. It means that if important links are broken, they will re-form. Some initial connectedness in a network, together with inputs to maintain the network, are required for self-organization to occur.

A potential negative of flexible and self-organising networks is the possibility of fragmentation of the network, and lack of responsiveness to forces outside the network as internal positive feedbacks and reinforcing dominate. The way to avoid this is having an outside overview of the network, with mechanisms to influence the nodes and links inside the network. Having this outside influence on a network to keep it functioning efficiently and responsively can be additional to internal self-organization, and is not incompatible with it. Appropriate avenues for management inside and outside of systems are discussed in the next section.

For the desirable characteristics of rapid and efficient transfer of material or information through a network with least cost, the arrangement of nodes and links is also important. Such networks are known as 'small world' networks. The architecture that makes a network 'small world' is a property of the networks as a whole, not individual nodes or links within them. As such, making a 'small world' network requires monitoring and intervention from outside the network.

Complex, hierarchical systems

The real world, and the way humans organise their perceptions of it, are organised into systems. A system is characterised by many linkages between parts of the system, but few linkages outside. And systems are nested within each other. For example, a car has electrical, braking and cooling systems among others. These systems are combined into a car, which is itself a system, consisting of the whole car, but also a driver, passengers and load. Each car (with its occupants and load) is part of the larger road transport system with other cars, motorcycles and trucks, and road transport is part of the whole transport system, including rail, sea and air. Transport systems exist within larger state and international systems.

While many properties of systems as a whole are dependent on the parts within, there are also emergent properties which are peculiar to the system as a whole.

Knowing these properties of systems means that they can be monitored and influenced at the right level. Characteristics of the parts making up a system are best managed within the system, and characteristics of the system as a whole are best managed from without at the next larger level. A corollary of this is that to manage systems from outside the details inside must be known. Because of these properties of hierarchical systems, this strategy has recommendations involving material within collections, the collections themselves, the collections system as a whole, and those outside the collections in the larger plant health system.

Considering complex, hierarchical systems in this way can be less appealing than simplifying them by collapsing multiple layers into one, ignoring diversity among the component parts of a system, and lumping separate components into an amorphous amalgam. A well-accepted body of theoretical and practical science says that such practices neither describe critical features of systems adequately nor result in the most effective management for particular outcomes.

Visible and invisible assets

The visibility and ability to easily measure an asset can influence greatly the perceived value of the asset. Assets that are prominent and quantifiable tend to be highly valued because they are likely to be perceived as valuable, irrespective of their intrinsic value. Assets that are invisible and not easily quantified—especially in terms of monetary value—are less likely to be perceived as valuable. A single physical object is likely to be valued more than many scattered virtual or intangible assets, even when the latter has more real value. These observations have led to the introduction of the terms 'intellectual', 'natural' and 'social' capitals because they are examples of values that are often undervalued because they are difficult to see and quantify.

Connectedness is another example of an often underestimated value of particular relevance to collections and plant health diagnostics.

Underestimating the values of intellectual and connection capitals can lead to poor outcomes. In many ways, the current deficiencies in both collections and plant health diagnostics are a result of the ways that assets have been valued—or not—in the past. This strategy seeks to address this issue.

Market failure

Simple models of direct support by those benefiting do not apply to collections because of market failure. Market failure can be caused by one of four main characteristics, but in the case of collections, every one of the characteristics applies: unclear, diffuse or complex relationships between cost and benefit; externalities; time lags; and time-inconsistent values.
Relationships between benefit and cost. There are many ways that collections support trade and biosecurity, and many beneficiaries, so that a single direct link cannot be identified because there are many links and they can be direct or indirect. Under such conditions, obtaining support equitably from all those that benefit is problematic.
Externalities collections support many national priorities in addition to trade and biosecurity; activities such as environmental protection, development of bioindustries, and the provision of basic scientific infrastructure. This means that there is an economic incentive to "free-ride" on others benefiting from the same resource. Especially with the many and indirect links, identifying all beneficiaries and then negotiating equitable contributions would be extremely difficult.
Time lags Although the costs of developing and maintaining collections are immediate, the benefits are delayed. There are thus strong incentives to not act economically rationally irrespective of how favourable the benefit to cost ratio may be. The frequent delay in receiving the benefits from collection support is a major barrier to investment even though the benefit-cost ratio is ultimately favourable.
Time-inconsistent values, the value placed on collections varies considerably over time: for example, it is much higher during an incursion than at other times. In short, collections are shared resources or "public goods".

Other shared resources and public goods—such as natural disaster preparedness, emergency services and human health care—share many of the characteristics that make collection support a difficult budgetary proposition under the most common models, such as user pays. The support model for national defence is perhaps the most appropriate: unsurprisingly given that biosecurity is defence against biological threats. As discussed elsewhere in this strategy, collections and plant health diagnostics share many of the characteristics of defence. Defence relies typically on central, national governments, with little discussion. Promotion of trade is similarly seen as a major role for central, national governments, although also with contributions from state government and industry.

The trade functions of collections perhaps suggest that an insurance model may be used for supporting collections. In the past Emergency Services such as fire have been funded on this model. However, this model of funding is now being replaced in all states by a direct levy on all potential users. The issue with such a direct levy in the case of export trade in agricultural products is that it represents a competitive disadvantage internationally.

A major role for central government does not preclude shared responsibility where this is appropriate. Neither does it necessarily preclude involvement by a range of service providers where this is appropriate. But the aim must remain effectively, efficiently and sustainably serving the needs of trade and biosecurity, rather than particular stakeholders. The structure of the system must be driven by the needs rather than the present or preferred structure driving what can be produced.

Shared Responsibility

Previous reviews of Australia's biosecurity arrangements by Nairn (1996) and Beale (2008) have emphasised the complex nature of biosecurity, the consequent challenges in building a sustainable support structure, and the need for all stakeholders—national, state, industry and others—to work together to achieve the goal of better biosecurity. This strategy builds on these reviews by identifying appropriate levels for responsibility for particular functions on both practical and theoretical grounds. Apportioning responsibility to the appropriate level of the diagnostic system means that there are indeed roles for many different organizational units operating across biosecurity diagnostics, and that the system utilises existing resources effectively. Thus in this strategy recommendations are separated according to the level of organization to which they are related: individual parts of the collections, the reference collections themselves, reference collections system as a whole, the coordinator of the collections system, the wider plant health diagnostic system, and the wider collections system.

Reference specimens from collections are essential for training diagnosticians

Reference collections, biosecurity and export trade

Below are some examples of collection contributions to export trade.

Dwarf bunt of wheat

Until it was proven to our trading partners that Australia does not have *Tilletia controversa*, the cause of dwarf bunt of wheat, exports to many countries required evidence of freedom from this fungal pest, increasing costs, decreasing competitiveness and potentially restricting market access.

Australia was considered to have the pathogen *Tilletia controversa* until 2005. It had been commonly recorded on the weed barley grass (*Critesion* spp.), but comprehensive studies comparing specimens in Australian reference collections with confirmed herbarium specimens of dwarf bunt on wheat from the USA proved that none of the records were actually of *T. controversa*. The samples held in collections were essential in this process to show that the organism on material from all over the country had been incorrectly identified. Without voucher material, it would have been more difficult, expensive and time-consuming to prove that dwarf bunt of wheat does not occur in Australia.

Karnal bunt of wheat

When Pakistan rejected 150,000 tonnes of Australian wheat in March 2004 because of suspicion of the presence of the Karnal Bunt fungus (*Tilletia indica*), collections were needed to show that the suspects were a different species.

The samples in Australian collections were already there, to be called upon when the unexpected announcement was made: there were 495 consignments at sea, all of them at risk of being rejected by Egypt, Saudia Arabia and South Korea. 40 pathologists from all of the wheat growing states were able to isolate spores from samples in collections and compare them with spores from local relatives. These comparisons, backed by the confirmed identification of specimens and the chain of evidence provided by vouchered material in collections, proved to our trading partners that *Tilletia indica* was not in Australia. that we could respond rapidly with science-based evidence to reports of pathogens on our exports, and that the 2 billion dollar export trade could resume.

Walnut anthracnose

The walnut industry was able to declare area freedom from the pathogen causing walnut anthracnose (*Ophiognomonia leptostyla*) because of a specimen kept in a collection since the 1940's.

The absence of walnut anthracnose is an important factor in keeping costs down, increasing competitiveness and allowing market access for the developing industry. Because the original specimen had been well maintained for 60 years, it could be re-examined to show conclusively that *O. leptostyla* was absent from Australia.

South African citrus thrips

In this case, material held by collections, combined with material specifically imported and held by collections for comparison, was used to show that there are biotypes of this insect of high biosecurity concern (*Scirtothrips aurantii*), and that Australia did not have the biotype of biosecurity concern.

The export of many crops, not only citrus, benefited because mangos, grapes, chillies, peas, green beans and blueberries are all hosts, and therefore have to be tested for its presence or absence. The biotype of biosecurity concern was shown to be absent from Australia because specimens originally reported as the pest could be re-examined, studied, and shown to be a different biotype. Importantly, this proof was of an international standard that is accepted by trading partners.

Reference collections, biosecurity and import trade

Chestnut blight eradication program

Collections were needed to differentiate the exotic fungus *Cryphonectria parasitica* (the cause of Chestnut blight) from closely-related native species as part of a huge emergency response in 2010.

Samples from over 150,000 trees and 1000 properties had to be compared with samples of the many native species collected for other purposes. The majority of samples – originally collected during forest surveys many years previously and stored in local collections – proved to be of a native fungus. *C. parasitica* was found to be restricted to nine properties, and the decision was made to attempt to eradicate the pest.

Blueberry rust

Comparison of specimens of *Thekopsora minima* (the cause of Blueberry Rust) and *Chrysomyxa rhododendri* (the cause of Rhododendron Rust) held in the one collection was used to differentiate the species in 2014 when interstate trade in nursery stock was suspended owing to *T. minima* being found in Victoria.

The trade could resume quickly because the specimens of both species were available and in the same collection, even though they primarily affect different industries (but can also occur on the same hosts).

Orchid anthracnose

DNA from specimens collected in 1902 and 1903 was used to verify the absence of *Colletotrichum orchideareum* (the cause of orchid anthracnose) in Australia when it was intercepted on imported orchids in 2016.

The collection material confirmed that the infected plants should be destroyed to protect Australia's cut flower industry.

Khapra beetle

Australia depends on being free from this highly trade-sensitive species: fast and effective eradication of an incursion is therefore essential.

Extensive surveillance activities mean that many related species are encountered and must be distinguished from the exotic pest (*Trogoderma granarium*). The identification tools that allow this are based on extensive collections of the many unnamed but distinct native species that are easily confused with the exotic pest species. The diagnostic tools could not have been developed without the extensive collections of natives as well as the exotic pest. The collections are also essential references while taxonomic work on this complex genus continues.

Pine wood nematode

Physical specimens and DNA vouchered and held in a central collection were used to determine that new discoveries of an exotic pine wood nematode (*Bursaphelenchus sexdentati*) were the same species as previous incursions.

Determining the threat to forestry and trade in wood products from this species required comparison of physical specimens with specimens of most species of the genus. Fortunately, such specimens had been specially imported and kept in a local collection following the first incursion. The diagnosis was used to decide against mounting an eradication campaign. The collection's targeted acquisition of confirmed examples of exotics, vouchering of local material for future reference, and holdings of linked physical specimens plus DNA, all made for a positive outcome ultimately saving money, protecting Australia's forests, and facilitating trade (by confirming that this was not a trade-sensitive species).

Other arthropods

Incursions of many other insects and mites of biosecurity concern has required collections of exotic pests and their Australian native relatives.

Collections have been instrumental in keeping Australia free of a great diversity of pests and suspected pests that have been intercepted or managed to make incursions because specimens have been gathered, ready to be used. Among the many well known and lesser known pests that have arrived are:

- **tomato potato psyllid** (*Bactericera cockerelli*), which damages many different crops, is a vector for a bacterial pathogen and affects trade;
- **hazelnut mite** (*Tetranycopsis horridus*), a pest of several commercial nuts but also amenity and environmental plantings;
- **Russian wheat aphid** (*Diuraphis noxia*), a major pest of cereals;
- **giant pine scale** (*Marchalina hellenica*) and cactus spine scale (*Acanthococcus coccineus*), pests of conifers and cacti;
- **pomegranate leaf curl mite** (*Aceria granati*), a relatively unknown pest of ornamentals and a small industry;
- the closely related **cotton and solanum mealybugs** (*Phenacoccus solenopsis* and *P. solani*), both with wide host ranges but also important differences in host ranges and biology;
- the species complexes of **woolly aphids** (*Adelges (Dreyfusia) nordmannianae* and *A. (Gilletteella) cooleyi,* which cause considerable taxonomic confusion; and
- **leaf beetle** (*Paropsides calypso*), an exotic pest of native trees.

Alignment with relevant national plant biosecurity strategies

The National Plant Pests Reference Collections Strategy (NPPRCS) underpins the National Plant Biosecurity Diagnostic Strategy (NPBDS), with a specific emphasis on Recommendation D3, and the underlying Action D3.2 and D3.3.

NBPDS Recommendation D3: Diagnostic capability and capacity for all HPPs be developed and maintained

> **Action D3.2:** Develop a national policy to facilitate access to reference material and positive controls for diagnostic tests by ensuring appropriate processes and containment protocols are in place for their importation, storage and handling
>
> **Action D3.3:** Regularly review current and future needs of the diagnostic system in terms of human resources, skills and infrastructure, and implement proactive approaches to ensure these are met

In addition, the implementation of the NPPRCS will address several other actions across all four recommendations in the NPBDS, including D1 for networking all the parts of the diagnostic system, D2 for implementing and supporting quality standards, and D4 for optimising information management and data sharing.

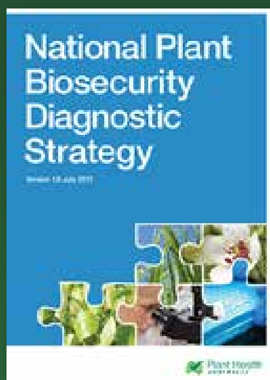
The direction provided by the NPBS (Recommendation 10) and IGAB (Priority Reform Area 4 of Schedule 4) align with the NPPRCS, providing further incentive to support the implementation of the recommendations in this document. In a broader view, the NPPRCS also aligns to elements of the National Plant Biosecurity Research Development and Extension Strategy.

National Plant Biosecurity Diagnostic Strategy

Recommendations

1. Develop a nationally integrated plant biosecurity diagnostic network that underpins Australia's plant biosecurity system
2. Implement and maintain appropriate quality management systems in diagnostic laboratories
3. Diagnostic capability and capacity for all HPPs be developed and maintained
4. Establish a national plant biosecurity information management framework to optimise data sharing

For more detailed information visit:
http://www.planthealthaustralia.com.au/biosecurity/diagnostics

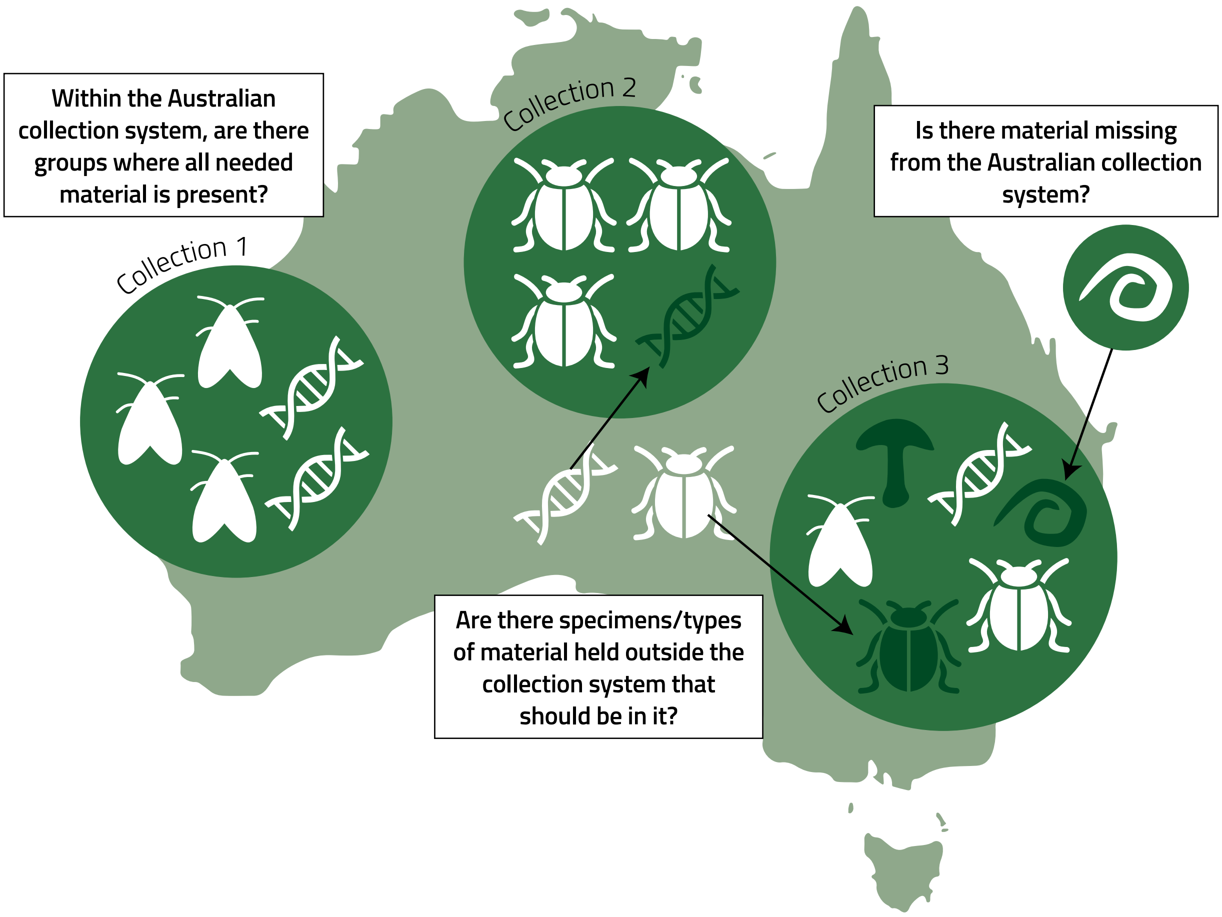


Summary of recommendations

The NPPRCS identifies six recommendations aligned to key reference collections needs. The recommendations stem from substantial analysis of trade, plant biosecurity and collections in Australia, as well as other parts of the plant health diagnostic system. Their implementation will ensure collections can deliver appropriate trade and biosecurity outcomes.

Coverage

Many of the identified priority exotic pests for plant production industries are not present in Australian collections, and therefore there is a requirement to to fill the known specimen gaps.



Recommendation 1

Develop and implement a system for regular assessment against national plant health priorities of the overall taxonomic, geographic and commodity coverage of all collections in the national system

Action 1.1: Develop standards to assess the value and relevance of the total content of national collections, including:

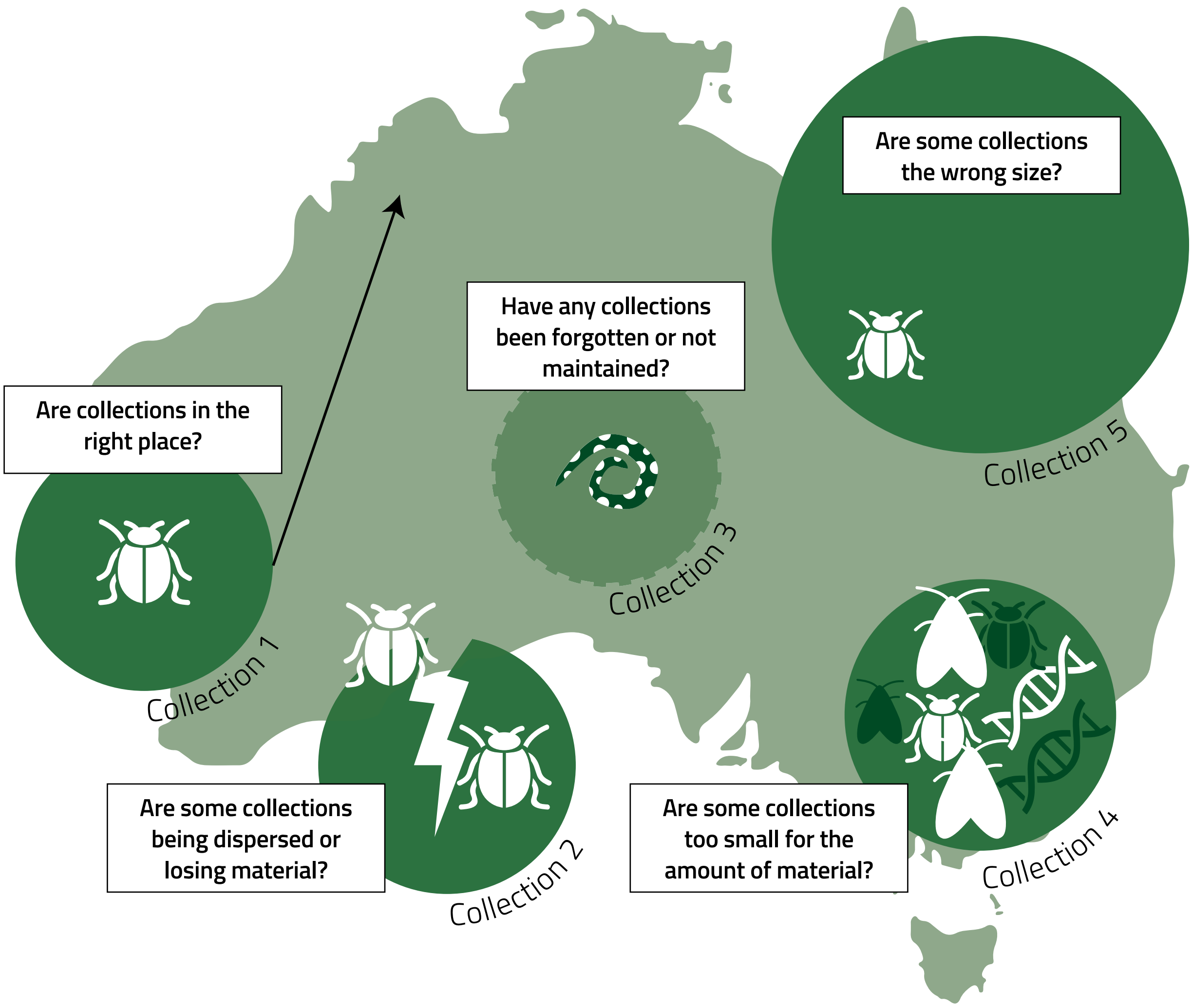
- taxonomic, geographic and commodity coverage
- accessibility and security
- delivery to trade and biosecurity outcomes

Action 1.2: Develop a mechanism for ensuring regular assessments and ongoing monitoring

Action 1.3: Develop a mechanism for filling gaps and weaknesses in reference collections identified as significant during the assessment process

Scope and Roles

Not only do collections require the right specimens, but they need to be stored so they can be used most effectively. This may require specimens to be included in more than one collection or location, and potentially in different types of collections. This should be driven by the efficient and effective utilisation for trade, biosecurity and plant health outcomes.



Recommendation 2

Identify, monitor and improve the scope and role of individual collections to support trade, biosecurity, and the national plant diagnostic system

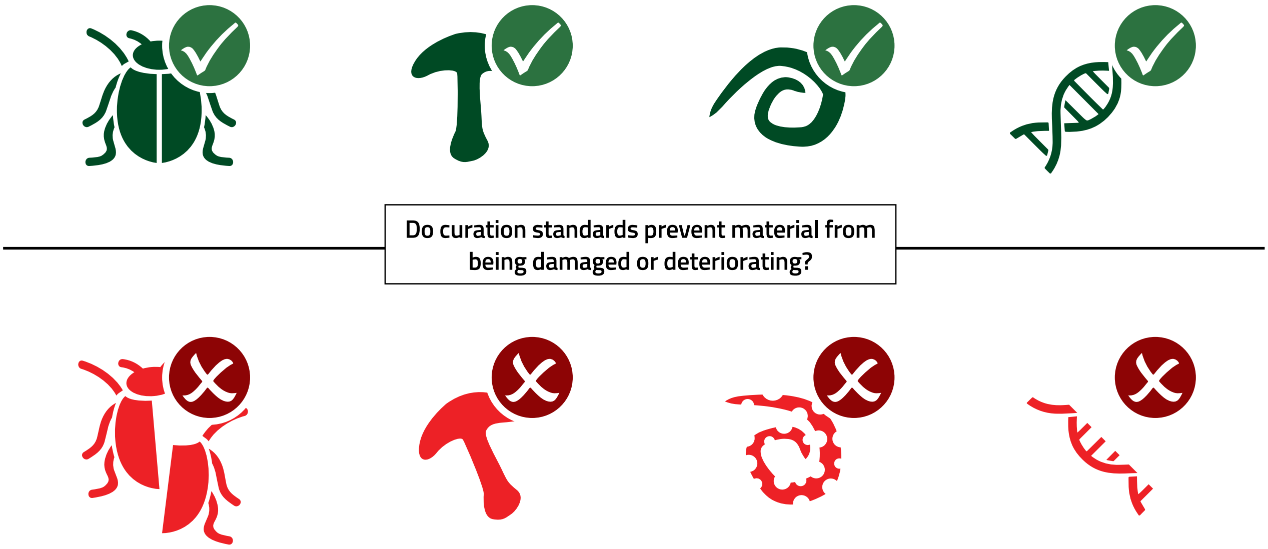
Action 2.1: Assess the requirements of the national plant biosecurity system and whether the distribution of collections, together with the scope and role of each collection, currently meets these needs

Action 2.2: Develop and implement a system for regularly monitoring the status of reference collections

Action 2.3: Develop and implement a method to address issues identified

Standards

Appropriate management of the reference collections is required to ensure that they are of a standard that will meet international obligations and deliver on local needs. This covers aspects of the physical infrastructure, human resources and intellectual expertise.



Recommendation 3

Implement national and international standards for curation and custodianship of collections, recognising different types of collections exist

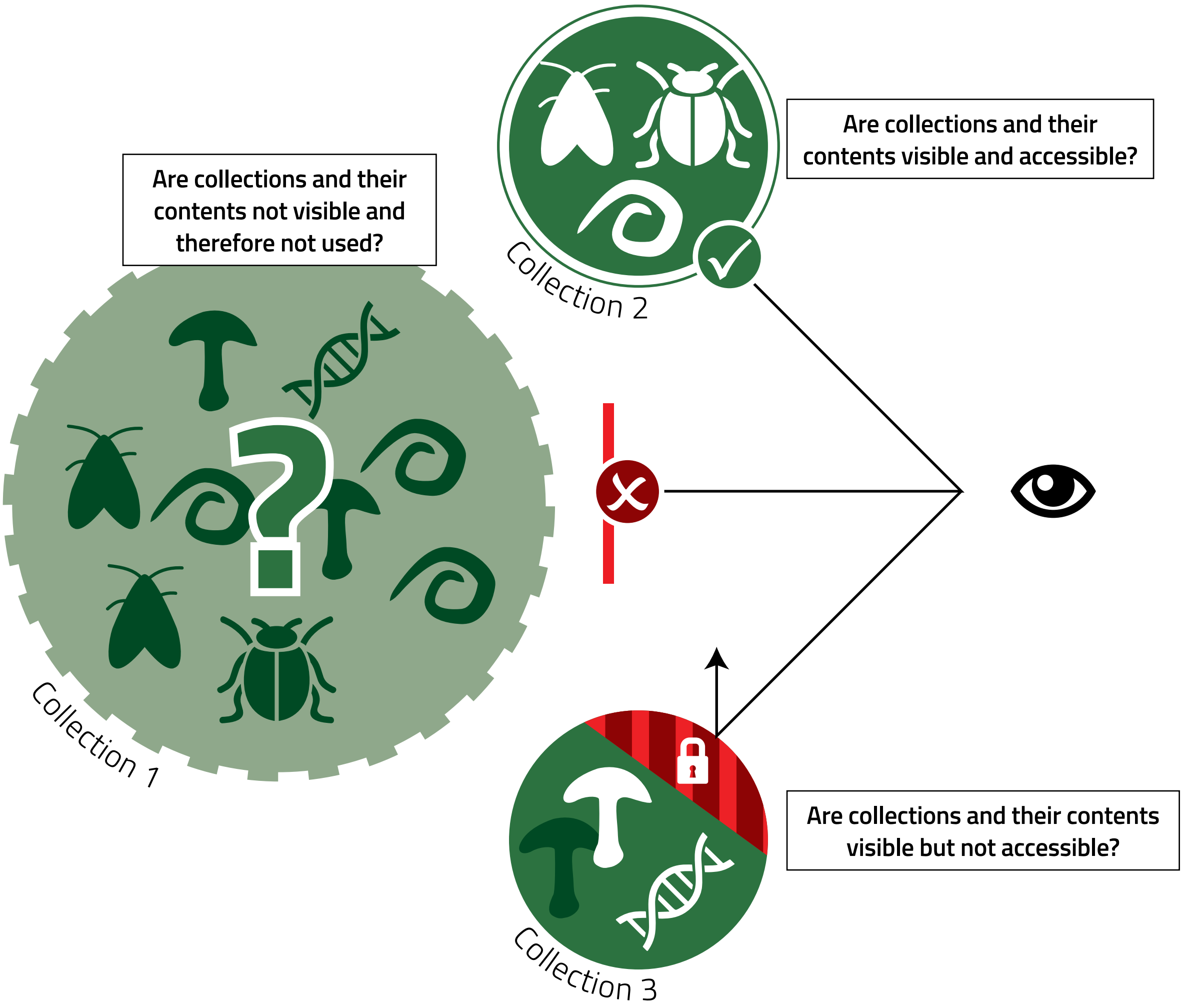
Action 3.1: Identify and develop appropriate standards for reference collection curation, custodianship and improvement

Action 3.2: Facilitate the adoption of standards in all reference collections

Action 3.3: Develop a mechanism for ensuring compliance to standards

Accessibility

A well-maintained, appropriate and comprehensive system of collections will not deliver to the wider plant health diagnostic community without effective communication. This must be delivered through the right formats, and include all the information about the collections, the physical specimens, and other material associated with them, such as images or site data.



Recommendation 4

Improve accessibility of all collection material and information—including specimen records, images, sequences, biological data and environmental associations—through a diverse, dispersed, responsive system meeting the scientific, regulatory and administrative requirements of trade and biosecurity stakeholders

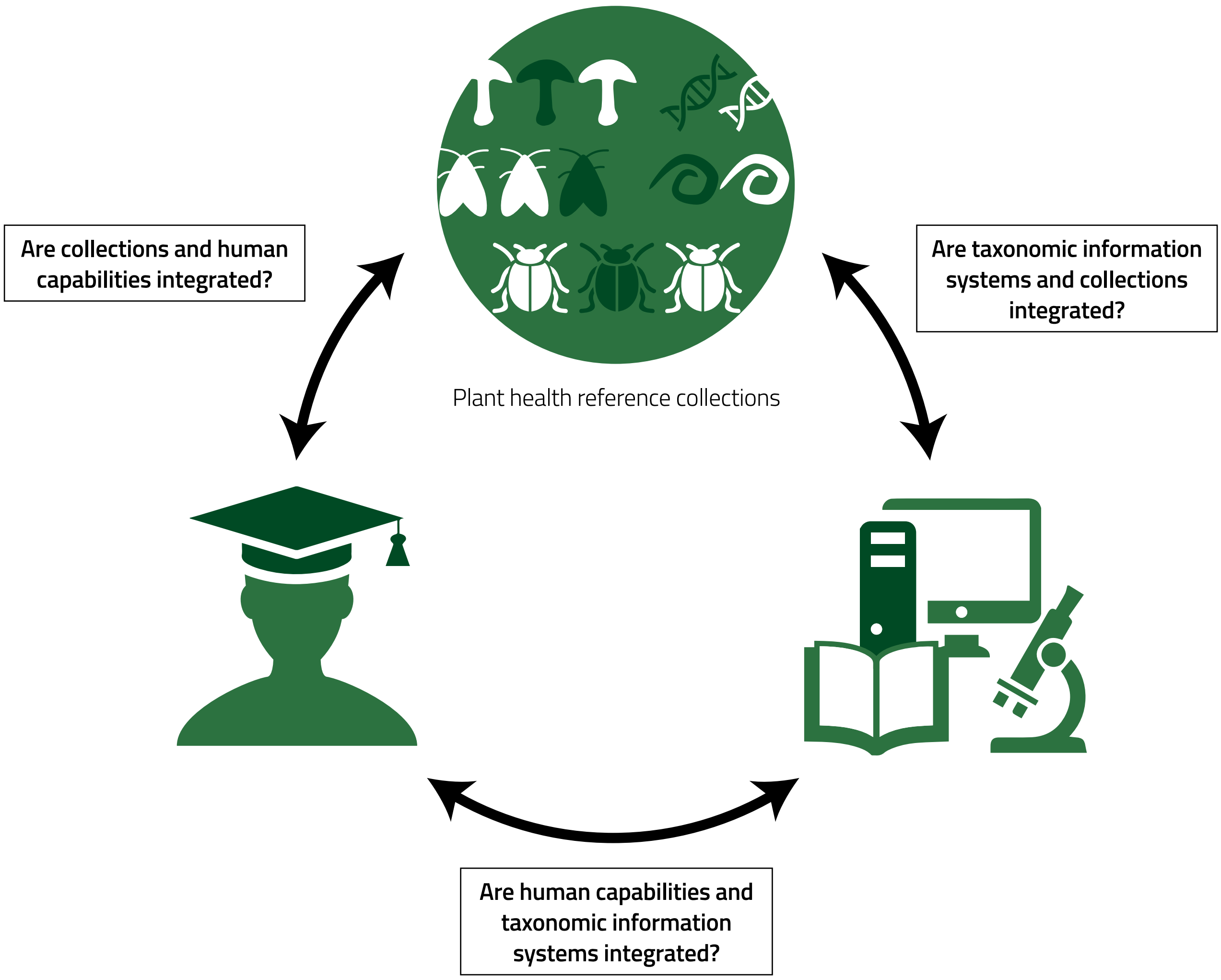
Action 4.1: Develop and implement systems to provide accessibility to all reference collections

Action 4.2: Ensure currency with developments in digital acquisition, presentation and delivery of information on all collection materials

Action 4.3: Monitor the system to ensure it meets stakeholder requirements and implement strategies to address gaps

Integration in plant health system

The plant health system is broader than collections, including elements such as human capability and taxonomic information. To deliver improved outcomes across the spectrum of the plant health system, there needs to be strong coordination and integration of all the separate elements.



Recommendation 5

Integrate the trade and biosecurity functions of biological collections within the plant health system

Action 5.1: Facilitate integration of collections within the NPBDN to ensure linkages between all reference collections and other parts of the plant health system

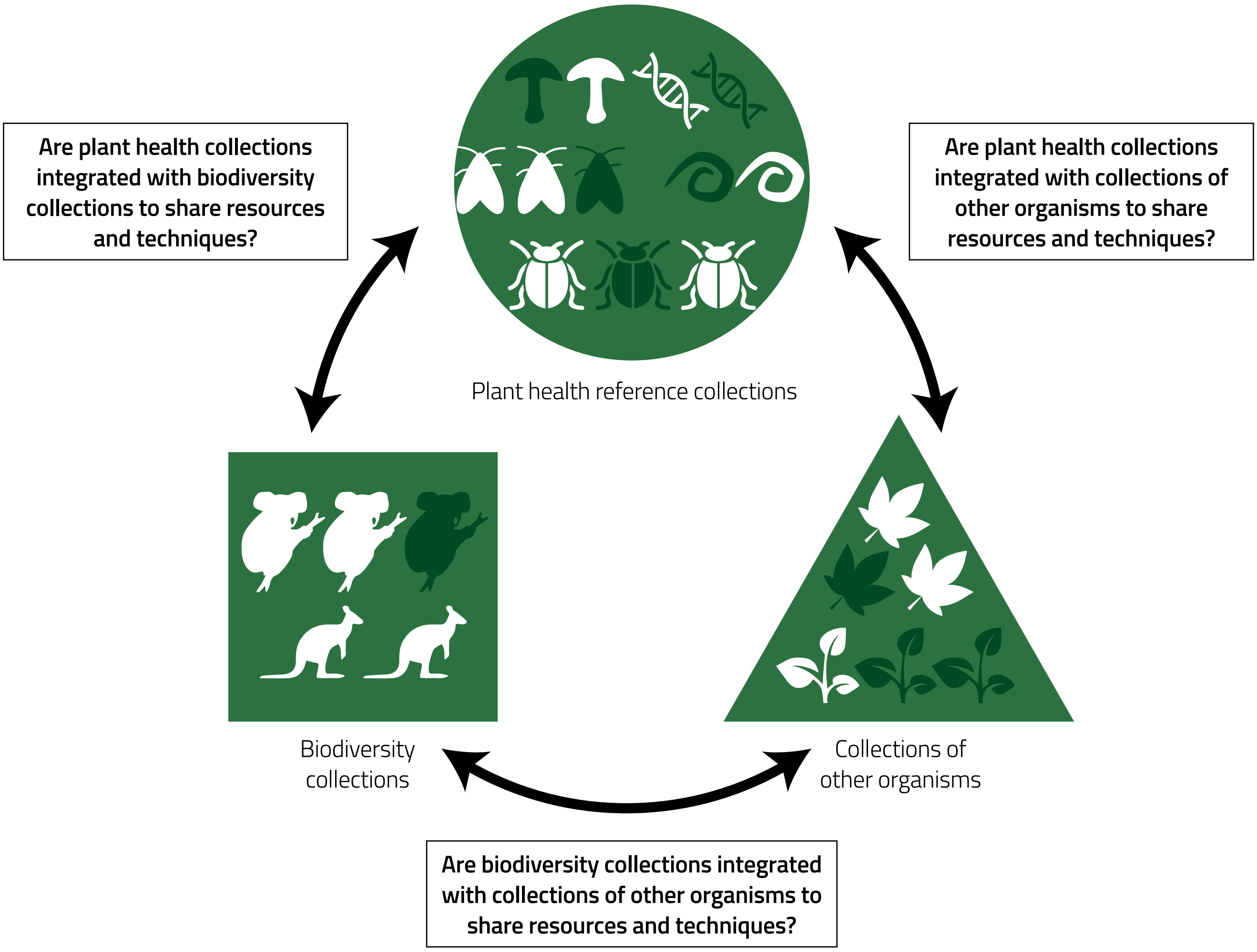
Action 5.2: Facilitate communication between collections and components of the plant health system outside the NPBDN

Action 5.3: Undertake ongoing assessment of reference collection coverage for priority pests relative to other diagnostic resources

Action 5.4: Promote awareness of the role of reference collections to trade and biosecurity

Coordination with other collections

Many collections serve other functions outside of trade and biosecurity, such as biodiversity or scientific record-keeping. There is considerable value in coordinating the different functions and realising synergies, as material collected for other purposes may have great value for plant health diagnostics and trade support.



Recommendation 6

Ensure that there is communication and coordination between the various stakeholder communities in collections, including environmental and scientific sectors

Action 6.1: Ensure exchange of information important to plant health among all stakeholders

Action 6.2: Enhance coordination of activities important to both reference collections and stakeholders

Recommendations in detail

Coverage

Recommendation 1: Develop and implement a system for regular assessment against national plant health priorities of the overall taxonomic, geographic and commodity coverage of the total contents of all collections in the national system.

For maximum value, diagnostic resources should cover as many of the pests of the highest priority as possible. This is the aim of the NPBDS. To ensure the collections as a whole include as many priority pests as possible, an assessment of overall holdings is needed. This is currently not available. Such a list should then be compared with priorities, and used to strategically improve the coverage of collections as a whole.

Checking the combined holdings of all collections needs to be at the level of the whole collections system not individual collections (see hierarchical complex systems). Currently there is no need for any particular collection to acquire and compare the consolidated holdings of all other collections with the various priorities for pests: the focus of each collection is (rightly) on their own holdings. So even if every collection had a complete catalogue of their holdings, combining and analysing every one of these is a function that needs to be completed at a higher level.

The adequacy of overall coverage depends on the overall scope of the material in all the collections. This may be assessed in many ways: against species lists, against potential origins of incursions, against potential areas for establishment, or against host crops. Coverage may also be assessed against combinations of these criteria because they are not mutually exclusive: for example, several distinct geographic and host variants of an exotic species may be needed.

The material in the system is only half the equation in assessing adequacy. The other half is the need. Different material is needed to deliver to trade and biosecurity outcomes for different situations, such as rapid diagnostics, definitive identification, proof of area freedom, or supply of positive controls. Different taxa, diagnostic methods and interception pathways need different material. The material in the system needs to be assessed against these needs.

Action 1.1: Develop standards for assessing the value and relevance of total content of national collections, including:

- taxonomic, geographic and commodity coverage
- accessibility and security
- delivery to trade and biosecurity outcomes

Once a system for assessing the adequacy of the overall taxonomic coverage of all collections is developed, then it needs to be implemented. There is currently no mechanism specifically for this, and there is no particular motive for any one collection to do it. Therefore, the strategy recommends that a mechanism be developed for implementation. Identifying responsibility for implementation is a critical part of that.

Trade and biosecurity priorities change. Taxonomic concepts change: advances in science mean that how a particular pest is defined and diagnosed changes over time; consequently, whether that pest is present in the collections can change, as can what material is needed. Material is added to collections and—hopefully rarely—lost. Technical needs change over time: for example, development of a molecular diagnostic test may mean that genetic material is now needed as a positive control. All these characteristics mean that coverage should be monitored over time to ensure that information on coverage remains up-to-date and relevant. Monitoring will also provide an estimation of the rate of change in the system.

Action 1.2: Develop a mechanism for ensuring regular assessments and ongoing monitoring

Once the overall coverage of collections relative to needs has been assessed, then identifying and prioritising the gaps and weaknesses in the overall coverage of collections is needed. There is currently no mechanism for filling such important gaps in the overall collection, so this strategy recommends that one be developed, so that the collections system moves towards containing the right material for all the highest-priority pests.

Action 1.3 Develop a mechanism for filling gaps and weaknesses in reference collections identified as significant during the assessment process

Scope and role

Recommendation 2: Identify, monitor and improve the scopes and roles of individual collections to support trade, biosecurity, and the national plant diagnostic system

A network of collections, each with the best characteristics to deliver for particular trade, biosecurity or plant health outcomes, is the goal of this recommendation. Not all collections should be the same, because a diversity of collections—big and small, specialised and broad—that are distributed where needed will maximise delivery to trade, biosecurity and plant health outcomes.

In order to support the needs of trade, biosecurity and plant health diagnostics, an evaluation of the demands on different types of collections is required, followed by analysis of how the different types of collections within the system can meet these demands, and then what distribution of collections scopes and roles will meet these needs. The results of the recent collections and capability audit will direct and support the evaluation process (Hodda *et al.* 2017b).

Action 2.1: Assess the requirements of the national plant biosecurity system and whether the distribution of collections, together with the scope and role of each collection, currently meets these needs

Collections will change over time, as will the demands on them. A mechanism is needed to maintain the alignment of the scopes, roles and distribution of collections with the demands of trade, biosecurity and plant health diagnostics.

Collections are at risk when reference material is no longer appropriately maintained or preserved. Too often collections have been orphaned or mothballed, resulting in irreparable damage or loss of valuable reference material. Such losses have significant economic consequences in the costs of delayed diagnosis of trade-sensitive species, confirmation of area freedom, documentation of surveillance results, and determination of biosecurity breaches. So, a mechanism is needed for regular monitoring.

Action 2.2: Develop and implement a system for regularly monitoring the status, scopes and roles of reference collections

With information on collections that are inappropriate for their role, or else at risk of loss, a mechanism (with appropriate identification of responsibility) needs to be developed and implemented to ensure that the collection material is not lost, nor has its value lessened by being in the wrong place. Such a mechanism may require coordination and agreement between collections themselves, their governing jurisdictions, and the body supervising collections overall. The mechanism may involve or flow out of plant health diagnostic involvement in general collection fora such as the Council of the Heads of Australian Entomological Collections (CHAEC) or Council of the Heads of Australian Herbaria (CHAH) as recommended later in the strategy (Recommendation 6). Or the mechanism may involve the coordinator of the National Plant Biosecurity Diagnostic Network (NPBDN) (Recommendation 5).

Action 2.3: Develop and implement a method to address issues identified

Standards

Recommendation 3: Implement national and international standards for curation and custodianship of collections, recognising different types of collections

Not only must the right reference material be in the right collections, but the reference material in each collection must be fit for purpose. Without adequate curation, preservation, storage facilities, monitoring and maintenance, collection material will depreciate in value. As with other infrastructure like buildings, there are ongoing costs to maintain collections up to standards in terms of the quality of material and accessibility. Proactive approaches are required, as much of the reference material held in collections is irreplaceable. Once deterioration starts and is noticeable, in many cases it is too late to prevent substantial loss.

There has been little documentation of the standards required to maintain reference material in collections that support the diagnostic system. Appropriate standards are needed around curatorial techniques, physical and digital infrastructure and support systems (human and management).

Curatorial techniques include preparation of physical reference material (eg. specimens or DNA) so that it will last into the future and characters needed for diagnosis are available. Continual development of curation techniques is desirable as new diagnostic methods are developed. The growth in molecular diagnostics has resulted in collections developing new procedures and protocols for preserving and storing new material in ways that were not needed even a short time ago. Stabilisation, maintenance and storage procedures for DNA or RNA have had to be developed. In the future, new diagnostic methods may require further changes to current preservation and storage methods. Curation techniques require continual improvement, development and refinement.

The physical infrastructure of collections includes buildings, storage units, freezers, microscopes, curatorial facilities and many other items. Essential services that this infrastructure must deliver to collections include maintaining temperature and humidity within limits, preventing pest damage, providing back-up power for equipment, and preparedness for fire: a comprehensive list has still to be developed.

Collection support systems, monitoring regimes, management systems and human capability (including staff training, development and retention of expertise) require standards that have yet to be developed.

In addition to standards for current best practices in curation techniques, infrastructure, systems and human capability, improvements are also needed. Unless there are continued improvements, costs will grow as more material is incorporated into collections. Housing more of the right reference material adds greatly to the value of collections, and is essential to achieving the goal that they completely cover National Priority Plant Pests (NPPPs) and industry High Priority Pests (HPPs). Continued development of methods, materials and staff is necessary to make collections sustainable as they expand in range of materials housed and coverage.

Some improvements in the efficiency of basic collection tasks will accrue from swapping experiences with collections primarily involved in serving other national priority areas, such as conservation, as suggested in Recommendation 6. However, many improvements in basic collection tasks may also flow from including development and research in these tasks within the eligibility for NPBDN grants. Funding collection curators and custodians to meet, train and travel to other collections is an important step to improving efficiency.

Digital infrastructure is another area where standards are needed, and perhaps one of the most important. If collections are to operate efficiently as a network, and as part of the larger plant health diagnostic network, then certain levels of computer hardware, software and processes for data capture, management and delivery are required.

Developing relevant standards recognising the different types of collections is the first step towards collections implementing quality standards and ensuring effective, efficient and consistent delivery of plant pest diagnostic materials. The NPBDS recommends that management of quality systems should be at a national level and supported by governments. Indeed, development and implementation of standards could be seen as part of the role of some larger collections in the system.

Action 3.1: Identify and develop appropriate standards for collection curation, custodianship and improvement

Once standards have been developed, then they should be adopted and implemented. This will require the standards being available and known by collections, as well as incentives and resources for adoption.

One way of achieving this is by incorporation into Quality Management Systems (QMS). Implementing and improving QMS is already being addressed by the broader National Plant Biosecurity Diagnostic Strategy. The stakeholders in the

Intergovernmental Agreement on Biosecurity (IGAB) have recognised their responsibility to support initial and ongoing costs of maintaining these standards (NPBDS D2.2).

Action 3.2: Facilitate the adoption of standards in all reference collections

The adoption of standards for reference collection curation and custodianship will require regular monitoring to ensure compliance. How monitoring and compliance is effected needs to be determined, as well as who has oversight of the systems for auditing and compliance.

Action 3.3: Develop a mechanism for ensuring compliance with standards

Insects stored in ethanol. Material in collections must be stored in appropriate ways to ensure preservation

Accessibility

Recommendation 4: Improve accessibility of all collection material and information—including specimen records, images, sequences, biological data and environmental associations—through a diverse, dispersed, responsive system which will meet the scientific, regulatory and administrative requirements of trade and biosecurity stakeholders

Information about the materials in collections, data associated with this material, and the collections themselves should be convenient and efficiently accessible to all legitimate users. This access ensures the best return on the total, national investment in collections.

Currently, access to the information in collections is through a combination of:

- personal contacts with taxonomic specialists and curators;
- networking via the NPBDN;
- looking up paper and other non-digital records;
- accessing the individual electronic databases associated with each collection;
- accessing consolidated databases, such as the Australian Plant Pest Database (APPD) and Australian Faunal Directory (AFD); and
- accessing databases through a data aggregator, such as Atlas of Living Australia (ALA).

This may seem chaotic and uneconomic, but in fact it is a very efficient way to provide fast, efficient, reliable access to collection materials (see Heterogeneous data, distributed databases, parallel architecture and universal searches). In fact, the current system requires only a handful of enhancements to meet the needs of plant health diagnostics for trade and biosecurity.

Recommendation 3 of this strategy includes actions which will assist custodians of collections to curate their collections and organise associated information, so that the collections and information are standardised, secure and accessible to the custodians themselves. These actions and especially the standards adopted are also the foundation for making the collections and associated information accessible to external users.

There are significant challenges to making the collections and associated information accessible to external users:

- collections comprise very heterogeneous physical materials
- collections contain exceptionally diverse information, some of which is readily digitised (e.g. locality data) but some of which is not (e.g. information on collectors)
- some user needs are predictable (e.g. the need for access to distribution data for pest fruit flies), but other needs are not (e.g. specimens required urgently to compare with suspect new detections of exotics)
- collections are geographically and institutionally dispersed, reflecting local needs, and will remain so
- local databases at different collections use a range of applications with markedly different schemas (although there are broad structural similarities)
- a single digital database is unlikely to be feasible, as the data is owned by various custodian organisations and jurisdictions involving significant legal and administrative impediments to consolidation
- no existing collection database is close to being comprehensive
- the totality of information in the care of collections is so great that the cost and difficulty of creating a single, national database and transferring data into it would be very high.

Despite the challenges, there are also recent developments in data capture, digital technologies, information management, network connectivity and search strategies that can be applied to enable access to collection materials and information. A system for managing access to these diverse data sources needs to be investigated and tested to ensure it meets the needs of both the owners and the users.

Accessibility to collection materials also requires access to an authoritative nomenclatural database, including a mechanism for keeping track of name changes and miss-spellings. A nomenclatural framework is required to manage material in collections and the associated information, and for users to search for material and information. Ideally, this nomenclatural framework is comprehensive, reflects a robust taxonomy, is stable and is universally accepted. Unfortunately, many plant pests belong to groups in which the taxonomy is a work in progress, and where new pests emerge frequently as crops and cropping systems change. Some pests are especially prone to nomenclatural changes because they comprise rapidly-reproducing populations dispersed across wide areas and diverse agricultural systems and separated by diverse barriers, all the while under strong selection pressure. New species, races or pathotypes can emerge rapidly. Phenotypic variation can occur without genetic divergence and genetic divergence can arise without obvious phenotypic change. As a result, the taxonomy of these groups remains in state of flux: names change and new names are proposed for newly-identified or redefined genetic lineages.

While electronic systems are important in providing access to the information associated with collections, taxonomic specialists and curators remain vital to the system. A great deal of knowledge relevant to the diagnostics of plant pests (for example understanding of linkages, inconsistencies and uncertainties) resides in the heads of taxonomists and curators (Hodda *et al.* 2017b) and, of course, users rely upon these individuals when access to specimens, samples and the like is required. Systems to ensure accessibility to this knowledge, to the material contained in the collections and to improve opportunities for users to visit collections need to be developed as part of the accessibility requirements.

Action 4.1: Develop and implement systems to provide accessibility to all reference collections

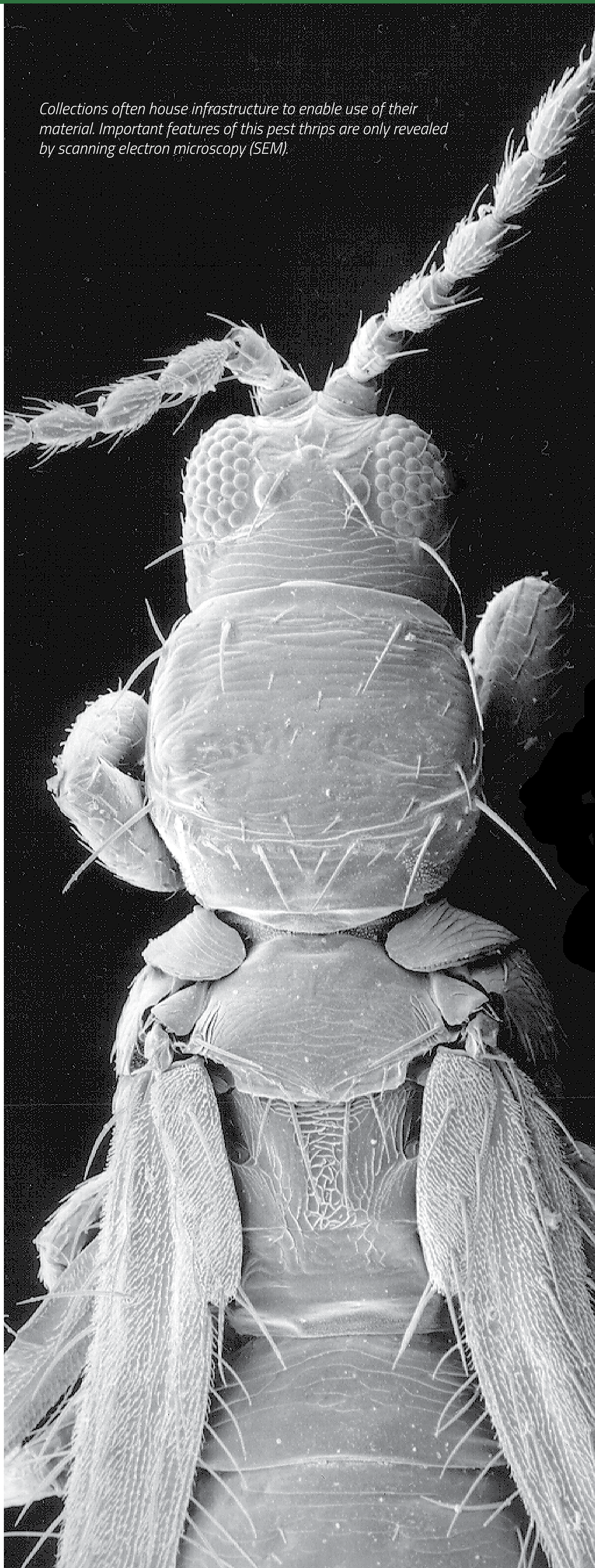
Digitisation of information associated with collection is still largely manual. Developments in artificial intelligence, robotics and image recognition, for example, may make more automated data capture feasible. More powerful technologies for consolidating, searching, and visualising data, and different computer interfaces are all likely in the future. Developments should be monitored to ensure that the strategy currently recommended and its technical implementation remain optimal. For example, high-resolution imaging systems for photographing entire insect drawers are becoming available, and images from these systems could be helpful for those needing to know whether a particular collection has material relevant to them or whether putative identifications are correct. The suitability, cost, physical and training requirements of these and other new technologies will need to be monitored and assessed relative to accessibility needs.

Digital systems are only as good as the data they have available. Development of such systems at the expense of improved data or other channels of access to collections may be detrimental.

Action 4.2: Ensure currency with developments in digital acquisition, presentation and delivery of information on all collection materials

The system for providing access to collections and information associated with collections should be monitored to ensure that it is meeting evolving user expectations. This monitoring should include a feedback mechanism to the collections from users of collections.

Action 4.3: Monitor the system to ensure it meets stakeholder requirements and implement strategies to address gaps



Collections often house infrastructure to enable use of their material. Important features of this pest thrips are only revealed by scanning electron microscopy (SEM).

Integration in plant health system

Recommendation 5: Integrate the trade and biosecurity functions of reference collections within the plant health system

The contributions of reference collections to the diagnostic system need to be coordinated with other elements of the system. Reference collections are just one element of the plant health system, along with human capability, information and the communication network between all of them. To deliver to trade, biosecurity and plant health priorities, all these elements should work together. This involves communication and coordination of the contributions of collections with other elements of the system.

The NPBDN is an important forum for exchanging plant health information in a secure environment. Membership is open to institutions as well as individuals, so ensuring all reference collections are members of NPBDN will greatly facilitate linkages, better connect diagnosticians to collections and allow sharing of potentially sensitive information. Membership of NPBDN allows participation in schemes to enhance the plant health diagnostic system, such as sponsored training courses and laboratory residential visits. The schemes have considerable potential to enhance the interactions between reference collections and human capability. The current scheme is already used to improve taxonomic capability using collection materials and to revise specimen identifications. Expansion of these schemes could include more focussed collection activities such as curation, sorting and taxonomic work with collections.

Action 5.1: Facilitate integration of collections within the NPBDN to ensure linkages between reference collections systems and other parts of the plant health system

Vouchering is a key role of reference collections in facilitating trade and biosecurity. It has been seriously neglected, with consequent potential to cause economic damage to Australia. International trade and biosecurity systems operate under the International Standards for Phytosanitary Measures (ISPM). Under the ISPM, vouchering of specimens and associated data is required to provide proof of surveillance for area freedom status. Attention to such vouchering is currently declining in Australia. Additionally, although there is mandatory reporting of new pests via the PIDS system, deposition of a representative sample into a reference collection is often not followed through. Coordination of reference collections with diagnostics and surveillance systems is required to improve this situation before Australia is caught out. Communication from the collections system as a whole is needed to the surveillance and diagnostic communities of the requirement for vouchering their specimens. Communication of collections' technical needs for material to be validly vouchered is needed to those supplying material. Communication from the surveillance and diagnostic communities to reference collections is needed on the nature and volumes of material to be delivered to collections.

Collection materials and information also contribute to particular surveillance and diagnostics tasks, such as determining whether an organism is a new pest or not. They can contribute more to policy makers and key industry representatives on the presence or absence of pests, determining which are high priority pests and the currency of EPP lists. Collections will better contribute to trade, biosecurity and plant health outcomes with better communication to surveillance, industry, policy and other parts of the plant health system outside the NPBDN.

Action 5.2: Facilitate communication between collections and components of the plant health system outside the NPBDN

The different parts of the plant health diagnostic system can substitute for one another to a certain extent (Hodda & Dawson 2017, Hodda *et al.* 2017a,b). For example, with collections containing specimens of all variants of a pest, together with closely-related and easily-confused species, a person with general diagnostic skills could diagnose a pest without specialist taxonomic skills in the group or sequence information or keys: the excellent collection resource substitutes to a certain extent for human capability and information. Conversely, with very limited collection material but a specialist taxonomist plus extensive literature and sequence information, diagnosis of a pest can also be completed: the human capability and information resources substitute to a certain extent for the collection.

To enable the coordination of the different parts of the plant health diagnostic system the needs and contributions must be evaluated. This must be done for each pest separately because the contributions of the different elements varies among pests. For example, diagnosis of Khapra Beetle relies heavily on collections for diagnosis, but Plum Pox Virus and *Xylella fastidiosa* rely mostly on sequence information. Hence an evaluation of the needs and contributions of the different diagnostic resources—collections, human capability, information and linkages—is needed for all high-priority pests.

Action 5.3: Undertake ongoing assessment of reference collection coverage for priority pests relative to other diagnostic resources

The contributions of reference collections to the national goals in trade and biosecurity, as well as local and specific issues, must be recognised to maintain sustainable support for their activities. Evaluating these contributions has been the subject of previous recommendations but the results of these evaluations should be communicated to those with responsibility for the whole system. This is a specific recommendation because such communication is not the role of any particular reference collection.

Action 5.4: Promote awareness of the role of reference collections to trade and biosecurity

Right: Some longhorn beetles are serious exotic pests, but some are benign natives: collections such as this help differentiate the two.

Coordination with other collections

Recommendation 6: Ensure that there is communication and coordination between the various stakeholder communities in collections, including environmental and scientific sectors

Many of the collections serving trade and biosecurity serve other functions as well, such as biodiversity or scientific record-keeping. Some collections are particularly focussed on organisms directly related to plant health, while others are not particularly focussed on plant health at all. In practice though, all collections—whatever their primary focus—are of value for plant health diagnostics. Common native relatives and lookalikes of exotic pests are often the province of biodiversity studies and environmental collections rather than plant health collections, yet are essential material for developing accurate plant health diagnostics.

Material collected for monitoring the environment may be essential historical records for surveillance of plant pests. Conversely, material in plant health collections may be needed for identification when pests are found in natural environments during environmental studies. Such records of pests in natural environments also need to be reported back to the plant health system. Type specimens of plant health pests may be held primarily as scientific records, rather than specifically for plant health diagnostic purposes. There are many techniques for curation, storage, information capture, data management and other tasks that are common to all collections whatever their focus: sharing such techniques has considerable value.

To ensure that the potential synergies are recognised and realised, all stakeholders in all types of biological collections should be recognised and communicating. Environmental biosecurity, biodiversity and national infrastructure are some potential stakeholders, but others require identification. Communication among all collections is also central to coordinating them for the greatest benefit to trade, biosecurity and plant health diagnostics (as well as other functions). Therefore, exchange of information between the representation of the plant health diagnostic community and presentation of plant health issues at the fora for collections is required.

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Action 6.1: Ensure exchange of information important to plant health among all stakeholder

There are many opportunities for synergies and coordinated activities with the wider biological collections community, for example new curation techniques, specimen collections and collection management issues. Currently, these opportunities are often missed because they fall across traditional organizational and funding boundaries. A mechanism needs to be developed to ensure these opportunities are realised.

Action 6.2: Enhance coordination of activities important to both reference collections and stakeholders

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Storage and protection of collection assets requires substantial infrastructure of a sufficient standard

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