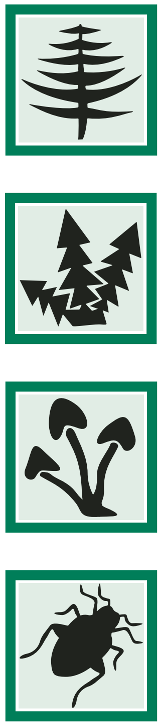
Guidelines for surveillance for plant pests in Asia and the Pacific

Teresa McMaugh



Australian Government

Australian Centre for International Agricultural Research

Rural Industries Research and Development Corporation

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Foreword

Countries negotiating trade in agricultural commodities that may provide pathways for moving pests into new areas must be able to access information on the biology, distribution, host range and economic status of plant pests.

While plant health has become a trade policy issue, knowledge of the health status of a country's agricultural and forestry industries has other important applications. These include the development of robust quarantine policies and the management of endemic pests.

Plant health problems affect society in many ways. As yields are reduced, farmers' incomes are similarly affected. Consumers have less food and fewer food choices or the food may contain chemical residues. As well, many areas of society may be affected by incursion of new pests, diseases and weeds into a community.

Virtually all of Australia's livestock and cropping industries are based on exotic germplasm. Through rigorous quarantine action over the last 100 years Australia is free from many serious exotic pests and diseases. The favourable health status of Australia's agricultural industries provides a competitive advantage in accessing foreign markets.

It is important to all of ACIAR's partner countries to know what plant and animal health problems occur in their territories. ACIAR has previously published instruction guides on how to survey for animal health problems and aquaculture health problems. ACIAR has also helped individual developing countries to survey specific pests — for example, fruit flies in a number of Asian and South Pacific countries, whiteflies in the South Pacific and others. However, no systematic attempt has been made to give countries generic skills to undertake their own surveys in the field of plant health.

Production of this manual has also been supported by the Rural Industries Research and Development Corporation (RIRDC). It is important to RIRDC that Australia has the capacity to take pre-emptive actions to mitigate threats posed by exotic pests. This manual, through training plant health authorities in regional countries to describe the health status of their crops, allows Australia to address pest threats at source rather than after they are detected in Australia.

This manual will assist plant health scientists to devise surveillance programs and to transmit specimens to the laboratory for identification and preservation. Countries can then begin to share results of the surveys with each other and this should lead to increasing wider cooperation in plant health research.

This publication is available for free download from ACIAR's website www.aciar.gov.au.

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Preface

In 2001–02, the Australian Agency for International Development (AusAID) funded the Office of the Chief Plant Protection Officer, Australian Government Department of Agriculture Fisheries and Forestry (DAFF) to report on the state of the arthropod pest collections and plant disease herbaria in the ASEAN countries. The work was undertaken in collaboration with ASEANET.[1] In their reports[2], the authors concluded that none of the countries of the region had a capacity to provide an adequate description of the health status of its crops. The problem was attributed, in large part, to the small numbers of specimens of plant diseases held in biological collections. The arthropod pest collections were generally much better populated than the plant disease herbaria, but all would benefit from additional resources and assistance to bring them up to contemporary international standards.

Pest[3] collections are significant because they provide the most reliable evidence of the plant health status of a country. These records are the foundation for developing robust policies for domestic and international quarantine and for developing pest-management strategies at the farm level. The collections have taken on particular significance since the establishment of the World Trade Organization (WTO) in 1995, which was heralded as opening a new era in trade liberalisation.

Unlike its predecessor, the General Agreement on Tariffs and Trade, the WTO is a rules-based organisation, with the rules governing trade in agricultural commodities set out in the Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS Agreement). While trade in agricultural commodities has expanded since 1995, exports from developing countries have not expanded to the same extent as trade between the developed members. The developed countries have expanded exports by using the rules of the SPS Agreement to prise open markets previously closed on questionable quarantine

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1 ASEANET is the South East Asian LOOP (Locally Organised and Operated Partnership) of BioNET INTERNATIONAL, a body that works collaboratively to develop regional self sufficiency in taxonomy and biosystematics.

2 Evans, G., Lum Keng-yeang and Murdoch, L. 2002. Needs assessment in taxonomy and biosystematics for plant pathogenic organisms in countries of South East Asia. Office of the Chief Plant Protection Officer, Department of Agriculture, Fisheries and Forestry, unpublished report.

Naumann, I.D. and Md Jusoh, M. [Md Jusoh Mamat] (2002). Needs assessment in taxonomy of arthropod pests of plants in countries of South East Asia: biosystematics, collection and information management. Office of the Chief Plant Protection Officer, Department of Agriculture, Fisheries and Forestry, unpublished report.

3 The term is used herein to include arthropod pests and plant pathogens.

grounds. At the same time, governments in the many countries are under pressure from their farmers to use the rules to exclude commodities that they see as posing a threat to their industries. Plant health has become a major trade-policy issue.

A country that cannot provide an adequate description of the health (pest) status of its agricultural industries is at a disadvantage when negotiating access to foreign markets. Prospective importers will assess risk based on their knowledge of the pests in the country seeking to export, the likelihood of introducing exotic pests of concern with the imported commodity and the availability of phytosanitary measures to reduce risk to an acceptable level. Extensive specimen-based records are the key for developing countries to negotiate with developed countries on a fair trading system.

Many collections of arthropod pests and plant diseases are the product of work dating back a century or more. The early curators of these collections sourced specimens from practising plant-health scientists, farmers and from their own collecting trips. While specimens submitted by plant-health scientists and farmers are still valuable, the collection of specimens has become more purposeful than in the past, driven by the need to expand scientific knowledge about biodiversity, concern about the need to recognise alien pests in new environments and a desire to expand trade in agricultural commodities.

Countries wanting to expand exports of agricultural commodities under the rules of the WTO do not have the luxury of building their pest collections over an extended period. Nor do they have to. The development of specimen-based pest lists can be accelerated through structured surveillance programs, focusing on the pests that might be carried on the commodity to be exported. Often the trading partner will specify the extent of the surveillance activities to be undertaken, but not always. These guidelines have been written with a view to helping plant-health scientists needing to undertake surveillance activities, for whatever purpose.

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Glossary[4]

area

An officially defined country, part of a country or all or parts of several countries

area of low pest prevalence

An area, whether all of a country, part of a country, or all or parts of several countries, as identified by the competent authorities, in which a specific pest occurs at low levels and which is subject to effective surveillance, control or eradication measures

delimiting survey

Survey conducted to establish the boundaries of an area considered to be infested by or free from a pest

detection survey

Survey conducted in an area to determine if pests are present

general surveillance

A process whereby information on particular pests which are of concern for an area is gathered from many sources, wherever it is available and provided for use by the NPPO

International Plant Protection Convention (IPPC)

An international convention deposited with FAO in Rome in 1951 and as subsequently amended

International Standard for Phytosanitary Measures (ISPM)

An international standard adopted by the Conference of FAO, the Interim Commission on Phytosanitary Measures or the Commission on Phytosanitary Measures, established under the IPPC

international standards

International standards established in accordance with Article X paragraph 1 and 2 of the IPPC

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4 For International Standards (ISPMs) and definitions, see: International Phytosanitary Portal at <https://www.ippc.int/IPP/En/default.jsp>, the official website of the International Plant Protection Convention.

monitoring survey

Ongoing survey to verify the characteristics of a pest population

National Plant Protection Organization (NPPO)

Official service established by a government to discharge the functions specified by the IPPC

> The IPPC (1997), in relation to its main purpose of "*securing common and effective action to prevent the spread and introduction of pests of plants and plant products,* (Article I.1) requires countries *to make provision, to the best of their ability, for an official national plant protection organization,*" (Article IV.1) whose responsibilities include the following:
>
> "*…the surveillance of growing plants, including both areas under cultivation (*inter alia *fields, plantations, nurseries, gardens, greenhouses and laboratories) and wild flora, and of plants and plant products in storage or in transportation, particularly with the object of reporting the occurrence, outbreak and spread of pests, and of controlling those pests, including the reporting referred to under Article VIII paragraph 1(a)…*" (Article IV.2b).
>
> **ISPM 17**

non-quarantine pest

Pest that is not a quarantine pest for an area

pest

Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products

pest free area (PFA)

An area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained

pest free place of production (PFPP)

Place of production in which a specific pest does not occur, as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained for a defined period

pest free production site (PFPS)

A defined portion of a place of production in which a specific pest does not occur, as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained for a defined period and that is managed as a separate unit in the same way as a pest free place of production

pest record

A document providing information concerning the presence or absence of a specific pest at a particular location at a certain time, within an area (usually a country) under described circumstances

pest risk analysis (PRA)

The process of evaluating biological or other scientific and economic evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it

pest status (in an area)

Presence or absence, at the present time, of a pest in an area, including, where appropriate, its distribution, as officially determined using expert judgment on the basis of current and historical pest records and other information

quarantine pest

A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled

Regional Plant Protection Organization (RPPO)

An intergovernmental organisation with the functions laid down by Article IX of the IPPC

regulated pest

A quarantine pest or a regulated non-quarantine pest

regulated non-quarantine pest (RNQP)

A non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party

specific surveys

Procedures by which NPPOs obtain information on pests of concern on specific sites in an area over a defined period of time

surveillance

An official process which collects and records data on pest occurrence or absence by survey, monitoring or other procedures

survey

An official procedure conducted over a defined period to determine the characteristics of a pest population or to determine which species occur in an area

Abbreviations

ALPP	area of low pest prevalence
APHIS	Animal and Plant Heath Inspection Service
APPPC	Asia Pacific Plant Protection Commission
AQIS	Australian Quarantine and Inspection Service
ASEAN	Association of Southeast Asian Nations
ASEANET	South East Asian LOOP of the BioNET INTERNATIONAL
AusAID	Australian Agency for International Development
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization of the United Nations
GPS	geographical positioning system
ICPM	Interim Commission on Phytosanitary Measures
IPPC	International Plant Protection Convention
ISPM	International Standard for Phytosanitary Measures
ISSG	Invasive Species Specialist Group
LOOP	Locally Organised and Operated Partnership
NAPPO	North American Plant Protection Organization
NAQS	Northern Australia Quarantine Strategy
NPPO	National Plant Protection Organisation
PFA	pest free area
PFPP	pest free place of production
PFPS	pest free production site
PNG	Papua New Guinea
PRA	pest risk assessment
QDPI&F	Queensland Department of Primary Industries and Fisheries
RPPO	Regional Plant Protection Organization
RSPM	Regional Standard for Phytosanitary Measures
SPC	Secretariat of the Pacific Community
SPS	Sanitary and Phytosanitary Measures
USDA	United States Department of Agriculture
WTO	World Trade Organization

Chapter 1

How to use these guidelines

1.1. Scope and readership

These guidelines were written to assist plant-health scientists design surveillance programs for detecting arthropod pests and plant pathogens in crops, plantation forests and natural ecosystems. The publication covers the planning of surveillance programs for building specimen-based lists of pests[5], surveillance for monitoring the status of particular pests, surveillance for determining the limits of distribution of pests, surveillance for determining the presence or absence of pests in particular areas, and general surveillance.

Those who were initially responsible for planning the production of these guidelines had in mind the needs of plant-health scientists in developing countries of the region, particularly those countries wanting to build specimen-based pest lists to support negotiations to expand trade in agricultural commodities. To that end, the Australian Centre for International Agricultural Research (ACIAR) and the Rural Industries Research and Development Corporation (RIRDC) provided sufficient funds to involve plant-health scientists from a number of the developing countries in Southeast Asia and the Pacific in the production of these guidelines. ACIAR also provided funds to engage selected specialists from Australia in the process. Together, the regional and Australian specialists constituted a 'reference group' that convened in Canberra, Australia, in November 2004 to oversee the production of this publication. The reference group was concerned that the manual should not be too prescriptive, noting that the approach to surveillance for plant pests needs to be flexible, taking into account such matters as the resources available and difficulties in accessing some sites where pests might be found. With these limitations in mind, the reference group was of the view that the word 'guidelines' should appear in the title rather than calling the publication a 'manual' or 'toolbox'. A number of the members of the reference group also volunteered contributions that form the case studies at the end of the guidelines, based on surveys for plant pests in selected countries of Southeast Asia, some Pacific island countries and Australia.

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5 The term pest is used throughout this publication in a generic sense and includes reference to arthropods, plant pathogens and weeds.

The guidelines take the reader through a series of easy-to-follow steps to design a surveillance program, emphasising the need to carefully document the process. At each step, useful tips are provided on things to think about in advancing a surveillance plan. The guidelines also provide advice on how to approach the critical issues of how to design a statistically valid surveillance program that will meet the most rigorous demands of bureaucrats, trading partners and others who must have faith in the results, for whatever purpose the surveillance is undertaken.

The reference group, ACIAR and those who were responsible for the production of this publication expect that it could be used by any plant-health scientist planning a surveillance program. Those scientists who are novices at surveillance should find the guidelines particularly useful. The process of planning a surveillance activity drawing on these guidelines will quickly build the confidence of any novice and greatly improve the design of pest surveillance programs.

1.2. ISPMs and terminology used in these guidelines

International standards have been developed to guide how trade in agricultural commodities can be achieved with the lowest possible risk of moving pests between the trading countries. The main standards are the series of International Standards for Phytosanitary Measures (ISPMs). These have been developed and endorsed by the Interim Commission on Phytosanitary Measures (ICPM) under the aegis of the International Plant Protection Convention (IPPC). The purpose of the IPPC is to secure common and effective action to prevent the spread and introduction of pests and to promote measures for their control. Contracting parties to the IPPC have the right to use phytosanitary measures to regulate the entry of articles, including whole plants and plant products, capable of harbouring plant pests.

As international standards have been developed that relate to surveillance for plant pests, the guidelines in this book have included and followed the ISPMs whenever possible. As the standards were written to encompass many countries and situations, it has been necessary in these guidelines to provide a great deal more information about designing surveys than is in the standards. Wherever the ISPMs are relevant to sections in the guidelines, the appropriate ISPM passages are given. It should be noted that the ISPMs primarily target trade-related surveillance, which is not the only reason surveillance is performed. These guidelines cover the design of surveys for most purposes, including trade-related activities.

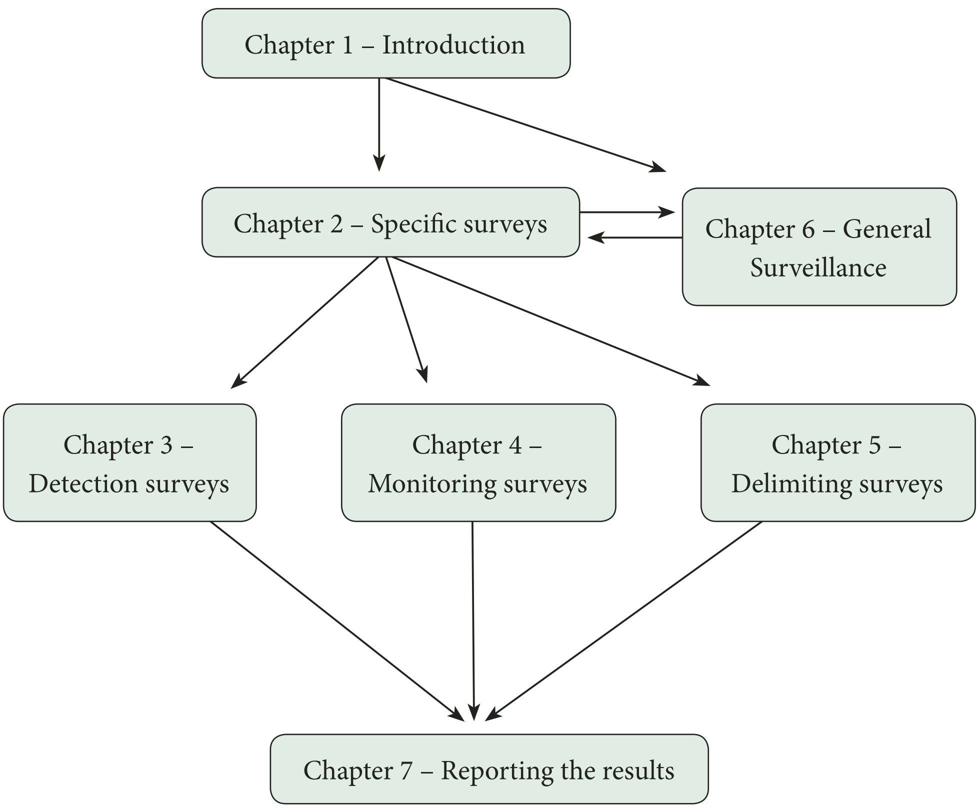
Whenever possible, ISPM definitions are used in the guidelines. The glossary of ISPM terms that relate to surveillance is published in ISPMs 5 and 6. The most relevant entries are reproduced in the glossary of these guidelines.

An important distinction to be made at the outset is use of the terms 'general surveillance' and 'specific surveys'. Often, people misunderstand 'general surveillance' to mean performing a field survey for all kinds of (general) pests. On the contrary, general surveillance is an umbrella term that is not clearly defined in the ISPMs. In these guidelines, the term is understood to include a range of activities. The first and most common use is the gathering of information about a particular pest. Other activities include public-awareness campaigns as well as reporting networks specifically for NPPOs. Specific surveys are those survey activities that involve field work; so specific surveys include surveys that look 'generally' for pests or for 'general' pests in the field.

1.3. How best to use these guidelines

The focus of these guidelines is to provide guidance on how to design specific surveys. The ISPMs divide specific surveys into three categories: detection surveys, monitoring surveys and delimiting surveys. Chapter 2 is the most important chapter of these guidelines and should be read and understood, irrespective of what type of survey you intend to design. Chapter 2 provides information about the basic components and content for any specific survey. The design is set out in 21 steps. The first 20 steps are in Chapter 2. Step 21—Reporting the results—is covered in Chapter 7.

Chapters 3, 4 and 5 provide additional information about the three ISPM categories of specific surveys and each relates back to Chapter 2. Chapter 6 is dedicated to general surveillance. Chapter 7 details how to report survey findings. Chapter 8 includes a number of examples of specific surveys that cover a wide range of pests and conditions. These case studies were contributed by numerous plant-health experts from the Southeast Asian and Pacific regions and Australia.



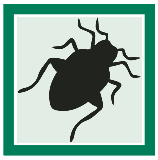
1.4. Symbols in the text

Symbols have been added throughout the text to draw the attention of people who are particularly interested in one or other of four main topics: weeds, forests, plant pathogens, and insects and allied forms. The key to the symbols is:

Forests

Weeds

Plant pathology



Insects and allied forms

Chapter 2

Designing a specific survey

2.1. Introduction

Specific surveys involve field work—going out and looking for the pests. This chapter covers the steps on how to decide where to look, how many places to look in and what sort of data to collect. The chapter goes on to provide information on how to collect and preserve specimens, followed by discussion of other important considerations to make the most of your survey, including guidance on what to do with the data collected.

Before you can go into the field and begin looking for pests, there are many planning decisions to be made. A survey plan needs to be robust, and the results should represent the actual pest status. The plan needs to be feasible both physically and financially.

There are no hard and fast rules about the correct number of samples, or one correct way of designing a survey. Because of this, it is important that the reasons for the design steps chosen are transparent.

When planning a new survey, the details of the design need to be carefully recorded and justified. If you provide justifications, or reasons for particular choices, it will be easier and faster for you or someone else to design similar survey plans. By providing reasons, you will also assist anyone who might later use your report as part of general surveillance. Your reasons and decisions may need to be justified if the plan requires approval from an NPPO.

While some decisions may change when the plan is put into practice, these changes can be added along with reasons for the changes.

The remainder of this chapter describes the 21 steps involved in the design and conduct of a survey. These are shown in Figure 1.

2.2. Step 1. Choosing a title and recording authors

Choose a simple title for your plan. You may wish to revise it as you go along.

Include the names of the people responsible for producing the survey plan and where they can be contacted.

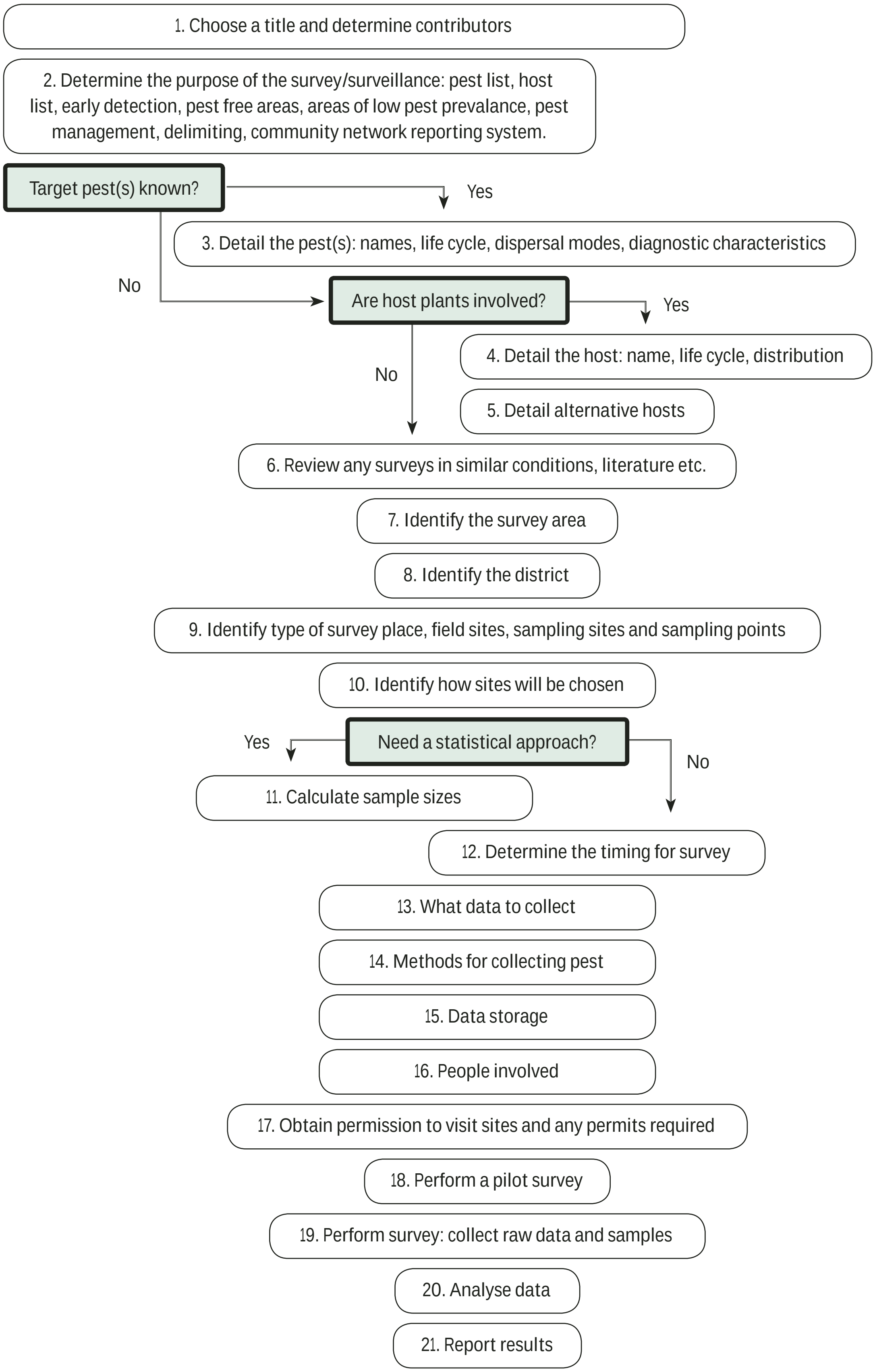


Figure 1. Steps to designing a specific survey.

Step 1

- ▶ Record the title of your survey.
- ▶ Record the names of authors.

2.3. Step 2. Reasons for surveying

There are many reasons for surveying pests. As discussed in Chapter 1, some of the reasons are:

- to develop a list of pests or hosts present in an area
- to demonstrate a pest-free area (the absence of a particular pest in an area) or places of low pest prevalence for trade purposes
- to develop a baseline list of pests before ongoing monitoring for changes in pest status
- for pest management and control
- for early detection of exotic pests
- for early detection of established organisms becoming pests
- to delimit the full extent of a pest following an incursion
- to monitor progress in a pest eradication campaign.

You may have other reasons that are combinations of the above.

Box 1. Surveying to test an association

If you are trying to see if the presence of a pest is associated with another factor, such as a particular type of place (for example, on road verges or near mobile-phone towers) or variety of host, then an experiment testing the hypothesis needs to be designed. This 'hypothesis testing' is different from surveillance.

Testing an association must be very carefully designed to exclude all other possible explanations of pest distribution and be able to isolate the factor. In this situation, you would need to test if the effect was true or false without biasing the results. Such experimental design is not covered in these guidelines. For more information, search for the term 'hypothesis testing' on the Internet.

Step 2

- ▶ Record the purpose of your survey.

2.4. Step 3. Identify target pests

If the targeted pests are not yet known—for example, you intend to survey for new weeds—skip ahead to Step 4.

If you do know which pests you intend to survey, this step involves gathering as much information as possible about the pests.

2.4.1. Useful sources of information

Finding information on pests—their life cycles and identifiable characteristics—can be easier for pests that are already present in a country, because there are likely to be local and overseas experts (entomologists, pathologists, plant health and quarantine officers). Information on exotic pests can be obtained from countries where the pest is known to be present. This may involve contacting the agricultural department of the government (in particular, the NPPO), by finding published material or by searching on the Internet (be careful to assess the credibility of the source of the information). There are numerous lists and databases that can be accessed that describe a wide range of pests, e.g. the CABI Crop Protection Compendium.

From ISPM 6 (FAO 1997, p.7):

> These [information] sources may include: NPPOs, other national and local government agencies, research institutions, universities, scientific societies (including amateur specialists), producers, consultants, museums, the general public, scientific and trade journals, unpublished data and contemporary observations. In addition, the NPPO may obtain information from international sources such as FAO, Regional Plant Protection Organizations (RPPOs), etc.

Other sources could be:

- existing PRA reports, either conducted by your own country or by agencies of other countries
- reference collections of insect pests and plant pathogens of agricultural importance
- pest and disease interception databases from quarantine authorities
- the Internet (see Box 2, page 24).

2.4.2. Verifying the information sources

ISPM 8 has a basis for evaluating the reliability of a pest record that could equally be applied to assessing information sources to be used in developing your survey. The relevant elements in a table provided in ISPM 8 are the categories of expertise of contributors and the quality of written information sources. Examine any available sources of information in terms of authoritativeness of the people associated with the material and the quality of the information provided.

2.4.3. Pest names

Begin by creating a list of the scientific and common names of the targeted pests. Include synonyms.

2.4.4. Pest vectors

Identify any vectors of the pests that are to be surveyed. If the pests have vectors, they will need to be included in your list of target organisms.

2.4.5. Possible pest impacts

Consider why these pests are chosen—are they regarded as major pests or pest threats? Do trade partners want more information on the status of specific pests in your area?

In general terms, describe how the pests would be likely to affect a host, production system or ecosystem, and the industry as a whole.

2.4.6. Pest characteristics: how would the pest be identified in the field?

The diagnostic characteristics of a pest, or symptoms of its presence, can be compiled from many sources. For pests that are already present in a country, farmers and foresters may be familiar with the pest. Ensuring that the pest has been correctly identified may require confirmation by a plant pathologist for plant pathogens, an entomologist for insects and allied forms, or a botanist for weeds. You may need to create a list of specialists and laboratories that have experience with the pests and the diagnostic capacity to identify them, depending on what pests you intend to survey.

Where host plants are involved, describe the parts of the plants most likely to be infested or infected, and which parts of the plant should be examined, e.g. stem, bark, leaves, roots, crown, base of plant. Does the pest target a commodity, e.g. fruit or grain? Is the pest associated with particular stages of a host plant's growth? Is the pest attracted by light or pheromones? Describe where the pest or the characteristic symptoms would be found on the host or commodity; for example, flying above a crop, bored into bark, the underside of leaves, frass at the base of plant, presence of curly leaves, growing along the crop rows. A botanist can assist in identifying the range of possible hosts for a plant pest. Are there any factors that affect symptom development, such as host cultivar, growth stage, season, pesticide application and climatic conditions?

Include all available information about the pest's life cycle.

2.4.7. Collecting reference specimens and images

For both general and specific surveys, images of the diagnostic features of the pest and any effects on host plants would be useful for reports. Having handout material that can be used in the field may be critical to detection, particularly if the pest has not been seen before by the surveillance team. Having a reference collection of pressed examples of plants or affected plants, or small specimen collections of invertebrate animals may also prove useful as long as they are not cumbersome and can be protected from damage. Electronic images can be collected from a number of sites on the Web, photographed using a digital camera, or you may request them from colleagues or email networks. These can be used to create pest information sheets.

Box 2. Internet resources for pest information

Animal and Plant Heath Inspection Service (APHIS) of the USDA

At: <http//:www.aphis.usda.gov/ppq/index.html>

This website has links to the North American Plant Protection Organization (NAPPO) standards as well as the International Standards for Phytosanitary Measures. The site has manuals on a number of invertebrate pest species, with useful information on identification, survey methods and pest control. Pest risk assessments of commodities being considered for import into the United States are available for numerous pests and these can provide readily accessible information about host ranges and surveillance methods, amongst other useful sections. APHIS also provides a useful website at <http//:www.invasivespecies.gov/databases> with links to a wide range of pest information databases; for example, those databases listed in this box under HEAR and ISSG, journal article databases and some dealing with aquatic pests.

American Phytopathological Society (APS)

At: <www.apsnet.org>

APSNet contains discussions of plant pathogens through newsletters, and a limited image collection. It also contains a database of pest lists for different crops and commodities (see 'Common names of plant diseases' under 'Online resources' and type in a host or pest name). The Society produces four journals available on subscription: Phytopathology, Plant Disease, Molecular Plant–Microbe Interactions and Plant Health Progress.

CAB International (CABI)

At: <www.cabi.org>

CABI aims to generate, disseminate and encourage use of knowledge in the applied biosciences field. This includes the areas of human welfare and the environment. CAB International publishes numerous books and other reference material that are listed online at <www.cabi-publishing.org>. CABI publishes a comprehensive database of abstracts from scientific publications. This is available via subscription on CD and online.

CABI Crop Protection Compendium

The compendium contains fact sheets on a wide diversity of pests. To use the compendium online or from CD, a licence must be purchased and the software installed on a computer. More information and a free trial are available at <www.cabicompendium.org/cpc>.

Diagnostic Protocols (DIAGPRO)

At: <www.csl.gov.uk/science/organ/ph/diagpro>

This website is coordinated by the UK Central Science Laboratory to produce diagnostic protocols for fifteen organisms that are harmful to plants.

These protocols provide information about sampling, in addition to diagnostic features and methods.

European and Mediterranean Plant Protection Organization (EPPO)

At: <www.eppo.org>

This organisation coordinates numerous aspects of plant protection across most of the European countries. EPPO has produced a number of standards on phytosanitary measures and plant protection products. While these standards need apply only to dealings with the European Community, they also provide insight into the quarantine barriers in use. Some of the standards provide a list of pests and information about their control for different crops and about identification in the field (see 'Good plant protection practice' and 'Phytosanitary procedures' under 'Standards').

Germplasm Resources Information Network (GRIN)

At: <www.ars-grin.gov/cgi-bin/npgs/html/index.pl>

This site can provide information about taxonomy of plants. It permits searches at family, genus and species levels, as well as for common names. While it is not clear how to navigate the site (currently), it is worth persevering as the database is extensive.

Global Invasive Species Programme (GISP)

At: <www.gisp.org>

This program is partnered by the Convention on Biological Diversity. The GISP website largely discusses invasive species in general terms and provides useful links, such as those in this box. The CBD website (<www.biodiv.org/programmes/cross-cutting/alien>) has a number of case studies on a diverse range of invasive species, including those affecting agriculture.

Hawaiian Ecosystems At Risk (HEAR)

At: <www.hear.org>

The Hawaiian Ecosystems at Risk project aims to provide information and resources to assist in management of exotic invasive species in Hawaii and the Pacific.

The website contains links to a global compendium of weeds at <www.hear.org/gcw>. This compendium has unillustrated fact sheets containing what limited information has been collected to date. The sheets cover alternative names, pest status, origin, environmental extremes tolerated and whether or not the plants are cultivated.

The HEAR website contains links to the report: 'Invasive species in the Pacific. Technical review of regional strategy', produced by the South Pacific Regional Environment Programme (SPREP). This report reviewed the pests that posed threats to the Pacific region when written in 2000. See <www.hear.org/AlienSpeciesInHawaii/articles>.

International Plant Protection Convention (IPPC)

At: <www.ippc.int/IPP/En/default.htm>

The IPPC website contains the ISPM standards and links to other multinational plant protection organisations.

Invasive Species Specialist Group (ISSG)

At: <www.issg.org>

This site has two useful products: a list-server of specialists; and the Global Invasive Species Database.

ALIENS-L is an email list-server of the Invasive Species Specialist Group (ISSG) of the World Conservation Union (IUCN) Species Survival Commission, organised through the SPC. This is a discussion forum for any type of invasive organism and so the topics can be broad. This is an easy way to ask questions of an expert group.

To subscribe to the email list send an email to <Aliens-L-request@indaba.iucn.org>, with a blank subject line, and 'join' in the text field.

The Global Invasive Species Database provides information on species that threaten biodiversity, and covers both plants and animals.

The database can be found at <http//: www.issg.org/database/welcome/>.

Landcare Research, New Zealand

At: <www.landcareresearch.co.nz/databases/index.asp>

Landcare Research holds a number of biological and resource collections and databases. Lists of specimens held in collections are provided, which may be a useful resource if you require specimen copies, assistance with diagnosis or are looking for useful electronic images of pests. The collections include nematodes, arthropods, fungi and other pathogens, and plants that are native to New Zealand.

Pacific Island Ecosystems at Risk (PIER)

At: <www.hear.org/pier/index.html>

This website focuses on potentially invasive plant species that threaten Pacific island ecosystems. In addition, there is resource material, such as images and distributions of agriculturally important weeds.

PestNet

At: <www.pestnet.org>

PestNet provides an email network similar to that of the ISSG but is more targeted at agricultural pests. Its purpose is to help plant-protection workers in Southeast Asia and the Pacific. The topics discussed commonly relate to pest identification, requests for specimens and methods of controlling pests.

PestNet has a website that provides information on how to join the email listserver. Follow the instructions on the website for 'Join PestNet' at <www.pestnet.org>. The site also has a photo gallery of numerous pests.

Secretariat of the Pacific Community (SPC), Plant Protection Service (PPS)

At: <www.spc.int/pps>

This group coordinates issues of plant protection across Pacific countries and territories. The PPS focuses on preventative quarantine barriers, preparedness for incursions and management of pests. The site has specific reports on forest pests, their surveillance and management, and a Pacific pest list database.

Traditional Pacific Island Crops

At: <libweb.hawaii.edu/libdept/scitech/agnic>

This website is produced by the USDA's Agriculture Network Information Center (AgNIC) <http://laurel.nal.usda.gov:8080/agnic>. The site contains information on cultivation, pests and marketing issues of numerous Pacific crops such as kava and betel nut. Links to related sites at the University of Hawaii are included.

Enviroweeds

The Enviroweeds list server is moderated by the Cooperative Research Centre for Weed Management in Australia. It is used to distribute and discuss information on the management of environmental weeds in natural ecosystems. To subscribe to Enviroweeds, send an email message to <majordomo@adelaide.edu.au> and in the body of the message type <subscribe enviroweeds>. Do not type anything in the subject line.

2.4.8. Pest information sheets

Pest information sheets provide identifying details of target pests that the survey team can refer to in the field. You might call these sheets a 'field guide'. You will have collected all this information so far in completing this step and so can make your own pest information sheets. These sheets should be simple and easy to read.

A pest information sheet would include:

- the pest's common and scientific names
- host range
- symptoms and morphology
- colour photographs or diagrams of the pest showing the typical morphology at characteristic stages and on multiple hosts (as appropriate)
- preferred habitats—this might include 'unnatural' settings such as plant pots, dunnage (wood packing), market stalls, silos and ship containers
- if appropriate, details of pests that the target pest could be confused with.

Weed sheets would include pictures of the juvenile and mature plants and diagnostic parts such as flowers, leaves and buds in detail.

Step 3

- Record the names of the pest.
- Record the importance of the pest.
- Record the diagnostic characteristics of the pest, including the life cycle.
- Create any pest information sheets you will use in the field.

2.5. Step 4 Identify target host(s)

If host plants are not involved—for example, in the surveying of weeds or pheromone trapping of insects—skip ahead to Step 5.

2.5.1. Host names

List the common and scientific names of targeted host plants.

For forests, list the dominant tree species and common names.

2.5.2. Value of host or commodity

Describe the importance of the hosts; for example, their nutritional value to small communities, and their national or regional economic importance.

2.5.3. Growth habits and life cycle of host plants

Describe the growth habits of each host and any aspects of their life cycle that are relevant to the diagnosis of the pests to be investigated.

List how the host plants of interest are grown; for example, in fields, as a plantation crop, in home gardens, as amenity trees in public spaces.

How tall and bushy does the vegetation grow? How much of the plant could you see and access? Could you collect a specimen from the crown, the middle near the main stem, the tips of the growth, or at the base of the plant?

For weeds, what is the vegetation type in the area to be surveyed?

2.5.4. Accessibility of the host plants

If you are designing a specific survey, consider the vegetation and the areas in which the pest will be surveyed. Information about the accessibility of hosts would be important for a person using your report as part of general surveillance, as it may explain to them why only certain places were surveyed.

Box 3. ISPM quarantine pest categories

regulated pest A quarantine pest or a regulated non-quarantine pest

quarantine pest A pest of potential economic importance to the area endangered and not yet present there, or present but not widely distributed and being officially controlled

non-quarantine pest A pest that is not a quarantine pest for an area

regulated non-quarantine pest (RNQP) A non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party (ISPM 5)

RNQPs are present and often widespread in the importing country (ISPM 16).

Comparison of quarantine pests and RNQPs (ISPM 16)

Defining criteria	Quarantine pest	RNQP
Pest status	Absent or of limited distribution	Present and may be widely distributed
Pathway	Phytosanitary measures for any pathway	Phytosanitary measures only on plants for planting
Economic impact	Impact is predicted	Impact is known
Official control	Under official control if present with the aim of eradication or containment	Under official control with respect to the specified plants for planting with the aim of suppression

The remaining organisms would be unregulated (or ‘non-regulated’), whether or not they are a ‘pest’ in some other place or places.

How are the host plants ordered? If they are evenly in rows, could you walk between the rows? Could you see the entire plants in a row if you walked down it (consider potatoes compared to oil palm trees)?

If the vegetation is random, like native forests or market gardens, or even continuously planted, such as broadacre grain, where can you walk or drive? How much damage caused by walking through the crop would be accepted by the property managers? How far do you expect that someone could see into the crop or forest? What is the terrain like? Are there remote parts? Are there any dams, rivers or fences that may affect how you can access the site?

2.5.5. Regional distribution of the host

Describe the distribution of the host in the country/region of interest. List all of the locations by name. For commodity sampling, describe the environment where the commodity will be held during the survey. For example, packing sheds or local markets.

Step 4

- Record the names of the host plants.
- Record the importance of the host plants.
- Record the growth habits of the host plants.
- Record the likely accessibility if considering a specific survey.
- Record the regional distribution of the host plants.

2.6. Step 5. Alternative hosts

The timing of life cycles of other pests and hosts can interact with the pest of interest. Alternative sources of the pest might include other host plants nearby, or in nursery stock or in a seed bank in the case of weeds. These hosts would include *alternate* hosts for fungal pathogens that have an obligatory asexual or sexual life stage on alternate hosts.

Identifying the entire host range is particularly important for early detection surveys of exotic pests as well as delimiting surveys investigating the extent of a pest incursion.

This type of information can again be found from talking with locals, and from publications, databases and resources on the Internet.

Step 5

- Record alternative pest reservoirs.

2.7. Step 6. Review of earlier survey plans

Find out if your colleagues or others in your organisation have designed any surveillance plans. Contact your NPPO and ask the people there if they have any existing plans or can put you in contact with others in your country who have designed surveillance plans. If the plan is connected with trade, the NPPO will need to become involved as part of the process. You could also use the email address lists discussed in Box 2 to seek plans for similar pests or hosts under similar conditions.

These reports may provide you with useful information as you continue to design your plan.

Step 6

- Collect any accessible survey or surveillance plans or reports.

2.8. Steps 7 to 10. Site selection

There are usually six levels involved in site selection (Figure 2).

1. The first is selecting the 'area'. This is *an officially defined country, part of a country or all or parts of several countries* (ISPM 5) that encompasses where you would look for pests.
2. The second is selecting the 'district(s)' involved—these might be growing districts, or regions of the area that appear to fall into rough groups on a map.
3. The third is selecting the 'places' in the districts that could be surveyed; farms, forests, communities, villages, ports or markets, for example.
4. The fourth is selecting the 'field sites' within each place. These could be fields, plantation lots, market stalls (selling the target commodity) or agroforestry gardens.
5. The fifth level is selecting the 'sampling sites' within each field site. This could mean the quadrats, individual plants, trees or produce, transects, trees to which pheromone traps could be attached, or crop rows.
6. The sixth is selecting the 'sampling point', which is relevant when you need to choose specimens within a sampling site. For example, you may have selected 20 papaya trees per orchard as your sampling sites and intend to collect three fruit per tree, or examine the third apical stem from the top. In some instances, such as pheromone baiting or sampling commodities at markets, the sample point would be the same as the sampling site.

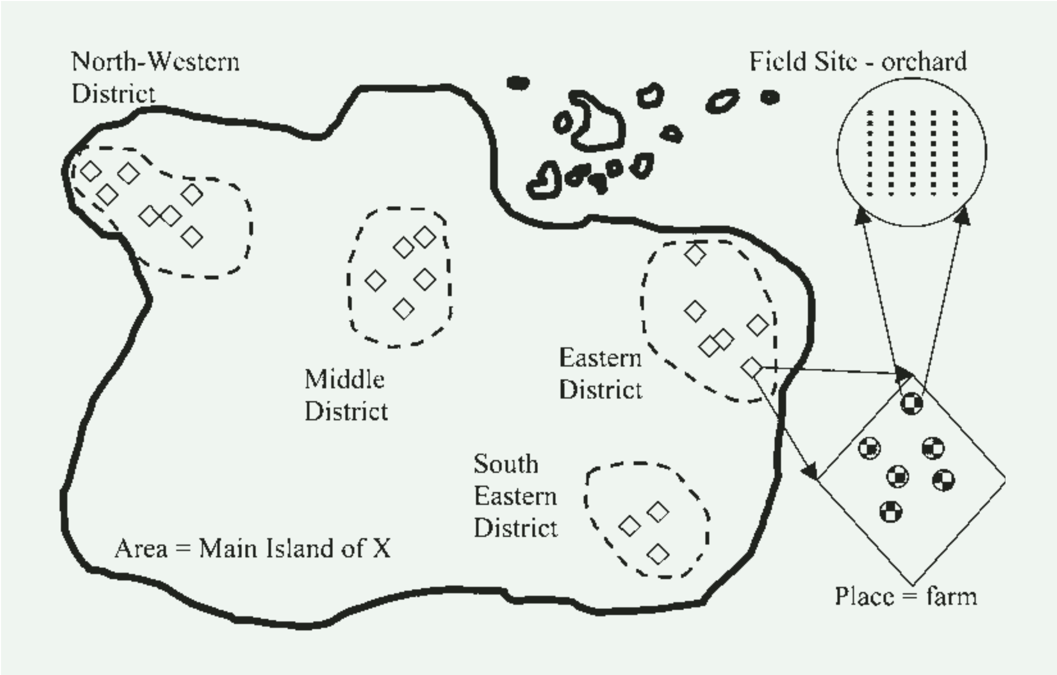


Figure 2. Diagrammatic map illustrating the concepts of area, district, place and field site

2.9. Step 7. Identifying the survey area

The area should be easy to determine. The area is either the entire country or a clearly defined part of the country around which effective quarantine measures can be established.

Step 7

- Record the area for your survey, which will be the same as that recorded at Step 5. Provide brief details on the climate, topography and geographic coordinates.

2.10. Step 8. Identifying the survey districts

If the districts in the area are not known, you will need to research where they are. This may involve speaking to people in the known districts; rangers or government and private organisations that represent particular growers, for example. It may require drawing the places on a map of the area to see trends. Districts may already be known, because they are climatically isolated, for example. There would normally be only one or a few districts and so they should be easy to identify.

Depending on your purpose for surveying, it will be clear to you which districts you need to survey.

Step 8

- Record the district(s) for your survey, clearly identifying each and providing general coordinates.

2.11. Step 9. Identifying the possible survey places, field sites and sampling sites

At this stage, work out what the characteristics of the places, field sites, sampling sites and sample points would be, i.e. what sort of locations they are. Refer to Section 2.7 for examples.

Some surveys will not have sampling sites or sample points, and some may not even require field sites. For example, a person viewing a forest for obvious symptoms from a cliff top could be surveying an entire place.

Step 9

- Record the characteristics of places, field sites and sampling sites.

2.12. Step 10. Methods for choosing sites

Every plan has to include surveying at the place level. This is the minimum level at which a survey can be performed. Some survey types are performed only at this level of site selection. These are surveying from a vantage point (see Section 2.12.3.12) and remote sensing (see Section 2.12.3.13).

Surveys that collect data only at place level are those that look at a large area from a high vantage point allowing the place to be scanned in its entirety. In order to do this, the symptoms or pests need to be obvious at a great distance. As the level of detail is low, surveying from such heights would be inappropriate for most survey purposes, especially those that need to satisfy the detailed requirements of trade partners.

Depending on the reason for your intended survey, you will either already know exactly which sites to survey or you will need to select the sites.

It is worth noting at this stage that there may not be a single best method for site selection. It also may not be possible to use the 'best' method, due to logistical or financial constraints. The main point is to transparently document your choices and reasons for the choices made. These can then be considered and discussed by other parties involved who may well agree with the basis of your choice, given the circumstances.

2.12.1. When you know which sites and how many to survey

Some surveys have to be targeted to particular places, field sites or sampling sites. A delimiting survey is one that involves looking at a pest infestation (so the place and field site are determined by circumstance) and working out how far the pest has spread and how it might have arrived. Delimiting surveys are covered in Chapter 5, but you should continue to work through the steps in this chapter.

In high-risk site surveillance, the places and field sites are determined largely by town planning—those sites where an exotic pest is likely to first appear and surrounding areas, such as sea- and airports. See also Section 2.12.3.1, Targeted site surveillance.

Blitz surveys (see Section 2.12.3.2) are different from all other surveys. They involve choosing a targeted field site (so the place, district and area are already known) and then performing an intensive and fast, 'full sample' at the sampling site level. See also Section 2.12.3.3, Full sampling.

2.12.2. When you need to choose which sites to survey

So how do you choose which sites to survey? Your approach will depend on any constraints imposed on the survey, the likely dispersal of the pest and the type of sampling plan that would best suit.

2.12.2.1. Logistical and physical constraints

The best scenario is being able to look at all places, field sites and sampling sites that are in the districts of concern. In many surveys, this is not possible, because of the costs involved. If you are unable to perform this 'full sampling' (see Section 2.12.3.3), identify your constraints and attempt to quantify these limitations. The point of this is that you may need to work backward and identify how many sample points and sampling sites you can feasibly survey within the limitations you may have on staff numbers, time, money, availability of expertise, weather or other factors. This may involve costing a hypothetical survey (in money and time) and thinking through how the survey would work in practice. This information may then provide clues as to how many locations, places and districts you could survey.

2.12.2.2. Pattern of spread of the pest

If you assume that the pest is present in the area of interest, how would the pest spread or be dispersed? Understanding how the pest spreads across a crop or other sites will affect how specific surveys are planned. This is also relevant to general surveillance when interpreting reports of specific surveys that may be used as a source of information.

Pests such as flying locusts will spread randomly throughout a crop, while others, such as nematodes and some weeds, tend to clump in small areas of the field. Pests may also prefer particular aspects of an area, such as along a watercourse or fence line.

If the pest is expected to spread randomly, or that clumps of pests will be randomly distributed, then sampling anywhere in the field should give you an equal chance of detecting the pest. This is important when you cannot observe all of the sites.

If the pest tends to prefer a particular area of a crop, then this area may need to be specifically targeted in the sampling plan (see Section 2.12.3.1, Targeted site surveillance).

2.12.2.2.1. What if the distribution is unknown?

If the pest is present, a preliminary inspection during a pilot study (Step 18) can be performed. The landowners and farmers may also have knowledge of any patterns of concentration of pests.

2.12.2.3. Surveying all sites

If you choose to do all the sites at any one level, this is called full sampling of that level. Full sampling provides the most detailed data of all the survey types. More information on full sampling can be found at Section 2.12.3.3.

Another source of robust data can sometimes be people who work at the field sites. If there are people available who are very familiar with the site and the targeted pests, they may be able to narrow the search. See also Section 2.12.3.4, Crop/forest worker observations.

2.12.2.4. Surveying some sites

If you cannot attend all sites at each level, you will need to select which ones to attend. To do this you can use one or a combination of four tools.

1. The first is random sampling. This involves assigning all sites (of the same level) a number or symbol and then by using a random number generation method, the sites are selected and recorded. See Section 2.12.3.5, Random sampling surveys.
2. The second is systematic sampling. This involves selecting criteria to divide the sites into some form of regular intervals and then selecting on that basis (see Section 2.12.3.7, Systematic sampling surveys). For example, surveying every second site when listed by name in alphabetical order, setting up a grid of traps or parallel transects of a site.
3. The third is stratification, which can be used in combination with random sampling. This involves dividing the sites into logical categories and then systematically or randomly choosing sites from within the categories.
4. The fourth is targeted site selection. The sites are chosen based on where the pest is most likely to be, thereby deliberately biasing the selection process in favour of finding the pest. See Section 2.12.3.1, Targeted site surveillance.

> Surveys should normally be designed to favour detection of specific pests concerned. However, the survey plan should also include some random sampling to detect unexpected events. It should be noted that if a quantitative indication of the prevalence of a pest in an area is required, the results from targeted surveys will be biased and may not provide an accurate assessment.
>
> **ISPM 6**

For more information on bias, read Box 4.

There are some other methods that people use to select sites but the methods introduce selection biases and do not have an element of genuine randomness.

The first is haphazard sampling (see Section 2.12.3.9), in which a person tries to select (for example) places randomly without using independent random number generation methods.

The second is convenience sampling (see Section 2.12.3.10). This involves selecting sites according to ease of access, such as those closest to a road. This method is often used in forestry when large distances may need to be covered, and is termed a 'drive through' or 'walk through' survey (see Section 2.12.3.11). It can be used in conjunction with additional detailed surveys in selected sites.

Other survey designs that do not involve randomness, but are nonetheless valuable tools for assessing large areas of crops or forests, are viewing from a high vantage point (see Section 2.12.3.12) and remote sensing (see Section 2.12.3.13).

Step 10

- Record method for choosing places to survey.
- Record method for choosing field sites to survey.
- Record method for choosing sampling sites to survey.
- Tabulate all possible places, field sites and sampling sites being considered, providing these with individual identifiers.

As mentioned above, you may at this stage already know how many sites at each level to survey. If this is the case, go to Step 12 Timing of the survey.

If you have chosen a method, such as random sampling to select sites, you will now need to work out how many of these to survey. Go to Step 11 Calculating sample size.

2.12.3. How survey types affect site selection

2.12.3.1. Targeted site surveillance

Targeting particular sites is designed to maximise the chance of finding the pest.

Surveillance for early detection of exotic pests usually involves targeting sites that are the first point where exotic pests could arrive or infest. Goods and people that may carry pests enter a country by crossing borders or arriving at sea- or airports. Some pests can travel on the wind or down waterways that could cross between countries or islands. Depending on the possible routes of arrival, these sites are targeted for surveillance. The intensity of survey sites is highest around the first points of entry and then is reduced in frequency with distance.

Targeting can also be in the field or forest where surveillance is focused on host plants or sites where the pest is most likely to be present (and thereby deliberately introducing bias). This might include surveying fruit that ripen or drop early or are rejected in the packing shed; or areas in the field adjacent to a creek.

Field workers, property managers and others working at the places of interest, may be able to provide local knowledge of where any pests present may have been observed. This could identify particular niches where the pests could be found.

Advantages

- Useful for early detection of exotic pests.

Disadvantages

- Of limited value in providing information about the prevalence of the pest.

Box 4. More information on biasing the results

When samples or observations have been collected, recorded or interpreted in a way that consistently affects the data, either by overestimating or underestimating the actual number of pests, this effect is called bias and causes error in the results. This can easily happen in a number of different ways and, in some survey designs, aspects of site selection are deliberately biased. Deliberate biases may be introduced when the survey designer is trying to select the sites where the pests are most likely to be, rather than work out what the prevalence is over a large area.

In situations such as determining pest prevalence and investigating whether or not an area is truly free of a pest, it is important—in order to collect accurate information—to prevent as many causes of bias as possible.

Selection bias

It is easy to select a plant or site based on the characteristics of the sites that are being surveyed. Some symptoms or weeds are easily visible from a distance and naturally draw the eye toward these areas. Consciously or unconsciously, a person may head towards or away from pests. A person may want to avoid difficult or tedious locations, or tire of repetitive searching.

Counting bias

This bias results when counts, say pest per square metre, are consistently less or greater than the true number because the person involved consciously or unconsciously prefers a low or high score. This can be worsened if more than one person is involved in the counting and each person has a different counting bias. The capacity to identify a pest or its symptoms may vary between people inspecting sites.

Recall bias

Bias can be introduced when a person records data on a pest based on memory of earlier observations. Errors can result from not remembering accurately where, when or which pests were present or absent. These biases can be reduced by the collection of a specimen when possible and recording details at the time of observing the pest or symptom. If this is not possible, the recalled observations will need to be confirmed or treated with a degree of caution.

Sampling error

Sampling error could arise, for example, from any of the following circumstances: when insects on a plant are disturbed and then cannot be counted; where weather influences the count, e.g. leaves hang differently when wet; because of differences in pheromone plume carriage; or failures in collecting equipment. Errors from assessment arise when there are faults in measurement, such as incorrectly calibrated instruments, setting the traps to capture insects at times that do not show peak numbers or placing them too close together or too far apart, variation between different people's counting methods and diagnostic capacities, using the wrong pheromones, or inability to use equipment correctly or to handle samples appropriately.

2.12.3.2. Blitz surveys

The purpose of blitz surveys is to detect all pests present, even those in low numbers, and to identify less visible symptoms and newly emerging pests. These surveys involve the intensive inspection of all plants in a given field site or at a set time, generating pest lists for a host or range of hosts. The survey may be restricted to a list of pests that have particular relevance or risk. Blitz surveys are generally used only in high-risk areas such as ports. The surveys require a range of specialist botanists, entomologists and pathologists to be involved in identifying the weeds, insects or pathogens of interest. The effectiveness of blitz surveys to identify new pests depends on the vegetational structure—for example, surveillance of large trees is difficult, particularly for pests or symptoms that affect the tree crown—and on the resources and expertise of the specialists to diagnose the pests.

Advantages

- Provides high confidence about the pest status in a small area.
- Can be used to determine the pest prevalence in the area.

Disadvantages

- Information is restricted to a small area.
- Can be expensive or difficult to coordinate, particularly organising the involvement of numerous experts.

2.12.3.3. Full sampling

Full sampling involves examining all the sites at a particular level. This could be full sampling of all places right through to surveying all sampling sites at a field site. This term overlaps with blitz surveys which entail full sampling at the field site level.

Advantages

- Sampling all units means that there is no selection bias in the sampling plan and provides a high confidence in the data.
- Can be used to estimate prevalence and as part of early detection of pests or in monitoring surveys.
- If there is a low predicted prevalence of the pest, this type of survey will detect any pests present.

Disadvantages

- Full sampling has limited application, as often it is not possible to survey all host plants, sites or regions because of financial and logistical constraints.
- Full sampling may not be the best use of resources if, for example, there are many fields that could be surveyed, and only a few are surveyed in full. Resources would instead be better spent surveying fewer host plants per field and visiting more fields, as there may be wide variations in field-to-field prevalence of the pest.

2.12.3.4. Crop/forest worker observations

In this case, people who manage crops or forests report to a central person, say the property manager, pests that they have seen during their work. The workers must recall where, when and what they observed. Alternatively, landowners show surveyors where they have observed pests or diseased plants. Given an understanding of the closeness of the relationship between the observer and the plants and area involved, the information may save a great deal of surveying for early detection of pests. In these situations, it is very important that field workers be well informed of what the surveyors want to know.

Advantages

- Economical because the surveying is performed during other activities.
- The quality of data may be equivalent to a full survey if the workers are very familiar with the sites and pests, and especially if they have knowledge of the sites over time.
- Can be valuable in the detection of new pests.

Disadvantages

- Cannot provide a quantitative measure of prevalence unless the prevalence is low and obvious.
- The timely detection of pests relies on the frequency of the activity that brings workers to a site. This may be too infrequent; for example, in forests with difficult terrain.

2.12.3.5. Random sampling surveys

Usually, all sites and host plants cannot be examined and so a subset number of sites or host plants need to be chosen for surveillance. To avoid selection biases, all hosts and sites need to be equally likely to be surveyed. In random sampling surveying, the sites and plants are chosen by an impartial method that reduces the influence of human biases in the site selections. These impartial methods—methods to introduce randomness into a survey plan—are detailed in Box 5, page 42.

Systematic sampling (see Section 2.12.3.7) can also be viewed as having a random element if the intervals of the sampling are independent of the expected pest distribution. For example, regularly spaced sites should not coincide consistently with the presence or absence of the pest.

Advantages

- As the selection of sites is independent of the pattern of pest spread, a random element may detect pests where other survey designs might not. Because of this, the ISPM recommends that all survey plans *should also include some random sampling to detect unexpected events* (ISPM 6).
- Can be simple to introduce randomness into a plan.
- Can be used to determine pest prevalence as part of detection or monitoring surveys.

Disadvantages

- May lead to impractical site choices or order of sites to be visited and may need to be combined with other methods, such as stratification of higher levels than those randomised.
- Randomisation of sites may miss clustered pests, and may be frustrating if the pests are visually obvious and the survey design is committed to randomly selected sites that all miss the pests. (In this instance, you would reconsider the design choice.)
- There are some aspects of sampling that cannot be randomised. For example, trees in an orchard can be randomised as they are fixed in number and location. The selection of fruits on each tree cannot be randomised (before going to the field) as each tree will vary in the number and exact location of branches, leaves or fruit (etc.) on the tree. However, even in this case, a dice could be thrown where the numbers specify branch number from top or bottom or a hypothetical slice/portion of a plant. With a little imagination, randomness could be added to most elements of the sampling site selection process if needed.

2.12.3.6. Stratified random sampling

In stratified random sampling, the host plants or sites are systematically divided into groups and sites or host plants are randomly chosen within each group.

Example: 20 villages (level: place) are to be surveyed for banana diseases. Each village has 15 farms (level: field sites), a total of 300 farms. If 100 farms are to be surveyed, we could randomly choose the 100 from all 300. By chance, this may result in some villages having all their farms surveyed and others having none. If it is important that all villages be surveyed, the selection of the 100 sites can be stratified by village such that, for example, five farms per village are chosen randomly.

Advantages

- Provides a tool that allows an often practical element to be mixed with random sampling.
- Can be used to determine pest prevalence and as part of detection or monitoring surveys.

Disadvantages

- If the distribution of the field sites (e.g. number of farms per village) varies widely, sampling an even number from each farm may not show the true prevalence, as there would be an uneven distribution of the possible host sites. In this case, the selection of sites may need to be 'weighted' toward those places (villages) with more field sites (farms).

2.12.3.7. Systematic sampling surveys

Systematic surveys involve mapping out a site and surveying at regular intervals of distance, area or host plant. For example, examining the plants of every tenth row; every third farm; every eighth square metre; setting insect lures in a grid pattern; two apples from every tree; or performing parallel sweeps of a site.

Advantages

- It is simple and efficient.
- The sample number is proportional to the population size.
- It may not be necessary to count the entire population (i.e. to know exactly how many rows there are in all crops to survey) before developing and performing the survey plan.
- Survey staff have clear sampling instructions to follow.
- For pests with a clustered distribution, a systematic survey can provide a better chance of detecting the pest than can a random sample. This is because a random sample may completely miss even a large cluster that a systematic survey with close intervals would detect.
- Has a random element if the intervals are independent of the pest distribution.
- Can be used to estimate prevalence in monitoring surveys.

Disadvantages

- Difficult to use if the hosts are not growing in an ordered pattern or all areas are not equally accessible.
- Need to ensure that if the survey is subsequently repeated in the same locations, the same plants or square metres are not surveyed repeatedly. This could be achieved by moving the starting point (e.g. by one row) each time the survey is performed.

Box 5. Adding random elements into the survey plan

The 'W' sampling strategy and diagonals

Walking and examining hosts or square metres of soil in a very large zigzag pattern across the field or forest can add a random component to the sample sites chosen. Crossing the field diagonally, or in a large, inverted W pattern serves the same purpose. One problem with this approach is that if the field is to be surveyed more than once, then not all plants in the field have an equal chance of being examined and the same plants could be looked at repeatedly. Rotating or offsetting the starting point or direction to the field of the W, diagonal or zigzag could overcome this problem, providing there is little overlap.

Random number generation

Randomising the order in which sites are visited can be achieved by assigning each site a sequential number and carefully listing the sites and their numbers. It may be important to record the order in which the numbers are chosen because for some surveys, such as species-accumulation curves, this will determine the order of the sampling sites you will survey.

Generating a list of random numbers

Using dice, thrown objects, card decks and numbered pebbles

If there are only a few sites, randomly choosing the sites or order for sites to be surveyed can be achieved by rolling dice and recording which numbers come up and ignoring repeated numbers.

Alternatively, cards labelled with site numbers or names can be well shuffled and read off in the order they appear. Clearly, the cards must be very well shuffled as cards can clump and shuffle in groups, and the same sites could be selected more often than others. These methods are useful unless the number of sites is more than a literal handful of cards.

Another method is to stand at different positions in the field and throw a stick (or something that is visible and will not damage the crop). This method will be influenced by the individual's throwing strength, and if the object can be found. Throwing the object backwards may reduce the chance of throwing in a deliberate direction.

Pebbles numbered with a marking pen according to numbered sampling sites can be mixed and selected at random. Other items to hand, of reasonably uniform size, that could be numbered and mixed up could be equally useful.

Using Microsoft Excel on a standard computer

Work out the range of your site numbers. You may have 92 sites numbered 1 to 92.

Method one

Select a cell in a worksheet type in the function RANDBETWEEN. This function will generate numbers between a range that you choose. In this case, between 1 and 92. The equation would be

= RANDBETWEEN(1,92)

On pressing <enter>, a number between that range will appear. Copy and paste this formula into as many cells as you need, recording the numbers as they appear and skipping numbers that have already appeared. Record the number of random site numbers that you need. If this function does not work on your computer, use the Help feature of the program.

Method two

This method overcomes duplication. Using the example above, create a column containing numbers 1 to 92 in sequence. In the adjacent column cells, type = RAND( )[6] against the 92 cells. Select all the cells in both columns and <sort> (on the Data menu) using the column containing the random numbers as the sort column. This will sort the column containing the numbers 1 to 92 randomly, without any duplication. Then you can simply take as many numbers as needed working from the top.

Using the Internet

There are many sites on the Web that have tables of random numbers, or programs that generate random numbers which can be downloaded, but if you have access to the Internet, chances are that you will have access to Microsoft Excel and be able to create your own random number table. As website addresses often change over time, none are listed here. A simple search of the term ‘random number table’ will be sufficient to find useful sites.

Using random number tables

Tables of randomly generated numbers can be found in print. Essentially these tables are generated using programs such as that described above, randomising numbers between 00001 and 99,999, to get sets of five-digit numbers. A table has been provided on the next page. You can use the numbers across or down the page. If we continue the example above in which the highest site number is 92, which is a two-digit number, we read the numbers in sets of two digits and ignore numbers that are single digit and those that are less than 1 or greater than 92. The numbers 1 to 9 are preceded by a 0, i.e. 01 to 09. For example, the first row of numbers is:

56888 17938 03701 19011 21795 81858 84375 52174 30547 01838

This is read as 56 then 88, ignore number 8 as it is a single digit, then number 17, ignore number 93 as higher than 92, ignore the number 8, then 3 and 70, ignore the 1 and so on until enough sites have been chosen. The next time that you require random numbers, start somewhere else in the table, read down the rows or even read the numbers backwards.

---

6 Do not insert anything between the brackets

If you are choosing from a three-digit number, e.g. you have a total of 480 sites (so numbers between 001 and 480), read the first three digits and ignore the fourth and fifth of each random number, i.e. ignore 568 as greater than 480, ignore the 88, record 179, ignore the 38, record 037, ignore 01, then 190, ignore 11, then 217, ignore 95 and so on.

Latin squares

Another simple method for introducing a random component into the sampling plan works by assigning sites a number or letter. The order in which sites are observed is the same but the starting site at each successive survey changes.

This might be useful to reduce any bias that results from time including season. It is usually used when all the sites can be rotated through regularly.

e.g.	Visit sites in this order:				
time point 1:	A	B	C	D	E
time point 2:	B	C	D	E	A
time point 3:	C	D	E	A	B
time point 4:	D	E	A	B	C
time point 5:	E	A	B	C	D

Random number table

56888	17938	03701	19011	21795	81858	84375	52174	30547	01838
49616	05027	58559	77518	88818	15510	05166	17778	45383	63979
87810	50654	12571	64281	18565	63604	97574	77022	10497	70113
77768	24763	85849	17644	59367	55704	67362	91953	87927	54886
15685	77153	56972	83849	91933	04399	54762	71614	87482	66997
57092	05782	67929	96388	87619	87284	16247	86247	68921	61431
45805	97856	91292	58860	19103	04612	88838	39043	28360	38408
52092	41346	76829	28270	42199	01882	43502	20505	92532	87558
78094	24397	88649	24778	14083	25737	96866	53011	60742	04056
42069	88809	18431	08841	19234	28425	08699	86805	11950	71287
88748	65229	69696	94302	99033	64739	41696	46127	05953	25836
77027	57205	73195	17923	13149	23871	64516	54129	60723	12240
14727	32085	97754	87565	68544	47424	18127	39214	31843	50282
67741	79843	97622	21539	83690	87439	42371	92319	95824	77041
73620	81275	57875	76408	47690	23760	67511	71723	86944	46318
27839	40135	78953	09577	70296	79014	72997	52780	62760	34873
81980	85841	90030	81070	98649	97659	10671	89893	21450	57957
63538	95903	70908	23910	57908	67982	27523	62498	27636	02209
34182	62714	03756	64533	26160	20042	11142	00536	93365	08796
30918	27213	10699	59679	59136	82891	77801	62105	81536	91477
85473	23571	50458	11012	03006	83667	68269	23315	18286	48988
53811	39465	95669	80783	34150	65472	90418	48305	32304	23130
90354	51729	98512	79972	29695	38245	38004	81201	31328	38571
75420	48164	33446	07120	13909	10215	51857	19984	41887	17670
00454	95064	31329	06519	85296	07531	22075	30769	73421	17858
61307	17016	64835	16959	47499	42525	38932	33886	48382	88842

2.12.3.8. Insect-trapping surveys

Insects can be caught by static traps that attract insects by light, colour or pheromones. The insects are then removed from the trap and identified. These traps are useful primarily for identifying whether or not a pest is present in the area.

The siting and density of traps is critical. Siting and density are determined by the trap type and the manufacturer's instructions, and applied according to the survey setting.

Traps are often used to estimate the prevalence of pests in the area. In some cases, the number of insects trapped is directly proportional to the true pest prevalence (e.g. 1 trapped fly could reflect 100 flies in the area).

Advantages

- Once set up, the traps can be left unattended for weeks.
- Very useful in the early detection of attracted pests.
- Placement of traps need not damage the crop or forest.
- Can be used as an indicator of the pest prevalence.
- Traps with selective lures help to target the catch to specific pests.

Disadvantages

- Some traps can fill with rain or have other design problems that may need to be managed.
- Traps can attract pests from outside the targeted area or from plants in nearby crops or native vegetation. This can cause difficulty in interpreting the catch. In this case, the host range for each species may need to be checked to ensure that the pest interacts with the targeted host.
- Counting and identification of pests from traps can be time-consuming and laborious.
- Using the number of pests collected as a quantitative measure of prevalence or density is complicated because of the many variables involved.
- If not set up with the correct density and positioning, pests that are present can be missed.
- The selectivity of lures can be restrictive when surveying to determine the entire range of pests present.

2.12.3.9. Simulating randomness—purposive and haphazard sampling

Purposive sampling involves choosing places, field sites, sampling sites or even sample points that the observer decides are representative of the whole site. This is based on the observer's preconception of what the pest status is and the observer will, consciously or unconsciously, be biased toward fulfilling that preconception.

Haphazard sampling is the term for observers attempting to collect 'random' specimens by mentally selecting sites sporadically. There is, nevertheless, a tendency for people to distribute sites uniformly, or choose sites based on an idea of a 'randomised' pattern. For example, people generally would not consider choosing clustered sites within a large area, and yet such a configuration can result if the sites are chosen randomly. If the sampling points are chosen in the field, rather than pre-selected from a map, the observer's eye tends to be drawn to certain plants or symptoms. The observer is then faced with a quandary: is the sampling truly random if these sampling points are consciously included or consciously excluded? In most situations, it is impossible for a person to truly simulate random sampling.

Advantages

- May be useful in circumstances where true randomisation is not possible.

Disadvantages

- Introduces biases into the data that may compromise the outcome.
- Cannot be used to estimate pest prevalence.
- May be unable to detect new pests in a timely manner.

2.12.3.10. Convenience ('rule of thumb') sampling

Sites are selected that are easy, quick or inexpensive to survey because, for example, they are close to each other, close to a road or access point, topography is easiest, or because a tree has lower branches or more fruit than others.

Advantages

- The method is convenient and rapid.

Disadvantages

- This approach has selection bias.
- Cannot be sure how representative the data are of the whole field site.
- Has no element of randomness.
- Cannot be used to estimate prevalence or to detect changes in pest populations or as a reliable early detection survey.

2.12.3.11. Drive/walk through surveys

In this method, one or two people drive a car, walk or ride a bicycle or motorcycle around or through an accessible part of the crops or forest, looking as far as they can see for any obvious pests or symptoms. They may stop and collect specimens if a pest or symptom can be sampled. The reliability of this type of surveillance is dependent on the skills of the observer, the density and height of the vegetation and of the symptoms or pests, the topography and how representative the visible areas are of the entire crop or site. In optimal conditions where obvious symptoms are being surveyed, driving speeds should not exceed 15 km per hour. In such circumstances, an observer could not be expected to see reliably more than 40 metres away (unless they are along a high vantage point).

Advantages

- Provides the 'quick once over' perspective of obvious symptoms.
- Does not damage the crop or forest being surveyed.
- May be useful in targeted surveillance or early detection of pests when the pests are spread by vehicles and people, and so are likely to be found on road verges.

Disadvantages

- Cannot provide a measure of pest prevalence.
- Cannot provide information on pests or pest symptoms that are difficult to see.
- The surveying perspective is restricted to accessible paths and roads.
- Could be dangerous to the surveyors if the drivers are not watching where they are driving.
- Dependent on the layout and number of roads at the site.

2.12.3.12. Viewing from a high vantage point

This procedure involves viewing the landscape from a high point such as on the top of a hill or the side of a valley. Binoculars can be used to increase effectiveness.

Advantages

- Information on large areas can be collected in a short time.
- Provides a 'quick once over' perspective for obvious symptoms.
- Allows the crowns of trees or other tall host plants to be seen.
- Permits surveillance of terrain that is difficult to cross on foot or by vehicle.

Disadvantages

- The symptoms or pests need to be highly visible, which may mean that the pest is well-established and has already caused significant damage.
- Cannot be used to accurately determine pest prevalence and/or for very early detection of a pest.

2.12.3.13. Remote sensing

Remote sensing is an umbrella term for methods of surveillance that are performed high above the ground, either at the altitude of an aeroplane or of a satellite—sensing the landscape from a remote perspective. Remote sensing works on the basis that the pest or host symptoms of interest are distinct in appearance from adjacent vegetation. The images of the vegetation are captured using sensors, such as specialised cameras or radar, and the image can be processed by computer programs. The programs can produce maps of vegetational types present and perform calculations such as the percentage of an area infested by a pest. Remote sensing has been used to detect and monitor damage caused by insect pests and plant diseases, as well as the presence and spread of invasive plant species.

For further information see:

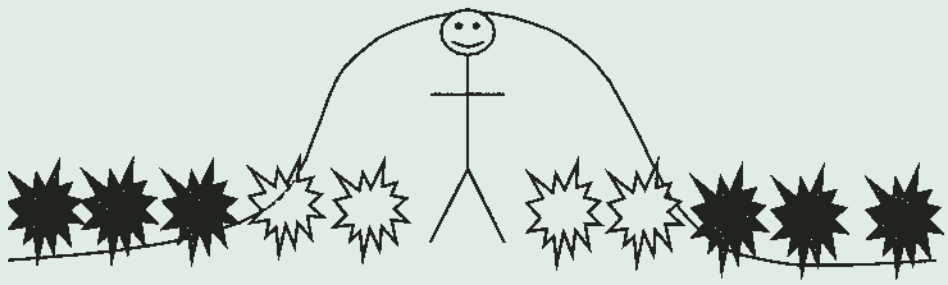
Greenfield, P.H. 2001. Remote sensing for invasive species and plant health monitoring. Detecting and monitoring invasive species. Proceedings of the Plant Health Conference 2000, 24–25 October, Raleigh, North Carolina, USA.

and the following journals:

International Journal of Remote Sensing
Photogrammetric Engineering & Remote Sensing.

Box 6. Validating data collected by viewing from a distance

When walking or driving in a straight line, a person is more likely to see pests or symptoms that are close by. As distance increases, there is less chance of them being able to see the pest or symptoms. Reliability is further influenced by the observer's height, visual acuity and speed of travel, weather conditions and the density of vegetation.



The ability of a survey team to detect pests and symptoms at various distances can be evaluated by placing artificial 'pests' at different distances along a pathway (or road etc.) and at different distances from either side of the pathway. The person placing the 'pests' records the distance of each one along and away from the path. Survey members then walk or drive along the path and record the distance along the path that they observe each of the 'pests'. The artificial pest should be something that simulates the size and appearance of the pest or symptom that will be surveyed, such as artificial frass (insect droppings) made from sawdust and glue that can be pinned to trees. The observations can then be collated for the team as a whole to work out at what distances from the path that the reliability of pest detection falls.

The tests could be repeated a number of times with the artificial pests being placed at different distances until enough data are collected.

Factors that may influence how effective team members are at detecting the pests will be the duration they have been surveying in the field on the day, weather conditions, the number of pests set out, the height of the pests and how obvious the pest or symptom is. Identifying factors that affect how the team perform could then be investigated to increase performance. For example, having breaks every 2 hours.

Advantages

- Information on vast areas can be collected in a short time.
- Can provide a crude estimate of prevalence.

Disadvantages

- Limited application as it can be costly (such as accessing satellites).
- Provides very general data.
- Will work only for pests or symptoms that are easily distinguishable from healthy adjacent vegetation.

2.13. Step 11. Calculating sample size

The purpose of a survey is the primary factor in determining the way sample size is calculated. The two approaches considered here are for detection surveys or monitoring surveys.

This section assists with calculating sample size for settings where you need to calculate the proportion of sampling sites or sampling units infested with pests; for example, either the pest is present on a fruit or tree or is absent. It does not deal with estimating a sample size to ensure an accurate measure of the *concentration* (or population density) of a pest, i.e. the number of pests per fruit or tree.

To calculate the sample size for your survey, there are parameters that need to be understood at least in concept. This step provides some basic calculations that you can perform, but statistics very quickly become complicated and this is when you may need to involve a mathematician or statistician who understands your statistical requirements. Once you have an understanding of the basic parameters explained here, you will be better prepared to provide the information that the statistician will need and have a better understanding of the outputs that they provide you with.

For more detailed information, you will need to read publications such as:

Binns, M.R., Nyrop, J.P. and van der Werf, W. 2000. Sampling and monitoring in crop protection. The theoretical basis for developing practical decision guides. CAB International, Oxon, UK and New York, USA.

This publication is written for people well-versed in mathematical statistics.

2.13.1. Statistical parameters for sample size calculation

The main parameters (expressed in percentages except for sample size which is in whole numbers) are as follows:

2.13.1.1. Actual prevalence

This is the true proportion of infested units in a population (infested by one or more pests).

2.13.1.2. Design prevalence

This is usually based on a pre-survey estimate of the likely actual prevalence of the pest in the field, and used to determine the sample size.

Clearly, for area freedom, the design prevalence and actual prevalence of a pest are expected to be near-zero. For surveys that monitor a pest that is known to be present, the design prevalence can range from near-zero to 100%.

If the design prevalence greatly overestimates the actual prevalence, the sample size calculated will be too small to detect the actual prevalence. If the design prevalence underestimates the actual prevalence, then the sample size will be larger than needed to detect the actual presence, leading to over-sampling. While over-sampling wastes resources, it is safer to over-sample than under-sample.

So how do you estimate the design prevalence? Even if it is near-zero, this parameter needs to be quantified. There are a number of ways to do so; see Box 7, Predicting prevalence. If you are unable to predict a meaningful prevalence, you need to choose a prevalence level that is acceptable to all parties.

2.13.1.3. Estimated prevalence

This is the prevalence determined during a survey, and is intended to estimate the actual prevalence.

The estimated prevalence found during the survey may not reflect the actual prevalence because of factors such as use of methods that have a poorer accuracy or sensitivity than was known or accommodated in the survey plan, or choosing a survey design that does not provide a true sample of the pest.

2.13.1.4. Confidence

Statistical confidence is the probability that the actual prevalence will be within range of the design prevalence.

If you surveyed and did not find the target pest, you cannot be 100% certain that it is not there without sampling every host plant or sampling site. Instead, you have to accept a degree of uncertainty about the plants or areas that have not been examined or tested. The relationship between confidence and sample size is simple—the more sites you survey, the more certain you can be about the accuracy of the estimated prevalence.

As a general rule, a detection threshold of at least 95% confidence is considered acceptable. Confidence up to 99.9% can be necessary in some instances. In some circumstances, choosing the confidence level will not be up to you. Trading partners may require a particular level of confidence that the pest would be detected in a survey, independent of any logistical or financial constraints.

Confidence is usually expressed as an interval of values for the prevalence, forming a range of values within which the actual prevalence is likely to occur with the chosen level of confidence. For example, a prevalence of 46.5% with a 95% confidence might be expressed as: 46.5% (95% CI: 44.2–48.8%).

The range of values is usually of equal ‘width’ (distance) from the prevalence and is termed the *confidence interval width*.

2.13.1.5. Accuracy of methods (sensitivity)

This deals with how well the survey will detect a pest when it is present.

Diagnostic methods used to classify the sample as positive or negative, particularly those involving chemical reactions, often have an estimate of how accurately the method detects positive results. For example, method accuracy can be altered if you are looking for pests on a row of trees but are inspecting only along a straight line. It is expected that the observer cannot see all of the trees if the foliage is dense or the symptoms or pests are not obvious (see Figure 3). An amount such as 80% can be specified as the accuracy of this method. Some methods can reasonably be expected to be 100% accurate. Method accuracy has a direct effect upon the ability to detect the presence of a pest and must be considered when estimating sample size.

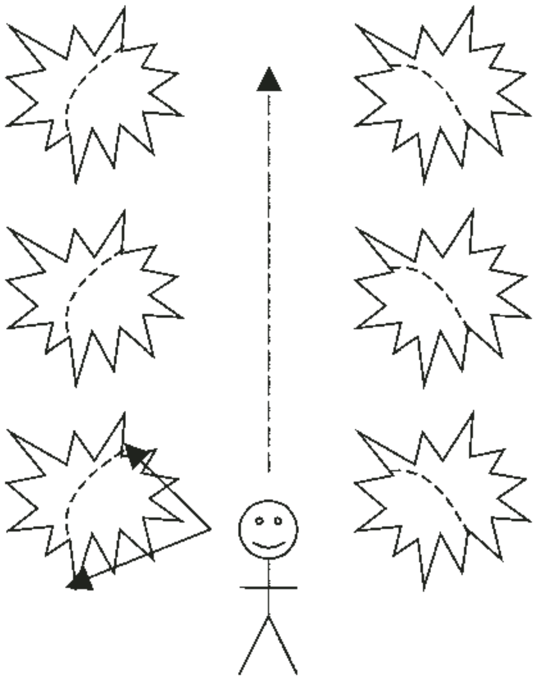


Figure 3. Straight line inspection of trees

2.13.1.6. Sample size

Sample size is the number of sites that you need to survey in order to detect a specified proportion of pest infestation with a specific level of confidence, at the design prevalence.

2.13.2. Formulas for detection surveys

These formulas are used when the survey is designed to detect a pest, and where the actual prevalence is likely to be rare.

A simple relationship exists between sample size, confidence level and detection threshold, where confidence is expressed as a percentage and detection threshold on a scale between 0 and 1.

Formula:

$$\text{Confidence level} = 1 - (1 - \text{design prevalence})^{\text{sample size}}$$

and therefore

$$\text{sample size} = \frac{\log(1 - \text{confidence level})}{\log(1 - \text{design prevalence})}$$

Table with calculations performed:

Table 1. Sample size without method accuracy adjustment

Confidence	1 – confidence	Design prevalence	1 – design prevalence	Sample size
0.95	0.05	0.01	0.99	298
0.95	0.05	0.02	0.98	148
0.99	0.01	0.01	0.99	458
0.99	0.01	0.02	0.98	228
0.95	0.05	0.001	0.999	2,994
0.95	0.05	0.002	0.998	1,496
0.99	0.01	0.001	0.999	4,603
0.99	0.01	0.002	0.998	2,300

If the method accuracy is less than 0.95, the sample size will need to be adjusted. Use the following formula.

$$\text{Adjusted sample size} = \frac{(\text{sample size above})}{\text{method accuracy}}$$

Box 7. Predicting prevalence

When the design prevalence is anticipated to be near-zero (detection survey setting)

To predict the pest prevalence, you need to estimate a 'pest prevalence start date' from when the pest could possibly have last entered the survey area. This date could be from when quarantine measures were put in place to prevent the pest entering the area. Alternatively, it could be when a pest was last officially eradicated from the area. At this time, it is assumed that a tiny number of the pests remained, so at the start date the prevalence is very low.

Next estimate the rate at which a small population of the pest would multiply and spread over time in the area as a percentage of the hosts/sampling sites affected. This is based on the pest's rate of multiplication, spread and survival. All predictions need to have some supporting documentary evidence. You then make a prediction of what the prevalence would be at the time you intend to survey.

When the predicted prevalence is thought to be greater than near-zero (monitoring survey setting)

Generally, if you know that the pest is present at the field sites you intend to survey, there will be data or anecdotes available about the prevalence of the pest at some time point. You may need to take into account how the time of survey relates to the pest's and host's life cycles, and any other conditions that may affect the prevalence, such as weather conditions. This activity falls under the category of *predicting by extrapolation* as detailed below.

Tools to help predict prevalence

Predicting by extrapolation

This is based on the observed rate of infestation of the same pest elsewhere, or in the same location before its previous eradication, allowing for different environmental conditions, through use of reports in journals, field observations and trials.

Predicting by comparison

This is based on the prevalence of a pest with similar population dynamics.

Predicting by modelling

This uses knowledge of the rates of infestation and spread under the conditions present since the 'pest prevalence start date'. It may involve complex computer modelling if there are no other useful or comparable sources of the likely pest prevalence.

Table 2. Sample size with method accuracy adjustment

Confidence	Design prevalence	Method accuracy	Adjusted sample size
0.95	0.01	0.80	373
0.95	0.02	0.80	185
0.99	0.01	0.80	573
0.99	0.02	0.80	285
0.95	0.001	0.80	3,743
0.95	0.002	0.80	1,870
0.99	0.001	0.80	5,754
0.99	0.002	0.80	2,875

2.13.3. Formula for monitoring surveys

Example scenarios:

1. Estimating the proportion of trees in an orchard or forest stand that is infested with a pest.
2. Estimating the proportion of fruit with a pest present.
3. Estimating the number of orchards infested with a pest.

The formula below is used when you choose to have 95% confidence and the expected prevalence is greater than 2%. This uses a variable called 'Z'. 'Z' is derived from the normal distribution and equals 1.96 for 95% confidence, used in the formula below. Note that for 99% confidence, 'Z' is 2.58 and for 90% it is 1.65. Confidence interval width and prevalence are expressed as a decimal between 0 and 1 for the formula:

sample size = (Z/confidence interval width)^2 × design prevalence × (1 – design prevalence)

For example, when the confidence interval width is within 5% and a design pest prevalence of 20% is selected:

sample size required = ((1.96/0.05)^2 × 0.2 (1 – 0.2)) = 246

Table 3. Example sample size calculations performed with a 95% confidence level

Confidence interval width[7]	Design prevalence					
	2% or 98%[8]	5% or 95%	10% or 90%	20% or 80%	30% or 70%	50%
± 1%	753	1,825	3,457	6,147	8,067	9,604
± 2%	188	456	864	1,537	2,016	2,401
± 5%	30	73	138	246	323	384
± 7.5%	13	32	61	109	143	170
± 10%	8	18	35	61	81	96
± 15%	3	8	15	27	35	42
± 20%	2	5	9	15	20	24

2.13.4. Determining sample size for multiple levels of site selection

Calculating sample size quickly becomes complicated when you need to determine many sites at more than one level. For example, you may have thousands of field sites to choose from as well as too many sampling sites at each field to be able to survey all of them. You may even have too many places to survey. These situations call for a hierarchical analysis of the number of sites to visit at each level. Such an analysis sequentially takes into account the number of sites selected at the preceding higher level. The complex mathematics entailed requires a trained person to perform the calculations.

Step 11

- Record the number of sites and samples needed, for the levels that you intend to survey.

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7 This percentage value (or 'percentage point') is a function of the design prevalence percentage. For example, a confidence interval width of 5% around a design prevalence of 20% means the width is equal to 5% of 20% i.e. ± 1%. This would also mean that the confidence interval ranges between 19% to 21%.

8 The sample size is the same for a design prevalence of 2% as 98% because the formula used to calculate sample size involves multiplying the design prevalence by 1 – the design prevalence, which means that pairs adding to 100% require the same number of sampling sites.