International Agricultural Trade and Policy Center

ECONOMICS OF MANAGING INVASIVE SPECIES IN TROPICAL AND SUB-TROPICAL AREAS OF THE U.S.A.: CASE STUDY DEVELOPMENT

By

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WPTC 03-5 **November 2003**

WORKING PAPER SERIES

UNIVERSITY OF FLORIDA

Institute of Food and Agricultural Sciences

INTERNATIONAL AGRICULTURAL TRADE AND POLICY CENTER

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Economics of Managing Invasive Species in Tropical and Sub-Tropical Areas of the U.S.A.: Case Study Development

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Introduction

The overall objective of this project is to provide decision makers and regulatory authorities with new resources for decisions involving invasive species management programs, including pre-entry quarantine measures and management of established pests. Within this broad objective, there are two specific objectives of the project:

1. Development of a comprehensive invasive species risk management framework that incorporates the economic impacts of invasive species.

2. Development of a collaborative interdisciplinary network of institutions and persons involved with invasive species management.

As part of these objectives, a number of case studies of particular invasive species problems in the collaborating regions will be done. The purpose of this paper is to provide project collaborators with background information for developing case studies of invasive species that will meet the project's objectives. The paper is in two parts. The first part of the paper outlines the requirements for developing case study proposals. The second part of the paper outlines data requirements from case studies for the risk management framework.

Part 1 Case Studies

The case studies are a key part of the project. They will:

- Provide the basis for studying important regional invasive pest problems.
- Develop applications of economics to the management of invasive species.
- Provide an initial database for the risk management framework being developed in the project, and that will be available for future studies of invasive species.
- Provide the basis of collaborative networks for invasive species management.

The following sections outline the context of invasive species management, the process for establishing case studies, the case study format and expected outputs.

1.1 National and International Context of Invasive Species Management

An "invasive species" is defined as a species that is a) non-native (or alien) to the ecosystem under consideration and b) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. (Executive Order 13112). Invasive species can be plants, animals, and other organisms (e.g., microbes) (http://www.invasivespecies.gov/).

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The problem of invasive (non-indigenous) species has become more urgent and far more complex today than in the recent past. “Animals, plants, and microbes can now migrate across the planet to new homes with unprecedented ease” (The Economist, 2000). The increased spread of invasive species is tied to the rapid pace of globalization and trade liberalization, which have resulted in more and faster trade and more opportunities for long-distance hitch hiking by invasive species. The increased trade in fresh commodities (particularly horticultural products, floricultural products, live animals and raw animal products) and increased international travel and trading have increased the risks associated with the spread of pests and diseases. In addition, they add to the concerns associated with enforcing quarantine, increased smuggling, food safety and the effects of pesticides and other control methods on the environment (Evans *et al.* 2002).

It is well established that invasive species, can impose considerable burden on society in the terms of damages and costs of eradication and control. However, it is only within recent times that there has been a greater appreciation of the full extent of the costs of the damages caused by pest incursions. For instance, invasive species can be extremely damaging to agricultural systems and, native plants and animals, particularly endemic species because natural predators and parasites that keep them in balance in the native land are usually not present in the new environment. Thus it is possible for an invasive species not to be a pest in its native land, but to cause significant damage in the new environment, which, in the extreme, could lead to the loss of biodiversity. Invasive species also have the potential to adversely affect important environmental service flows such as cropping systems, livestock grazing, and recreational uses. Water systems can also be affected when pests clog rivers, irrigation systems, and shorelines. In addition, they can have negative impacts on ecological services (Evans *et al.* 2002; Eiswerth and Johnson, 2002).

The risk of pest introduction or responses to actual incursions creates management issues for governments and regulatory agencies. Invasive species management starts with a pre-entry watch/alert system. Quarantine itself can involve permitting and/or inspection, pre-treatment standards and/or shipper certification, isolation for suspect shipments. If a species gets through the border, the next step would be monitoring, detection and identification of the organism, nature of the threat, location. If detected early, various management interventions can be tried to first contain the species including local quarantine, plus physical control (chemical, mechanical including capture/trapping, biological) measures. This is the best point for eradication. If the species is not detected or cannot be contained, it may spread to new locations and/or over a more extensive area. Management options are basically the same but more expensive and less effective. These issues can broadly be categorized as quarantine measures (pre-entry risk management) and invasive species management (post-entry management).

Once a pest has entered a country or region, invasive species management takes place. At this point, governments and regulatory agencies face a problem of how to manage the newly arrived species rather than how to manage the risk of it arriving. Typically this is an initial decision about eradication, but in the event that this is not undertaken, then decisions must be made about management. Depending on the pest, this may entail decisions about restrictions on movement of people or produce, regulations about control or public communication.

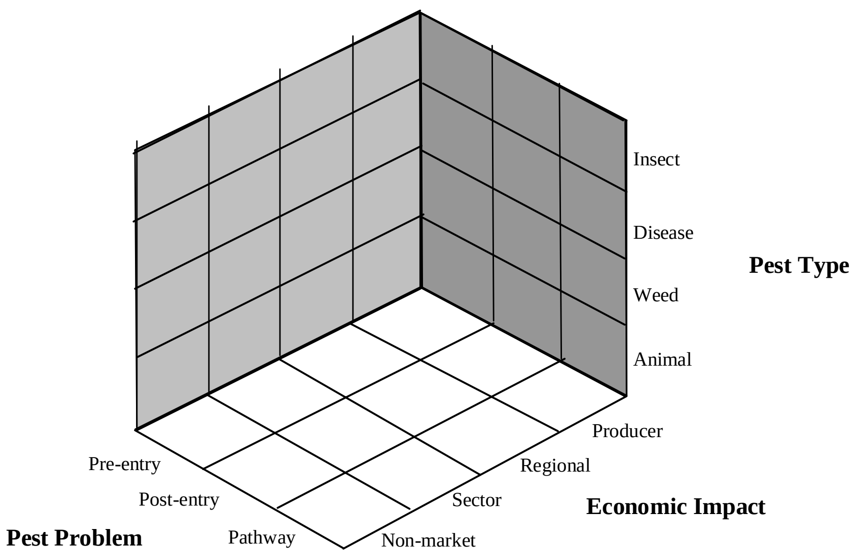
By and large, biological science researchers have developed the research agenda on invasive species, and much of the previous ‘economic’ research on invasive species has been conducted by non-economists. As such, the economic analysis either suffers from various methodological problems (e.g., incorrect economic valuation, ignoring non-market environmental damages) or from being peripheral to the biological study. Even though there are a few prototype theoretical economic models on managing invasive species, there has been little follow-up on these papers (Eiswerth and van Kooten 2002; Suter 1995; Thomas and Randall 2000). Many of the previous studies have been directed at specific situations with little attempt to draw out larger lessons.

1.2 Process for Establishing Case studies

The purpose of the case studies is to develop applications of economic analysis in resolving invasive species issues, and to provide data for a generic pest risk model. The case studies should be based on current pest issues in each region (potential or established pests), but in addition, collaborators should identify a range of potential and existing pest problems so that the development of a model will cover a comprehensive range of pest issues and management strategies. As a guide, Figure 1 outlines the range of potential pests and economic impacts that might be considered.

Figure 1

Case Study Matrix



As constructed there could be at least 48 different types of cases but the number of potential cases could easily exceed this amount since any of the categories listed in the matrix can easily be further subdivided. For example the category “Pathway” can easily be subdivided into “commercial” and “non-commercial”. In addition, since pre-entry quarantine actions are directed at commodities, any single measure will potentially impact more than one pest associated with the commodity. In-country measures, however, are directed at specific pests. Thus, the case studies will need to cover both individual pests as well as commodities.

Case studies will be carried out as separate projects, and published individually as they are completed. The exact format of each case study will be up to individual researchers. However, since a major aspect of developing the common conceptual framework in the project will be characterizing the pest risk assessment (biological and economic profiles) in each case study in a systematic way, the case studies must also provide standardized information for the generic pest risk assessment model. Each case study will estimate relevant probabilities and economic effects to identify the expected economic outcomes of likely management scenarios. This information is discussed in greater detail in Part 2 of the paper.

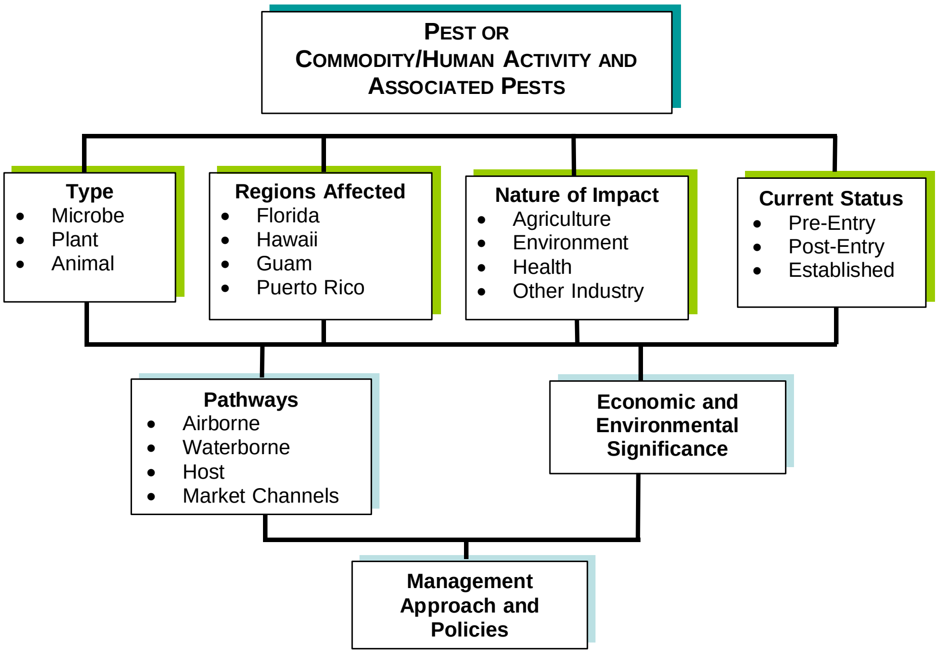
In order to ensure coordination of the project, the development of the case studies will follow this process:

- Preparation and circulation of a background paper on pest risk analysis outlining the types of information that will be required from the case studies.
- Initial identification of important pest problems and characterisation of the pest and its effects in the participating regions. Using the background paper, collaborators will identify cases that are important to their particular region.
- Convening of a Workshop to present and discuss potential case studies and provide feedback for the development of the conceptual framework and model.
- Confirmation of case studies.
- Conduct case studies.

1.3 Case Study Proposal Format

Development of the case studies should consider the full range of factors for a pest risk assessment (Figure 2). Some of the information is generic for a particular pest and some will be specific to a region or pathway.

Figure 2
Case Study Proposal Elements



The suggested format for preparing the case study proposals is outlined below. The purpose of this format is to provide sufficient information about how the case study fits into the wider project across all collaborators as well information about the specific research proposed in the case study. The proposals should be no more than 2 pages.

1. Principal investigator(s) and institution(s)

2. Pest problem
   - Commodity trade
   - Human activity
   - Pest name(s) (common and biological names)
3. Pest description
   - Type of pest (microbe, plant, animal)
   - Current status (pre-entry, post-entry, established)
   - Regions affected (Florida, Hawaii, Guam, Puerto Rico, other)
   - Type of impacts (agricultural, environmental, health, other industry)
4. Impacts of pest in case study
   - Pathways (commodities, mail, passengers, ballast water)
   - Economic or environmental significance (quantitative or qualitative description)
5. Management approach or policy options
6. Proposed Research
   - Research objective and approach
   - Previous and current work, known data bases (references)
   - Research Outputs
   - Potential Cooperating Institutions or Agencies
   - Funding Needed
   - Research Duration

1.4 Output

The output of this project is as follows:

- Decision Support System for invasive pests (Framework for invasive pest management, Invasive pest management software)
- Case studies of pest management
- Website and database
- Collaborative interdisciplinary network of institutions and persons involved with invasive species management

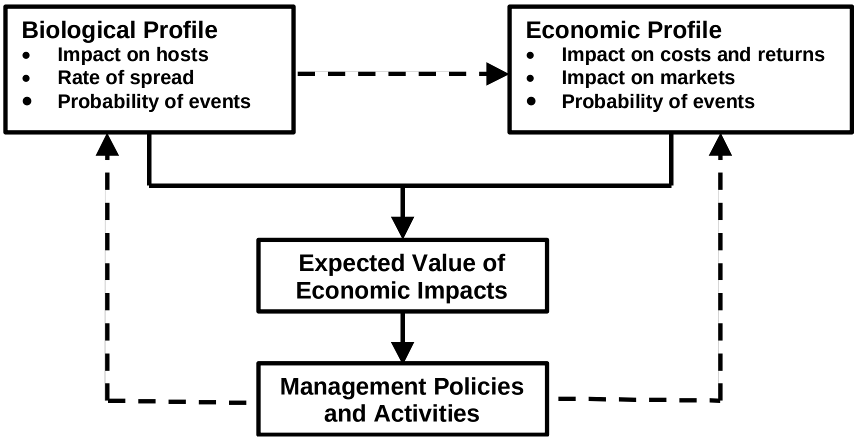
Section 2 Data for Risk Management Framework

The Society for Risk Analysis defines a risk as the potential for realization of unwanted, adverse consequences to human life, health, property, or the environment. Estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequences of the event given that it has occurred. Risk analysis is a management tool that incorporates scientific methods to enable decision makers to gather and assess information and data in a thorough, consistent, logical and transparent manner. In general the procedure involves the following steps:

1. Identification of the hazard or unwanted organism
2. Determining the likelihood of the introduction and spread of the organism
3. Assessing potential biological, economic and environmental consequences of entry, establishment and spread
4. Identifying policy options to effectively manage the risks posed by the harmful organism
5. Communicating the results, conclusions and recommendations to all interested parties

Figure 3, shows conceptually the general process to be followed in conducting the case studies. The project involves analysis of a range of different pest problems to identify the range of potential pathways, manifestation of pest effects and management strategies. This involves integration of scientific and economic inputs. Economic effects are linked to how a pest or disease manifests itself, or what can be called the biological profile of a pest. In turn, the biological and economic profiles combine to determine the expected value of economic impacts. Management policies and activities are stimulated by the expected value of economic impacts. In effect, management policies or activities are designed to change the expected value of economic impacts by modifying either or both of the biological and economic profiles. The following sections highlight each of these components.

Figure 3
Conceptual Model for Pest Risk Assessment



2.1 Biological Profile

The biological profile of a pest includes the physical effects a pest has on a host, the number of potential hosts, the effect of existing control measures, the probability of establishment and of becoming invasive once established, and the effect of existing management practices. This is in effect the science or technical component of the analysis where the impact of a pest on a host in the new environment and its rate of spread are considered. The biological profile is critical to defining the economic consequences of a pest.

As a guideline to what is required for a biological profile, APHIS's instructions for a pest description can be used as a starting point (APHIS 2000).

- Scientific name
- Selected references
- Limited pertinent information regarding:
  - The regulatory status of a pest, as determined by APHIS or other Federal Agencies
  - Pest biology (e.g. pest-parent species or pest-commodity association, pathway association, life history, climatic tolerance)
  - Geographic distribution with respect to the exporting country and the U.S.
  - Regulatory history (e.g. interception records at U.S. ports)

2.2 Economic Profile

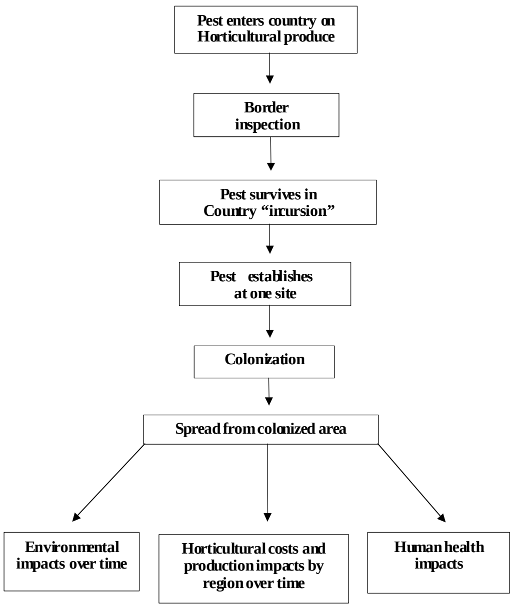
The economic impact component of the problem requires an analysis of potential pest effects. The economic impact assessment begins with a biological profile of a pest. The biological profile provides scientific information about the pest and its interaction with hosts. The biological profile provides the basis for an economic profile to be built. The economic profile determines the economically relevant effects of the pest and provides an indication of the appropriate scope and analytical approach for estimating economic impacts.

The key factor to consider here is that the type or method of economic analysis required depends on the economic consequences that have been identified as a result of the effects of the particular pest and host interaction. Each situation could be different, with economic effects possibly limited to a minor effect or a minor crop, or having a major effect on a key plant in an agribusiness sector. In this context, the pest's presence and way that the pest's effects are manifested are an important consideration.

2.2.1 Pest Presence

Figure 4 provides three definitions of pest presence.

Figure 4
General Model of Pest Introduction



While not strict demographic definitions, they allow all outcomes of pest entry and the costs of those outcomes to be specified. The definitions used include:

Pest incursion: At least one live pest is present but reproduction has not occurred (and may not be able to occur).

Pest establishment: The second generation of the pest is present i.e. it is possible for reproduction to occur and it has done so at least once.

Pest colonization: The pest is present in at least one region in numbers sufficient to have some impact on plant production.

2.2.2 Characterizing Pest Effects

For the purpose of pest risk assessment, economic effects can be categorized as direct and indirect pest effects, and as market and non-market effects. The direct and indirect categories refer to the way in which the effects of a pest are manifested, and in turn, point to the way in which the effects might be measured. Direct pest effect concentrates on direct impacts of a pest on a host species, and covers host-specific impacts like yield loss or mortality. It can include a range of hosts such as agricultural and horticultural crops, pasture plants, forests, and controlled or wild environments. Indirect pest effects cover non-host specific impacts. These are economically relevant effects that are not directly linked to the effect the pest has on its host. Indirect effects which are created by the presence of the pest, but not specific to the pest-host dynamic include public health issues, restrictions on traffic flow, key ecosystem function compromised, research requirements, market access problems and tourism. An indirect impact is generally a value that is not tied directly to an area or volume that has been infested as with the direct impact.

Market effects refer to those effects for which the market provides a valuation of the benefits and costs. Such effects can easily be identified in an existing market. This means that the effects of the pest can be identified in terms of (say) quantities bought and sold, and market prices. The key factor is that there is a market price and that quantities affected can be easily identified and measured (e.g. $/ton, acres, or volume). Market effects include a range of changes to producer costs and returns, such as direct producer costs, input demands or output, and change in product quality. It covers the full range of activities from farmers to processors and exporters. Market effects also cover peripheral changes like market access, where there might be changes in quarantine measures in export markets. It also covers wider economic change that might arise from a significant effect such as the loss of a domestic agricultural or tourist sector, which would cause unemployment, and changes to wages, land prices and exchange rates.

Non-market effects refer mainly to those changes for which there are no direct market valuation. In order words, these impacts do not have an existing market that can easily be identified, and thus there is no information on prices, costs, profits or quantities. Examples of such impacts include environmental effects and loss of biodiversity. The key factor here is that there is an intuitive understanding that there is a cost being incurred, but that there is a lack of information on what the cost might be. Consequently, a variety of techniques have been developed to measure the value of such effects, i.e. the change in consumer surplus associated with the effect.

The direct, indirect, market and non-market categorizations combine to form an economic impact matrix (Table 1) (Bigsby 1996). The economic impact matrix is used to identify and classify economic effects. An effect that is economic in nature is one that causes changes to what is done, or that causes a change that is important to other activities.

Table 1
Economic Impact Matrix

	Market Impacts	Non-Market Impacts
Direct Pest Effects	• Timber products • Pest/fire resistant species • Control costs	• Urban ornamental • Wildlife habitat
Indirect Pest Effects	• Tourism • Trade effects • Fire hazard	• Nutrient cycle • Hydrology • Political effects

Table 1 illustrates an example of how the economic impact matrix is used a study of a proposal to import larch logs into the U.S. from Siberia (USDA 1991). The importation of larch logs has the potential to introduce Larch Canker. Larch canker has the potential to cause mortality in a number of tree species in the western United States. Impacts that are caused by the effect of the pest on a tree, and that are commercial in nature include the financial loss of timber products, and the direct control of the pest. In the long term, revenue from timber would decrease and forest management costs would increase due to the pest and the loss of fire-resistant species from the forest. Direct impacts that are non-market include the loss of urban ornamental trees, measured as amenity value, or replacement planting costs. Indirect market effects could include impacts on property values. Direct and non-market impacts also included the loss of wildlife habitat.

In terms of potential indirect and market impacts, there is the loss of tourism potential in mountain areas with high tree mortality, the effects on trade if quarantine restrictions were placed on U.S. exports as a result of an infestation, and increased fire hazard with large-scale tree mortality and increases in fire prevention and suppression costs. Non-market and indirect effects include a reduction in biodiversity, and the effect this will have on nutrient and hydrologic cycles. There is also the potential for political effects due to pressures from industry and environmental groups, and conflict between state and federal jurisdictions.

2.3 Measuring Economic Effects

In the risk assessment framework, economic impacts are combined with probabilities of particular outcomes. In general, if the outcomes are mutually exclusive, then total expected economic impact of pest, associated with a given set of policy measures, is a sum of economic impacts of different possible outcomes, weighted by their individual probability of occurrence. This can be formulated as,

$$\text{Total Economic Impact} = \sum_{i=1}^{m} (Y_i \cdot P_i)$$

In this formulation, there are *m* possible discrete outcomes, the economic impact of any particular outcome, is the value of damages caused (Y_i) and the probability of that outcome (P_i). The total economic impact is thus the expected value of a particular action (policy), such as relaxing a particular phytosanitary barrier or attempting to control a pest.

2.4 Levels of Economic Analysis

The types of economic analysis that are available can be categorized according to the scope or level of economic activity that is measured. The FAO (1996) guidelines group economic analysis into partial budget, partial equilibrium, and general equilibrium.

Partial budget analysis, the narrowest in scope, deals with changes to the profits of individual producers. Partial equilibrium analysis is wider in scope than partial budget, dealing with a production sector as whole rather than individual producers and can model the effects of a pest on changes in prices. Partial budget and partial equilibrium analysis can also be termed microeconomic approaches.

General equilibrium analysis is a level higher than partial equilibrium analysis, encompassing an entire economy, and allowing for the effects of a pest on wages, exchange rates and national welfare to be measured. The general equilibrium analysis is a macroeconomic approach. These types of economic analyses form a progression of analytical opportunities that are available as the scope of a potential pest impact increases.

2.4.1 Partial Budget

One guideline is a New Zealand model based on partial budget calculations of changes to producer incomes arising from the introduction of a pest or disease (Greer and Bigsby 1995). In order to calculate changes to producer incomes, data related to changes in costs and returns must be collected. In a partial budget model, the implicit assumption is that changes to output will not have any effect on market prices or unit input costs, and that current market prices for outputs and inputs will continue.

Changes to revenue will occur as a result of:

- Change in the amount produced (yield or area)
- Change in quality or grade (price)
- Change in market access

Changes to total input or production costs will occur as a result of:

- Change in costs per unit output or area
- Change in output or area

Costs Incurred Between Pest Entry and Colonization

For many pests there is a very high probability that the only costs incurred as a consequence of their entry will arise between pest entry and colonization. These are primarily the costs of implementing eradication, movement control costs incurred by industry during a response and the market costs in the event that a pest enters the country and, although it does not establish, causes damage to horticultural produce that is detected in a foreign market. In order to estimate the total costs from pest entry to colonization a number of costs and other estimates can be defined. They include:

- The daily costs (per person-day) of mapping, trapping, and monitoring undertaken during a pest response.
- The costs per unit of area of using control measures to attempt to eradicate the pest.

- The costs of any alternative control costs (e.g. sterile flies, building of special facilities).
- The expected costs per pricing unit of movement control incurred by the industry per unit of produce from the affected area.
- The expected costs per pricing unit of movement control per unit of produce moving through the affected area.
- The expected proportion of host produce from a region which must pass through the first region infested on its way to export markets and thus may require some form of protection for the duration of the response.
- Expected duration (person-days) of monitoring and movement control after implementing a response. This will be a function of the area to be monitored and the period over which that area is to be monitored.
- The area over which control measures are implemented.

The total expected costs resulting from pest entry in any one year depends on the expected cost of a response, the number of responses expected in any one year and the probability that the pest is not already endemic (i.e. colonized and not been eradicated in past) in the country, in which case there would be no response to pest entry.

Costs After Colonization

The economic information that might be considered takes the following general forms.

- Potential for establishment - the potential for establishment, area at risk, present distribution or time until first occurrence, and rate of spread once established. All of these are expressed in terms of area or area over time.
- Direct economic impact - effects linked directly to some type of activity. Can be broadly separated into activities that are production-related, such as with agriculture, and those that are non-production related, such as recreational fishing. Production-related economic effects include direct costs of pest plant control or eradication, effects on crop or stock yields, effects on product quality and the effects of being required to change crops. Non-production related impacts include pest control costs or reduced values associated with that activity. These types of impacts are typically measurable as $/acre or $/unit output.
- Indirect economic effects - not linked to a specific effect on an activity. This could include government expenditures on publicity, administration, or compensation. These values are often expressed as annual amounts that are not linked to the area or volume of product infested.
- Periodic events - events such as fires or floods that have a higher probability due to a pest plant should also be included.

Cost and Yield Implications for Crops

A pest that affects an agricultural crop will require an estimate of the expected changes in cost, yield and quality. This can be done by estimating differences in annual yields and costs as a result of the pest and linking this to the area of crop infested. The types of factors that can be considered include:

- Net change in costs of pest control per acre to producers.
- Value of costs per pricing unit (e.g. tons) incurred by producers that depend on yield rather than area (e.g. transport).
- Value of costs per pricing unit (e.g. tons) incurred by marketers (e.g. fumigation) excluding costs associated with a pest.

- Post harvest costs of control per pricing unit.
- Expected reduction in yield in infected crops.
- Period during which the crop from infested areas cannot be sold because there are no acceptable control technologies available for use in domestic or export markets.

The expected crop losses in each year can be calculated by multiplying mean yields before pest entry by the proportion of the area affected and the percentage decline in yield as a consequence of infestation. The net change in production costs as a result of infestation depends on the infested area, the control costs per acre, the change in total yield and the costs which are dependent on yield rather than area such as transport, seed cleaning etc. which will be reduced as yield declines. The net change in post harvest costs such as fumigation incurred by marketers depends on the total yield, the post-harvest costs of controlling the pest, the market for which the crop is destined, the change in yield and the post-harvest costs excluding control of the pest.

There may also be a period during which the crop from infested areas is totally unsaleable because there are not acceptable control technologies available for use in domestic or export markets.

Revenue Implications

The revenue implications of changes in crop quantity and quality can be based on market shares for different end markets (e.g. export, domestic or processing), prices in each market and any price penalties imposed as a result of a pest. For example, revenue impacts could be derived for export, domestic and processing markets by measuring the total change in volume produced and the change in market shares for each of these markets as a consequence of quality changes. The export share of infested crops would be the original export market share minus the proportion downgraded to the domestic market and the processing market. Similarly the domestic market share of infested crops would be the original share to the market plus export downgrade minus the proportion downgraded from the domestic market to the processing market.

An export price penalty may also be imposed on infested crops. The volume of product on which the penalty is imposed in any year would depend on the total yield from infested crops, the export packout from infested crops and the percentage of the export volume that is subject to the penalty.

2.4.2 Partial Equilibrium

Changes to the market may be large enough in aggregate to cause market shifts in demand or supply. These types of impacts are not restricted to the direct effects of a pest introduction and the impact it has on producer costs or supply. The types of market changes that could be evaluated by a partial equilibrium approach include:

- Change to producer costs
- Change to producer returns
- Introduction of a new imported commodity
- Loss or gain of an export market

Many economic impact assessments of pests would be initiated either by consideration of a new lower-cost, imported products, or by the relaxation of existing phytosanitary measures that would permit new lower-cost, imported products. The general effect in the domestic economy will be a drop in domestic prices and an increase in domestic consumption. Thus one group in the economy that will be affected is consumers of a product or products that would now be available at a lower price. A second group that would be affected would be domestic producers who would face lower prices and potentially lose market share to imports.

These changes will occur without any consideration of a pest introduction. Where there is an introduction of a pest, the economic impacts are expanded to allow for the effect of the pest. In general the effects will be of two types, those that affect crop yields and thus producer returns, and those that are associated with the control or eradication of the pest and thus producer costs. The impact on producer returns from changes to yields will depend on the geographic rate of spread of the pest over time, and on the profile over time of the impact of the pest in a particular area. Both of these will in turn reflect the level of effort or expense in controlling or eradication the pest.

As a secondary effect, there may also be changes to the markets faced by exporters, importers or domestic producers in other product areas. This could be in terms of reciprocal reductions in barriers that expand trade opportunities, or if a pest is introduced there could be flow-on effects as other domestic producers are forced to make changes or export markets are reduced. In most cases there will at least be both consumers and producers of a product who are impacted, with these others as possibilities. Depending on the situation then, any or all of the following may be affected.

- Domestic market of the product in question
- Exporters of other products
- Importers of other products
- Other domestic markets

The type of economic effects would depend on the particular commodity and pest assessment scenario being considered. In general though, the economic impacts being considered as a result of new commodities being imported could be summarized as in Table 2.

Table 2

Market Effects of Pests

Who is Affected	Type of Effects
Product	• More sold locally at lower world price.
Other Exporters	• If there is a corresponding reduction in foreign phytosanitary barriers which opens up more markets, then more would be sold at the current price. If there is a corresponding increase in foreign phytosanitary barriers due to perceived increased risk, then more would be sold locally and the price of the product locally would fall. • If the pest affected the export crop then there would be reduced volumes at the world price.
Other Importers	• Shipping restrictions may reduce volumes and local prices would rise.
Other Domestic	• If the pest affected other crops then there would be reduced volumes and local prices would rise.

Partial Equilibrium Approach

Given the availability of data and the need to make a model easy to use, demand and supply functions can be specified as simple linear functions.

$$\text{Demand} \quad Q_D = c_1 + b_1P$$

$$\text{Supply} \quad Q_S = c_2 + b_2P$$

In the usual convention for graphing, demand and supply are specified as inverse functions,

$$P = C_1 + \beta_1 Q_D$$

$$P = C_2 + \beta_2 Q_S$$

where in this specification, Q_D is quantity demanded, C_1 is the demand curve intercept, $ß_1$ is the slope of the demand curve, Q_S is quantity supplied, C_2 is the supply curve intercept, $ß_2$ is the slope of the supply curve and P is the market price.

If there is a yield reduction, this assumes that there will now be lower output at the previous market price. If supply was,

$$Q_S = C_2 + ß_2 P_0 ,$$

then a new intercept can be calculated by rearranging the terms and solving for a new intercept,

$$C_2' = Q_S' - ß_2 P_0 ,$$

where Q_S' the reduced output specified by the user and P_0 is original price. If the reduction takes effect over a period of time or is modified by control measures then there will be a time element for Q_S'. A new intercept, C_2', will have to be calculated for each period where there is a different effect on yield.

If there is a grade reduction, this assumes that there will now be a lower market price at the previous output. This is the same as a downward shift of the supply curve. If supply was,

$$Q_S = C_2 + ß_2 P_0 ,$$

then a new intercept can be calculated by rearranging the terms and solving for a new intercept,

$$C_2' = Q_S - ß_2 P_1 ,$$

where Q_S the original output and P_1 is the new weighted average price specified by the user. If the reduction in grade takes effect over a period of time or is modified by control measures then there will be a time element for P_1. A new intercept, C_2', will have to be calculated for each period where there is a different effect on the weighted average price.

An increase in export markets means there is a growth in demand and supply at the prevailing world price. There will be a net increase in export earnings, but no change to prices or quantities consumed in the domestic market. If export markets are closed then the export supply is forced back on to the domestic market. This has the same effect as an outward shift of the supply curve. The effect is that market prices will have to fall in order to sell more than consumers intended to purchase at the old price. When this happens there will be greater supply at the old prevailing market price. If supply is,

$$Q_S = C_2 + ß_2 P_0 ,$$

then a new intercept can be calculated by rearranging the terms and solving for,

$$C_2' = Q_S' - ß_2 P_0 ,$$

where Q_S' the increased supply specified by the user and P_0 is original price.

2.5 Incorporation of Time

The inter-temporal impacts of pest introduction must be explicitly incorporated. These impacts include the probability that the pest colonizes and becomes endemic in the country over time and the rate at which it spreads through the country over time. The values of yield losses and costs through time can be converted to a single net present value using the discounting process.

2.6 Probability

In the calculation of probability, each P_i represents one element of a probability tree, where each element is an action or outcome of an action. As an example of how the probability tree is derived, Table 3 shows regulatory responses triggered by a fruit fly incursion in New Zealand (Greer and Bigsby 1995).

Table 3
Components of Fruit Fly Response Levels in New Zealand

Component	Response 1	Response 2	Response 3
Mapping	*	*	*
Trapping	*	*	*
Fruit monitoring	*	*	*
Fruit collection		*	*
Bait application		*	*
Ground spraying		*	*
Cover spraying		*	*
Movement control	*	*	*
Alternative methods			*

Figure 5 outlines an example of a probability tree for pest colonization in a post-entry analysis based on Table 3. This involves identification possible events (pathways) and determining a probability for that event. The probability of any outcome's occurrence is calculated by multiplying all probabilities along the pathway from pest entry to that outcome. The total probability of any outcome is the sum of the probabilities of the outcome over all pathways. The range of outcomes possible from Figure 5 is summarized in Table 4.

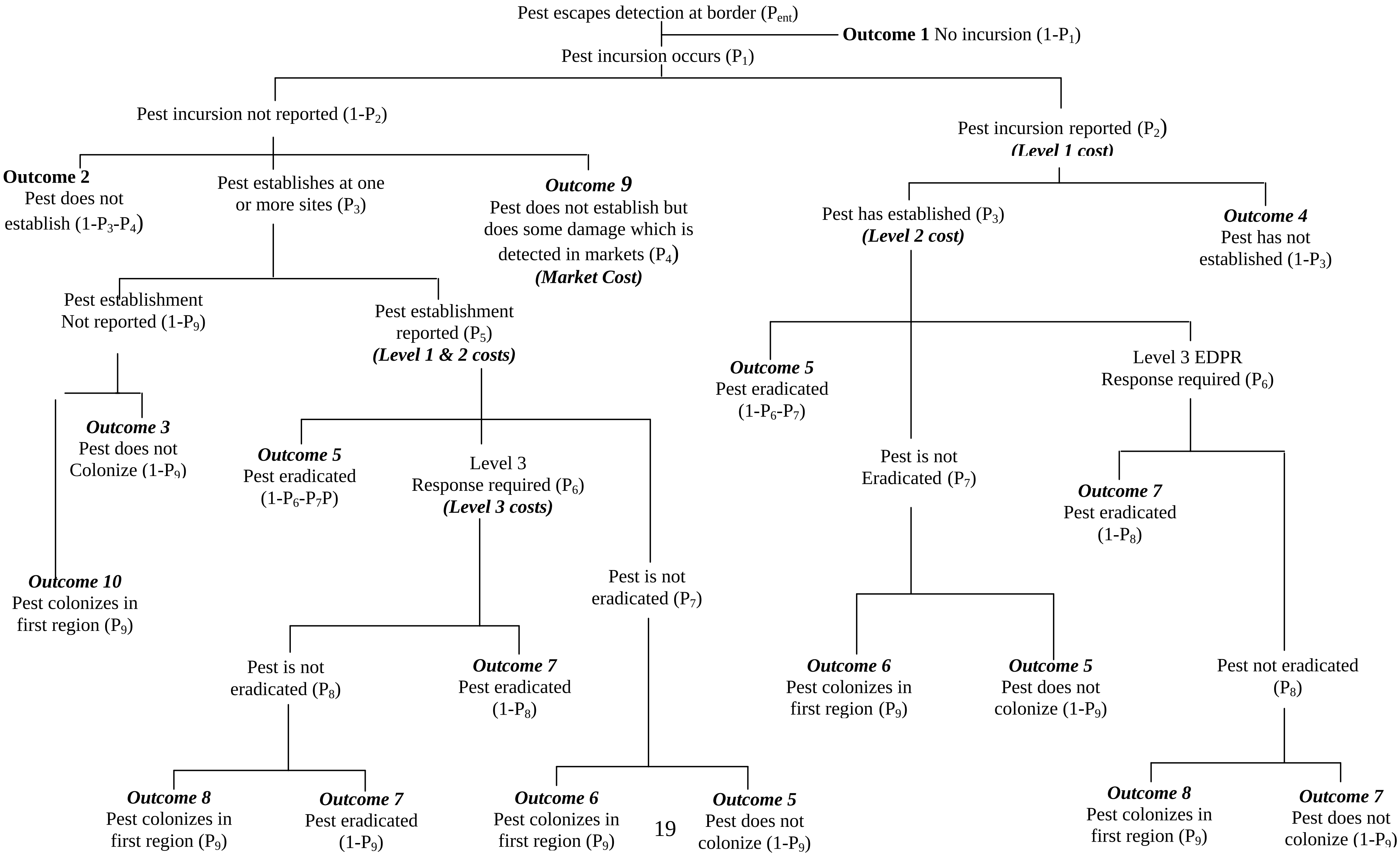
Table 4

Outcomes Between Pest Entry and Colonization

	Outcomes	Cost	Probability
1	Pest entry escapes border inspection but does not survive	N	$(1-P_1)$
2	Pest entry, incursion, no report, no damage, no establishment	N	$P_1(1-P_2)(1-P_3-P_4)$
3	Pest entry, incursion, no report, establishment, does not become endemic	N	$P_1(1-P_2)P_3(1-P_5)(1-P_9)$
4	Pest entry, incursion, report, Level 1 response, no establishment	Y	$P_1P_2(1-P_3)$
5	Pest entry, incursion, report, response to Level 2, eradicated or fails to colonize	Y	$P_1P_3(P_2+(1-P_2)P_5)((1-P_6-P_7(1-P_9))$
6	Pest entry, incursion, report, response to Level 2, endemic	Y	$P_1P_3(P_2+(1-P_2)P_5)P_7P_9$
7	Pest entry, incursion, report, response to Level 3, eradicated or fails to colonize	Y	$P_1P_3(P_2+(1-P_2)P_5)P_6((1-P_{8)}+P_8(1-P_9))$
8	Pest entry, incursion, report, response to Level 3, endemic	Y	$P_1P_3(P_2+(1-P_2)P_5P_6P_8P_9$
9	Pest entry, incursion, no report, some damage picked up in markets, no establishment	Y	$P_1(1-P_2)P_4$
10	Pest entry, no report, incursion, establishment, endemic	Y	$P_1P_3(1-P_2)(1-P_5)P_9$

Figure 5

Pest Entry to Colonization



Probability Over Time

Pest problems may have a time element that should be captured. An example is the potential for colonization resulting from pest entry over time, since colonization may occur in any year over the horizon of a study. Following Greer and Bigsby (1995), the probability that a pest colonizes in any particular $Year_n$, $P(Col)_n$ is:

$$P(Col)_n = P(Pot)_n \times (1 - P(Endem)_n)$$

$P(Pot)_n$ is the probability of a pest colonization in $Year_n$ if the pest is not already endemic. The probability that a pest is endemic during $Year_n$, $P(Endem)_n$, is the sum over all years up to $Year_n$ of the probabilities that the pest colonizes in any year (m) and has not been eradicated by $Year_n$.

$$P(Endem)_n = \sum_{m}^{m=n-1} (P(Col)_m \; x \; (1 - eradprob_{n-m-1})$$

As a result, $(l - P(Endem)_n)$ is the probability that the pest is not endemic in $Year_n$. The probability that a pest will be eradicated by the end of p years after colonization, $Eradprob_p$ is,

$$Eradprob_p = (l - ((l - Eradprobp_{p-l}) \times (l-Erad_p))) \times PMS$$

$Erad_n$ is the probability of successful eradication n years after colonization if the pest has not been eradicated by the end of $Year_{n-1}$ and PMS is the probability that a Pest Management Strategy would be implemented for this pest.

The probability that colonization will occur at some stage during the period will be higher than the probability that the pest is endemic at the end of the period unless there is no probability of eradication once the pest has established. This probability, P(Totcol), is,

$$P(Totcol) = 1 – ((l - P(Col)_n) \times (l - P(Col)_{n-l}) ... \times (l-P(Col)_l))$$

The probability that there will be neither colonization nor a regulatory response during the period, P(Nothing), is,

$$P(Nothing) = P(Noimp)_n \times P(Noimp)_{n-1} \; ... \times P(Noimp)_1$$

Where $P(Noimp)_n$ is the probability that there will be no colonization or regulatory response in $Year_n$ either because pest entry in that year would not have had any impact even had the pest not been endemic already, or because the pest was already endemic.

$$P(Noimp)_n = (l - P(Endem_n) * P(Nopot)_n + P(Endem)_n$$

$$P(Nopot)_n = (P(ent) * (Pout_1 + Pout_2 + Pout_3) + (1 - Pent))^{N(n)}$$

The probability that there will be no colonization during the period but that regulatory response costs will be incurred, P(Costs), is,

$$P(Costs) = P(Totcol) - P(Nothing)$$

2.7 Policy Alternatives

One of the important components of pest risk management is evaluating the cost effectiveness of existing and proposed invasive species policies. Table 5 lists a range of policy and production variables that can be used to characterize a broad range of managerial approaches.

Table 5
Policy and Production Variables

Policy variables	*Production variables*
• Policy type	• Level of economic activity
• Level of monitoring	• Level of compliance
• Level of enforcement	
• Level of control	
• Level of mitigation	

Depending on the context of the management problem, the outcome of the policy could be:

- Minimize the expected value of the total costs (damages and mitigation expenditures) from an invasive species and mitigation policies**.**
- Reduce the probability of pest establishment or spread through management actions relative to an established measure (e.g. appropriate level of protection).
- Improve allocation of invasive species mitigation budgets.

In the context of the risk assessment framework, the principle way in which management options are characterized is in the modification of the probability of pest establishment or spread through management actions.

2.8 Information Sources

APHIS lists a number of information sources for pest risk assessment (APHIS 2000).

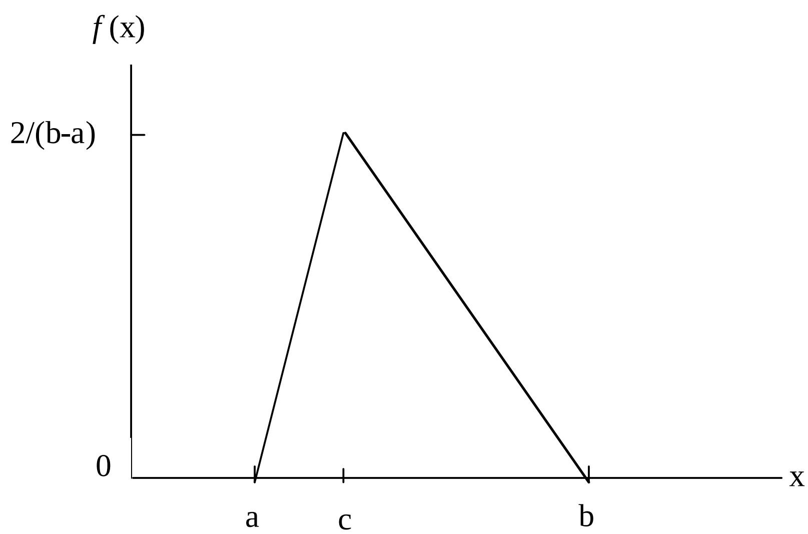
- Electronic databases, *e.g.*, AGRICOLA, CAB database, University of California computer information system, MELVYL
- Previous risk assessments for a commodity
- The PPQ catalogue of intercepted pests and interception records
- CIE and CMI. Distribution Maps/Descriptions of Plant Pests (Arthropods, Fungi,

Bacteria)

- Various texts and indices of plant diseases and pathogens
- PPQ files on Pests Not Known To Occur in the U. S. (PNKTOs) and Insects Not Known To Occur (INKTOs)
- International databases, *e.g.* EPPO, FAO, CABI/CPC

Some variables will be known with certainty, however, for many there will be little hard data on which to base subjective estimates. Consequently, for these parameters, there is the option of using something like @RISK to specify uncertainty. Using @RISK allows the definition of uncertain values as probability distributions. While almost any type of probability distribution can be specified in @RISK, the absence of data from which a distribution could be established means that a triangular distribution will be suitable. As more data become available it will be possible to specify uncertainty with more sophistication. The triangular distribution is described by three parameters as shown in Figure 6.

Figure 6
The Triangular Distribution



Source: Greer and Bigsby (1995)

The parameters in Figure 6 are:

a The minimum value
b The maximum value
c The most likely value

Where: a is a location parameter, b-a is a scale parameter and c is a shape parameter

Mean	$(a + b + c)/3$
Mode	c
Variance	$(a^2 + b^2 + c^2 - ab - ac - bc)/18$

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