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ACIAR investment in citrus rootstock, scion and production improvement in China, Vietnam, Bhutan and Australia

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Impact assessment of investment in citrus rootstock, scion and production improvement in China, Vietnam, Bhutan and Australia

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AgEconPlus Pty Ltd

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Cover photo: Dr Tahir Khurshid assessing the compatibility of Chinese rootstock with scions of Australian citrus varieties. This field trial was a component of one of several projects aiming to improve citrus production in China, Vietnam, Bhutan and Australia.

Foreword

The international partnerships that underpin research supported by the Australian Centre for International Agricultural Research (ACIAR) aim to improve the productivity and sustainability of agricultural, forestry and fisheries systems, as well as the resilience of food systems in partner countries. Importantly this research also helps improve Australian agricultural systems.

This impact assessment—focusing on ACIAR research projects that contributed to citrus rootstock, scion and production improvement—shows clear benefits to both research partner countries and the Australian industry.

The assessment reviewed four ACIAR projects in China, Vietnam and Bhutan, as well as Australia, between 1993 and 2013.

The independent reviewer determined that the ACIAR projects in China and Vietnam have helped to:

- preserve citrus genetics
- transfer technologies from Australia that deliver disease-free planting material
- build science capacity
- introduce more profitable varieties.

In China alone, the introduction of a new variety—Late Lane navel—is predicted to contribute about $38.4 million per year to orange grower producer surplus.

In Vietnam, ACIAR's investment in the supply of guaranteed disease-free planting material is helping to combat citrus greening. This will help the recovery in grower income in the Mekong Delta, where 40,000 ha of citrus production had been affected by this destructive condition.

In Bhutan, the reviewer found that the ACIAR projects have produced a qualified citrus research and extension team, as well as production improvement measures that benefit large and small mandarin growers.

A case study analysis showed that even with only a partial implementation of ACIAR production improvement measures, smallholder income has doubled. This was achieved without an excessive burden on the hours worked and the working conditions of women and young people.

In Australia, an economic analysis of the impact of the introduction of Chinese citrus rootstocks through the ACIAR projects showed significant potential for industry returns.

Chinese citrus rootstocks were accessed through the ACIAR projects at a time when China had an interest in foreign citrus genetics, and was willing to exchange native scion and rootstock material for material sourced from Australia. This window has now closed.

The gains to Australia from the introduction of Chinese citrus rootstocks are substantial, and will be sustained. The assessors have determined that a benefit:cost ratio of about 7:1 will be delivered for Australia from the ACIAR and industry investments.

The results of this study confirm the positive impact of the four ACIAR projects for citrus producers in partner countries, as well as the sustained benefits for Australia's own citrus industry. The assessment of these projects shows how ACIAR's long-term model of brokering and funding research for development partnerships can lead to benefits for all partners.

Andrew Campbell
Chief Executive Officer, ACIAR

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- Dr Zhao Xiaochun, Director, Citrus Research Institute, China Academy of Agricultural Sciences, Southwest University, China

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ARDC	Agricultural Research and Development Centre (Bhutan)
Auscitrus	Australian Citrus Propagation Association Incorporated
CAAS	Chinese Academy of Agricultural Sciences
CRI	Citrus Research Institute (China)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DoA	Bhutan Department of Agriculture
EMAI	Elizabeth Macarthur Research Institute (Camden, New South Wales)
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
HLB	Huanglongbing
JAF	John Allwright Fellowship (awarded by ACIAR)
NCVEC	National Centre for Virus Exclusion in Citrus, China
NSW DPI	New South Wales Department of Primary Industries
QDAF	Queensland Department of Agriculture and Fisheries
RIFAV	Research Institute of Fruit and Vegetables (northern Vietnam)
RMB	Renminbi (Chinese currency)
SOFRI	Southern Fruit Research Institute (southern Vietnam)
USA	United States of America
USDA	United States Department of Agriculture

Executive summary

This document is an impact assessment study of four ACIAR-funded citrus improvement projects in China, Vietnam, Bhutan and Australia. The four projects were:

- CS1/1987/002—*Citrus rootstock development (China and Australia)*
- CS1/1996/076—*Evaluation of East Asian citrus germplasm as scions and rootstock (China, Vietnam and Australia)*
- HORT/2005/142—*Improving mandarin production in Bhutan and Australia through the implementation of on-farm best management practices (Bhutan and Australia)*
- HORT/2010/089—*Adapting integrated crop management technologies to commercial citrus enterprises in Bhutan and Australia (Bhutan and Australia).*

The impact assessment study started with a review of the literature focusing on project proposals, project profiles and final reports. This was used to prepare a preliminary impact assessment framework and draft economic models.

The ACIAR Research Program Manager, Impact Assessment, reviewed the framework and models. Consultation included interviews with administrators, horticultural officers and researchers in China, Vietnam, Bhutan and Australia.

The impact assessment framework used the principles articulated in the ACIAR Strategic Plan 2014–2018 (ACIAR 2014). Economic modelling of the projects' impacts on the Australian citrus industry was completed using a standard welfare framework, consistent with ACIAR's guidelines (Davis et al. 2008). Case studies were prepared to provide additional detail on impacts in China, Vietnam and Bhutan.

Outputs delivered by ACIAR-funded research

Outputs from the ACIAR-funded projects included the:

- transfer of new technologies and citrus resources between participating countries
- generation of scientific knowledge
- development of citrus capacity
- delivery of policy goals.

The team collected and assessed germplasm from native citrus species and old local varieties in China, Vietnam and Bhutan. Australian molecular analysis technologies were transferred to China and Vietnam, and virus-free citrus progeny were established as mother-trees in all four countries.

The project generated new scientific knowledge on:

- the value of native and traditional citrus from China and Vietnam
- the worth of domestic germplasm in the citrus industries of other countries
- pests and diseases, including powdery mildew, Chinese citrus fruit fly, the psyllid vectors of Huanglongbing (HLB), trunk borer, citrus scab and *Phytophthora* root and collar rot.

Capacity development included the training of citrus professionals, the creation of professional networks and the construction of research infrastructure.

In China, Vietnam and Bhutan, a new understanding of the importance of disease-free budwood and grafted rootstock was developed. Training was completed in molecular analysis techniques for germplasm and disease assessment in China and Vietnam. The construction of insect-proof screen houses in China, Vietnam and Bhutan made maintenance of disease-free mother-trees possible.

Farmers in Bhutan received training in best-practice citrus production and biometrics, and demonstration farms in major citrus production districts supported farmer uptake of best practice.

The project established domestic and international networks for continuous learning in all three Asian countries. In Australia, mandarin growers were provided with a comprehensive production manual, and introduced to improved production techniques.

The project team developed additional skills in project management and the demonstration of citrus research and extension techniques. Australian researchers also developed additional knowledge on exotic pest detection and management.

Individuals trained through ACIAR investment have, for the most part, remained in-country, and have continued to serve in their respective research institutions.

Women accounted for 25% of those trained through the ACIAR-funded projects.

These projects achieved the policy goals of:

- extension of the Chinese citrus season into the festival and off-season market
- increase in Vietnam's citrus production from 11,000 tonnes in 1991 to 440,000 tonnes in 2000
- increase in Bhutan's citrus production capacity, with progress toward organic production
- the delivery of new rootstocks for the Australian citrus industry.

Adoption and outcomes

In China, the groups of outputs adopted as a result of ACIAR project investment were the:

- use of virus-free and more productive rootstocks and scions
- introduction of new varieties to lengthen the citrus season.

ACIAR-funded projects CS1/1987/002 and CS1/1996/076 gave impetus to the further development of citrus rootstock and scion improvement programs at the Citrus Research Institute (CRI), China.

Comprehensive training of CRI scientists in molecular diagnostic techniques served as a foundation to build improved pathogen-indexing capabilities. China also established the National Centre for Virus Exclusion in Citrus (NCVEC) at the CRI.

By 2018, the NCVEC had become the most important national centre for the supply of virus-free citrus mother-trees, and each year, nurseries supported by NCVEC provided more than 30 million virus-free trees to Chinese citrus growers.

The ACIAR-funded projects introduced Australian citrus varieties to China to lengthen the Chinese citrus season, including Late Lane navel and Ellendale Tangor. Late Lane navel has been widely adopted in the subtropical growing areas of China.

Newhall, an early season Californian navel introduced as part of the ACIAR projects, was used to develop two new local Chinese varieties. Two late season mandarin varieties were also developed from Chinese genetic material collected during the ACIAR projects.

Vietnam also adopted systems to produce virus-free and more productive rootstocks and scions, and used Australian varieties introduced through ACIAR project CS1/1996/076. Research institutes in both the north and south of the country have used methods developed in Australia to screen local and introduced rootstocks for *Phytophthora* tolerance, salinity tolerance and graft incompatibility.

Molecular diagnostic techniques introduced through the ACIAR project have served as a foundation to build improved pathogen-indexing capabilities, which have been used in a new laboratory at the Southern Fruit Research Institute to detect HLB.

HLB-free planting material is now provided to citrus growers across Vietnam. Australian citrus varieties, introduced through CS1/1996/076, and grown commercially in Vietnam, include the Leng navel and the Orlando tangelo.

In Bhutan, participation in ACIAR projects HORT/2005/142 and HORT/2010/089 has delivered a qualified citrus research and extension team, and resulted in better citrus production practices being adopted, and a professional nursery sector being established.

Better citrus production practices were communicated through demonstration farms, the training of Bhutanese Department of Agriculture staff and the training of Bhutanese citrus growers.

Existing Bhutanese orchards that adopted improved production techniques realised additional citrus yield and fruit of higher quality. Longer term, further gains in citrus yield and fruit quality are possible as the fledgling professional nursery sector increases the supply of disease-free grafted trees and new varieties sourced from Australia.

Disease-free grafted nursery trees, new varieties such as the Afourer mandarin, and the relocation of the industry above 1,200 metres to avoid HLB vectors will all improve the productivity of citrus production in Bhutan. Planned implementation of these ACIAR-funded research outputs offers the opportunity to further narrow the yield gap between Bhutanese and Australian citrus production.

An unintended positive impact of the ACIAR-funded projects in Bhutan has been the rapid take-up of stream-powered water pumps for irrigation of non-citrus horticultural crops. Stream-powered water pumps driving gravity-fed drip irrigation systems have been profiled in demonstration farms, and irrigation using these technologies has been incorporated into the most recent five-year plan for Bhutan.

In Australia, two groups of outputs were adopted as a result of ACIAR-funded project investment:

- The Australian Mandarin Production Manual was produced as part of HORT/2010/089. It is the first comprehensive guide to mandarin orchard establishment and management in Australia, and covers all aspects of mandarin production. A total of 330 hard copies have been distributed to industry. Distribution of this number of copies is sufficient to cover each Australian mandarin grower and their industry advisor.
- Chinese citrus rootstocks sourced through project CS1/1987/002 and CS1/1996/076 show considerable potential for lifting citrus fruit yield and quality in the short term. Longer term, Chinese citrus rootstocks might also help increase productivity, create intensive orchards and manage citrus production in an irrigation constrained saline environment.

Case study analysis of outcomes and impacts

Case studies were completed for China, Vietnam and Bhutan. Economic impacts were quantified in a welfare framework for the forecast take-up of Chinese rootstocks by the Australian citrus industry.

Case study 1 was an analysis of the impact of introducing Australian Late Lane navel to China. Late Lane navel was first introduced to China as part of CS1/1987/002 in 1993, and was again introduced to China as part of a China–United States of America (USA) citrus project in 1999. Late Lane navel, together with other Chinese developed citrus varieties, now fills a gap in the fresh fruit supply window. Late Lane navel grown in China is harvested between January and April, and coincides with the peak spend, January festival season and the period when most fresh fruit grown in China is out of season. Premiums are available for navel oranges harvested in this period rather than the traditional October–December season. Late Lane navel is now a major variety in China, and producer surplus generated from its harvest during the festival/off-season period is estimated at about $38.4 million per year.

Growth in the Chinese late navel market has come without cost to Australian navel growers, who are not in a position to supply China with export fruit until the middle of May. The Australian supply window closes, with no more fruit available for export, in October, well before Chinese grown Late Lane navels are harvested.

Case study 2 was an analysis of the potential impact of disease-free planting material on HLB in Vietnam. Since the completion of ACIAR project CS1/1996/076, the Southern Fruit Research Institute in Vietnam has continued to use project-delivered disease testing techniques, and supports the certified nursery scheme established as part of the project to produce guaranteed disease-free planting material for citrus growers. Clean planting material, together with removal of diseased trees and psyllid control, is an effective strategy for reducing on-farm production and income losses caused by HLB.

As a result of ACIAR's investment, a supply of guaranteed disease-free planting material is now available to combat HLB in Vietnam, and recovery in grower income can be expected. At the time the ACIAR research was completed, HLB affected 55% of the 40,000 ha of citrus production in the Mekong Delta, and 27% was severely affected. Smallholder income in areas severely affected by HLB was reduced by 25%–55%. In 2018, HLB remains a significant problem in both northern and southern Vietnam, and particularly in the Mekong Delta.

Case study 3 was an analysis of the impact of improved citrus production techniques on output, household income, gender roles and the environment, in Drujegang, Bhutan. Before HORT/2010/089, Drujegang had not been exposed to modern citrus production techniques.

ACIAR-trained extension officers used a farming systems-based approach to improve citrus production at the community level, including tree basin making, farmyard manure application, fertiliser application, use of plant protection chemicals, irrigation, tree canopy management and mulching. Adoption of a subset of these practices increased citrus yield by 27.5% and mean household income by more than 100%—that is, from A$2,182 to A$4,675 per year.

Mostly women attended ACIAR-funded training, accounting for 60%–70% of the farmers trained under the project. The implementation of improved farm management practices meant that women and young people were required to complete more work. But women interviewed by Department of Agriculture extension officers indicated that they were willing to accept this additional work in exchange for the increase in income, which could be used to educate children. Children worked in family orchards after school and were pleased to contribute to household income.

There were few, if any, negative environmental impacts associated with adoption of improved management practices. Drujegang citrus growers were reluctant to use both chemical fertilisers and insecticides. Construction of basins around citrus trees helped stabilise orchard soil, and avoid erosion and nutrient loss on steep slopes.

Case study 4 was a detailed economic assessment of the potential impact of Chinese rootstocks on Australian citrus production. Chinese rootstocks were introduced to Australia as part of projects CS1/1987/002 and CS1/1996/076, and the cost of these projects, including partner contributions, has been included in the economic assessment.

While the ACIAR-funded projects were responsible for bringing Chinese rootstocks to Australia, their subsequent evaluation was funded by Australian citrus growers through Horticulture Innovation Australia (referred to as Hort Innovation). The cost of Hort Innovation investment in rootstock development has also been included in the economic assessment.

Rootstock development benefits focus on potential returns to growers from the first seven Chinese rootstocks released commercially in 2017. The main potential economic benefits from Chinese rootstocks are increased saleable fruit yield and improved fruit quality (fruit size and brix).

Without ACIAR investment, the increase in saleable fruit yield and improved fruit quality attributable to the first seven Chinese citrus rootstocks would not have been realised, and these benefits will need to be sustained over the 30-year analysis period. China is now politely declining other country requests for rootstock germplasm, and rootstocks released commercially have a 50–70-year economic life.

Results from the economic assessment are summarised in Table S1.

The total investment in Chinese rootstocks of $16.72 million (present value terms) has been estimated to produce gross benefits of $56.28 million (present value terms), providing a net present value of $39.55 million and benefit:cost ratio of 3.4:1. The ACIAR investment in CS1/1987/002 and CS1/1996/076 has produced a favourable outcome for Australian citrus growers.

Sensitivity analyses of returns from Chinese citrus rootstocks in Australia were done for discount rate, rootstock adoption by Australian citrus growers and the share of total project costs that might be allocated to rootstock development.

Results were sensitive to the discount rate used, and reflect the time between initial investment, starting in 1993, and the realisation of project benefits, starting in 2025.

Results are less sensitive to grower adoption rate, remaining positive at about half the rate assessed in the core analysis. Finally, if the analysis is reworked, assuming that only half the ACIAR and Hort Innovation project costs are relevant to Chinese citrus rootstocks in Australia, then total project benefit:cost ratio is 6.9:1. While there is no data to support this cost allocation, it might well be argued that this is an appropriate reflection of investment returns.

Conclusions

This impact assessment has reviewed four ACIAR projects concerned with citrus rootstock, scion and production improvement in China, Vietnam, Bhutan and Australia.

In China and Vietnam, the projects have helped:

- preserve citrus genetic material
- transfer technologies from Australia that deliver disease-free planting material
- introduce more profitable varieties.

In Bhutan, the ACIAR projects have delivered a qualified citrus research and extension team, and a package of production improvement measures that are being realised by both large and small growers.

In Australia, an economic analysis of the impact of the introduction of Chinese citrus rootstocks through the ACIAR projects has shown significant potential for industry returns.

Table S1: Summary of returns from Chinese citrus rootstocks in Australia

Criterion	Total investment in projects (A$ million)	ACIAR investment in projects (A$ million)
Present value of benefits	56.28	19.16
Present value of costs	16.72	5.69
Net present value	39.55	13.46
Benefit:cost ratio	3.37	3.37

Note: A discount rate of 5% has been used.

1 Introduction

This impact assessment study focuses on four ACIAR citrus projects completed in China, Vietnam, Bhutan and Australia.

1.1 Background

China is the world's largest citrus grower, producing 21.2 million tonnes of mandarins, 7.3 million tonnes of oranges and 4.8 million tonnes of grapefruit in 2016–17 (USDA 2018). Citrus is mainly grown in the south-east of China. The main production provinces, which account for 95% of output, are Guangdong, Sichuan, Zhejiang, Hunan, Guangxi, Fujian, Hubei and Jiangxi.

With an annual production of 0.44 million tonnes in 2000, citrus was a crop of economic significance in Vietnam, with mandarins, oranges and pummelo dominating output. In 2016–17, orange production alone had increased to 0.64 million tonnes (USDA 2018), and total citrus production was 1.13 million tonnes (FAO 2016). Citrus is grown in both the north of Vietnam, predominantly on larger state-owned farms, and in the south, particularly in the Mekong Delta, on smaller farms in the provinces of Bien Hoa and Cuu Long.

In Bhutan, citrus is one of the most important agricultural commodities in the economy. In 2000, Bhutan produced 0.036 million tonnes of mandarins, the country's only citrus crop. Some 66% of production was exported to India and Bangladesh (HORT/2005/142 project document). In 2016–17, Bhutan produced 0.060 million tonnes of citrus (FAO 2016). Citrus exports have been static since the early 1990s. Citrus is grown in the humid and wet southern parts of the country. The key production regions are Punakha, Tsirang, Sarpang, Lhuentse, Mongar, Chukha and Dagana.

Citrus is also a major Australian horticultural industry, with annual production of 0.7 million tonnes, valued at A$678.5 million. Oranges (76%) and mandarins (16%) dominate production, and citrus orchards are focused on the Riverina, Sunraysia and the Riverland (oranges and mandarins) in the southern Murray–Darling Basin and Gayndah, Mundubbera and Emerald (mandarins) in Queensland. There is also a smaller citrus industry in Western Australia. In 2016–17, Australia exported 0.2 million tonnes of fresh citrus, valued at A$297 million (Hort Innovation 2018).

Modern citrus relies on suitable rootstocks, which are grafted onto appropriate budwood scions to produce profitable cultivars. Productivity depends on suitable rootstocks and disease-free cultivars. Tree size, tolerance to severe conditions, fruit size, total yield and fruit juice quality are all determined by rootstock. Rootstocks must be adapted to local conditions, survive pathogens built-up from previous orchards, and be tolerant of salinity, alkalinity, and *Phytophthora* root rot and collar rot.

Worldwide, the long-term future of the citrus industry lies in more efficient high-density production systems. High-density planting saves harvest costs, makes the most of resource inputs, substantially reduces time required to reach economic breakeven point and allows greater flexibility in catering to changing market requirements. However, it requires dwarfing rootstock to control tree size. Rootstocks in use at the moment are characterised by a high degree of inherited vigour, and are unsuitable for high-density plantings.

An increase in the variety and performance of scions is also needed to meet consumer preferences and expand market opportunities. Consumer demand is for larger, visually appealing, sweeter, seed-free and easy-peeling fruit. New cultivars must be virus-free and able to tolerate specific climatic zones.

The introduction of integrated crop management technologies to Bhutan offered the potential to expand its citrus production and export sector. The Bhutan Government has identified growth in citrus exports as a national priority.

Production technologies required to deliver export growth include:

- the use of rootstocks
- demonstration farms
- irrigation
- pest and disease management strategies
- development of high health status propagation material
- the training of a dedicated citrus team.

There were also incremental gains to be had for the Australian citrus industry from the ongoing adoption of integrated crop management technologies in the expanding mandarin production sector.

1.2 Terms of reference

The terms of reference for the impact assessment study were:

- Conduct an impact assessment of ACIAR's investments in citrus in Australia, China, Vietnam and Bhutan. Specifically, the projects include:
  - *Citrus rootstock development* (CS1/1987/002)
  - *Evaluation of East Asian citrus germplasm as scions and rootstock* (CS1/1996/076)
  - *Improving mandarin production in Bhutan and Australia through the implementation of on-farm best management practices* (HORT/2005/142)
  - *Adapting integrated crop management technologies to commercial citrus enterprises in Bhutan and Australia* (HORT/2010/089).
- The impact assessment should include details of the impact pathway(s) developed within the projects and leading to impacts of:
  - impacts through the value chain
  - impacts on household/farm level and industry, and where possible women and youth
  - impacts on the environment
  - capacity built
  - scientific knowledge arising from the project investments made by ACIAR and its partners.

Consideration of impacts on policy, where applicable, should also be described and assessed at least qualitatively. These impact pathways should address next and final users of project outputs, outcomes and impacts (intended and unintended), and describe in detail economic, environmental and social and capacity-building impacts in China, Vietnam, Bhutan and Australia. While the projects did not explicitly target gender impacts or women's empowerment, the evaluation should collect, where possible, impacts on women, youth or minority groups in different settings. This would include capacity building. These assessments will need to establish and describe the counterfactuals, detailing the various other relevant research investments undertaken by other investors that contributed or had an impact on the ACIAR projects, as well as their impacts, along with other external factors including scientific, market or policy factors in Australia or partner countries.

- The economic analysis component will be consistent with the ACIAR's *Guidelines for assessing the impacts of ACIAR's research activities* (Davis et al. 2008), including presentation of a counterfactual to value impacts and investment returns. This will require the development of Australian citrus supply and demand models to quantify the impact of Chinese rootstocks, secured through the ACIAR projects, on the Australian citrus industry. Where appropriate, consider quantification of other project impacts, such as the value of Late Lane navels to China.
- Describe in additional detail economic, environmental, social and capacity-building impacts in China, Vietnam and Bhutan. Detailed case studies could be used to document and present evidence of these impacts, both quantitatively and qualitatively.

1.3 Impact assessment study methods and activities

The impact assessment study began with a review of the literature focusing on project proposals, project profiles and final reports. This review and the results of preliminary consultation were used to prepare an initial impact assessment framework based on the principles articulated in the ACIAR Strategic Plan 2014–2018 (Figure 1).

Preliminary consultation focused on discussions with Dr Tahir Khurshid, Plant Physiologist, New South Wales Department of Primary Industries (NSW DPI), Dareton Primary Industries Institute, who was responsible for managing and selecting Chinese citrus rootstocks introduced to Australia as part of the ACIAR research.

The subsequent impact assessment study included detailed analysis of citrus research projects in a refined impact map and a series of refined impact pathways.

Interviews were completed with:

- Dr Zhao Xiaochun, Citrus Research Institute (CRI), China Academy of Agricultural Sciences (CAAS) Southwest University
- Dr Nguyen Minh Chau, Southern Fruit Research Institute (SOFRI), Long Dinh Vietnam
- Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, Department of Agriculture, Bhutan.

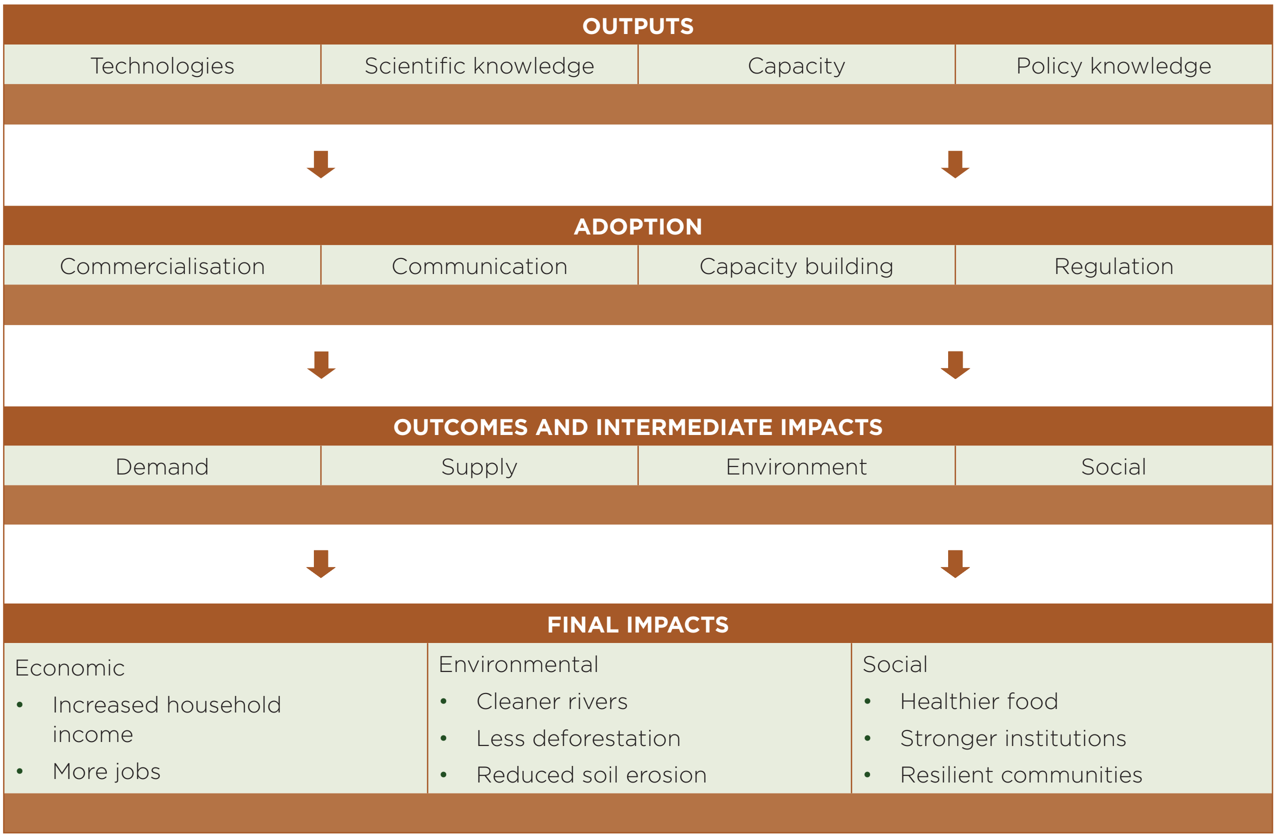

Figure 1: Impact assessment framework

Source: ACIAR 2014.

As a result of the assistance provided with data collection and assessment by key stakeholders in China, Vietnam and Bhutan, a field trip to these countries was deemed not to be necessary.

Australian interviews included a further meeting with Dr Tahir Khurshid, and field work with Graeme Sanderson, Research Horticulturalist, NSW DPI, Dareton Primary Industries Institute. This field work included:

- an inspection of Chinese citrus rootstock mother-trees
- a meeting with Tim Herrmann, Manager, Australian Citrus Propagation Association Incorporated (Auscitrus), to discuss take-up of Chinese citrus rootstocks by the Australian industry
- a meeting with Steven Falivene NSW DPI, Citrus Industry Development Officer, to discuss the potential economic implications of Chinese citrus rootstock adoption.

Economic modelling of the projects' impacts on the Australian citrus industry was completed using a standard welfare framework that was consistent with ACIAR guidelines (Davis et al. 2008).

Case studies were prepared to provide additional detail on economic, environmental, social and capacity-building impacts in China, Vietnam and Bhutan.

1.4 Project summaries

Table 1 summarises the key ACIAR projects considered. Data were mostly obtained from ACIAR project records and the ACIAR website.

Table 1: ACIAR projects considered in the impact assessment study

Project number	Title	Countries	Objectives	Associated reviews and materials
CS1/1987/002	Citrus rootstock development	• China • Australia	• Collect and exchange citrus rootstock material including species native to China and Australia, local clonal selections and hybrids arising from breeding programs. • Cooperate in the evaluation of potential rootstock material on isozyme analysis, disease tolerance, salt tolerance and horticultural attributes.	• Project document (proposal) • Final report (Barkley & Zhusheng 1997) • ACIAR project profile • Gardner & Khurshid (2018)
CS1/1996/076	Evaluation of East Asian citrus germplasm as scions and rootstock	• China • Vietnam • Australia	• Collect and exchange citrus rootstocks, clones, public access hybrids and species native to each country. • Cooperate on evaluation of citrus rootstock material, including germplasm characterisation, assessment of tolerance to pathogenic and environmental stresses and assessment of horticultural potential. • Collect and exchange citrus scion germplasm of economic significance to each country. • Assess, improve and maintain the health status of citrus scion germplasm. • Investigate the feasibility of citrus seed introduction to reduce juvenile period for fruiting budwood. • Establish source trees for important new citrus cultivars in each country.	• Project document (proposal) • Final Report (Barkley & Bevington 2003) • ACIAR project profile • National program for screening and evaluation of new citrus rootstocks (Khurshid et al. 2008) • Economic evaluation of the National Citrus Rootstocks Program (Clarke & Chudleigh 2010) • CS1/1996/076 adoption report (Bevington 2006)
HORT/2005/142	Improving mandarin production in Bhutan and Australia through the implementation of on-farm best management practices	• Bhutan • Australia	• Develop a commercial nursery production system in Bhutan which can provide high-quality planting material. • Implement a sustainable pest management program to control Chinese citrus fruit fly and the psyllid vector that transmits citrus greening disease (HLB). • Develop and demonstrate improved management practices, such as the use of certified seedlings budded onto improved rootstocks, tree training and pruning, control strategies for the major pests/diseases, basic tree nutrition, irrigation and crop management principles. • Build capacity in the Bhutanese citrus research and extension sectors, by demonstration and training in commercial citrus production practices.	• Project document (proposal) • Final report (Hardy & Dorjee 2011) • ACIAR project profile

Project number	Title	Countries	Objectives	Associated reviews and materials
HORT/2010/089	Adapting integrated crop management technologies to commercial citrus enterprises in Bhutan and Australia	• Bhutan • Australia	• Improve Bhutanese citrus nursery production practices, establish high health status mother-trees, collect and secure local citrus germplasm in an insect proof screen-house, and introduce a selection of commercial citrus varieties from Australia for local evaluation. • Improve knowledge and management of key citrus pests and diseases. • Improve citrus management practices, tree nutrition and evaluation of water supply options for the orchard. • Build the capacity of Bhutanese scientists, extension agents and leading farmers through in-country training and four-week training visits to Australia for key staff.	• Project document (proposal) • Final report (Sanderson & Tenzin 2018) • ACIAR project profile <http://aciar.gov.au/project/hort/2010/089> • Project fact sheet

2 Research investment

2.1 ACIAR investment in four citrus projects

Table 2 shows ACIAR investment in the four citrus projects.

Project CS1/1987/002 was a partnership between ACIAR, NSW DPI, CSIRO Plant Industry of Australia, and the CAAS, CRI, Beibei, Chongqing and Sichuan, China.

In addition to ACIAR's investment shown in Table 2:

- NSW DPI invested $100,000 in salaries and $500,000 in facilities and equipment
- CSIRO Plant Industry contributed $40,000 in salaries and $500,000 in facilities and equipment
- CRI, Chongqing, invested $10,100 in 1993, $15,100 in 1994 and $25,000 in 1995 for staff and equipment.

Table 2: ACIAR investment in four citrus projects (year ending 30 June)

Year	CS1/1987/002 ($A)	CS1/1996/076 ($A)	HORT/2005/142 ($A)	HORT/2010/089 ($A)	Total ($A)
1993	84,295	0	0	0	84,295
1994	117,886	0	0	0	117,886
1995	117,074	0	0	0	117,074
1996	6,616	0	0	0	6,616
1997	6,616	0	0	0	6,616
1998	0	360,826	0	0	360,826
1999	0	258,610	0	0	258,610
2000	0	145,913	0	0	145,913
2001	0	45,913	0	0	45,913
2002	0	35,912	0	0	35,912
2003	0	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0
2006	0	0	0	0	0
2007	0	0	96,248	0	96,248
2008	0	0	188,429	0	188,429
2009	0	0	197,715	0	197,715
2010	0	0	170,189	0	170,189
2011	0	0	113,064	0	113,064
2012	0	0	15,002	88,623	103,625
2013	0	0	0	252,442	252,442
2014	0	0	0	287,392	287,392
2015	0	0	0	250,448	250,448
2016	0	0	0	205,861	205,861
2017	0	0	0	151,718	151,718
Total	**332,487**	**847,174**	**780,647**	**1,236,484**	**3,196,792**

Source: ACIAR project records.

Projects preceding CS1/1987/002 included an Australian International Development Assistance Bureau China (AIDAB) citrus development project in Hunan Province, China (citrus pathology, virus indexing, nutrition, entomology and budwood multiplication), and a Food and Agriculture Organization of the United Nations (FAO)/United Nations Development Program citrus rehabilitation project in South-East Asia (RAS/86/022). Initial investigations before this project included a field trip to China by NSW DPI and ACIAR in 1986 and a feasibility study in 1988.

Project CS1/1996/076 was a partnership between ACIAR, NSW DPI, CSIRO Plant Industry, Australia, CRI, Beibei, Chongqing and Sichuan, China, SOFRI, Tien Giang, Vietnam, and the Research Institute of Fruit and Vegetables (RIFAV), Hanoi, Vietnam. Table 3 shows partner investment in the project.

Initial investigations before the project included a trip to Vietnam in 1997 to assess the extent of citrus genetic diversity and the technical competency of research staff.

ACIAR and the International Plant Genetic Resources Institute also funded a regional workshop on conservation of citrus germplasm and rootstock improvement, held in Brisbane in 1997. Representatives from Pakistan, India, Thailand, China, Japan, Australia, Indonesia, Philippines, Nepal, Vietnam and Malaysia attended the workshop, with guest speakers from France, USA and Spain.

Project HORT/2005/142 was a partnership between:

- ACIAR
- NSW DPI
- the Horticulture Division of the Bhutan DoA
- the National Plant Protection Centre, Bhutan
- the National Soils Services Centre, Bhutan
- the National Postharvest Centre, Bhutan
- Regional Extension Services, Bhutan
- the Druk Seed Corporation, Bhutan.

Project partners made no financial contribution. But the project leveraged funds from other sources, such as the European Union (EU)-funded Agriculture Sector Support Project, to set up four additional demonstration sites in Bhutan and insect-proof screen-houses to produce disease-free grafted citrus trees at the National Seed Centre, Bhur, and the Tsirang Research Centre.

Additionally, a new insect-proof nursery facility and a mother-tree repository were built at the Renewable Natural Resources Research Development Centre, Mithun, Tsirang, with the financial support of the United Nations Development Program.

Projects preceding HORT/2005/142 included:

- *A survey of fruit flies in Bhutan and a field control program for the Chinese Citrus fruit fly* (CS2/1997/101)
- *Improving subtropical citrus production in Sikkim and Australia* (developed improved nursery practices) (HORT/2002/030)
- *Huanglongbing (HLB) management in Indonesia, Vietnam and Australia* (strategies for the control of HLB and the psyllid vector) (CP/2000/043)
- *A survey of fruit flies in Bhutan and a field control program for Bactrocera minax [Enderlein] the Chinese fruit fly* (recommended a tentative fruit fly management program for Bhutan) (HORT/1997/101).

Table 3: Partner investment in CS1/1987/002

Partner	1998 (A$)	1999 (A$)	2000 (A$)	Total (A$)
NSW DPI	160,417	170,953	196,230	527,600
CSIRO	107,507	110,195	217,834	435,536
China	15,300	19,550	16,800	51,650
Vietnam	15,300	19,550	16,800	51,650
Total	**298,524**	**320,248**	**447,664**	**1,066,436**

Source: ACIAR project records.

The Bhutan project also worked closely with HORT/2005/160 (Increasing citrus production in Pakistan and Australia through improved orchard management techniques and more efficient use of inputs). Initial investigations before HORT/2005/142 included an in-country scoping study in 2006.

Project HORT/2010/089 mostly retained the same group of partners as HORT/2005/142. Partners included:

- ACIAR
- NSW DPI
- the University of Western Sydney
- Bhutan DoA Horticulture Division
- the National Plant Protection Centre
- the National Soils Services Centre
- the Renewable Natural Resources Research Development Centres
- the National Postharvest Centre
- district extension services
- the National Seed Centre.

Project partners made no financial contribution.

2.2 Australian investment in citrus rootstocks

Australia has had a National Citrus Rootstock Improvement Program managed by Hort Innovation (Horticulture Innovation Australia Limited), which has been responsible for further evaluation of Chinese and Vietnamese rootstocks sourced via ACIAR projects, CS1/1987/002 and CS1/1996/076. Projects conducted by Hort Innovation include:

- *Evaluation of new citrus rootstocks* (CT317)
- *National program for screening and evaluation of new citrus rootstocks* (CT03025)
- *Assessing the horticultural performance of new rootstocks via short-term orchard trials* (CT07002)
- *Evaluation and commercialisation of new rootstocks* (CT13042)
- *Evaluation of new rootstocks for the Australian citrus industry* (CT17002).

Since 1997, Hort Innovation projects have been delivered by Dr Tahir Khurshid, Plant Physiologist, NSW DPI. Table 4 shows Hort Innovation and partner investment in citrus rootstock evaluation.

The current Hort Innovation rootstock evaluation project (CT17002), which is relevant to the assessment of economic benefits to Australia from ACIAR investment in Chinese citrus rootstocks, has the following objectives:

The performance of selected rootstocks on a range of scion varieties will be assessed in newly established short-term semi-commercial trials on grower properties in five Australian states.

A newly established field trial at NSW DPI Dareton will be evaluated, comprising M7 navel, Atwood navel and Tang Gold mandarin on semi-dwarfing Chinese rootstocks identified in CT07002 and dwarfing rootstocks imported from the USA.

An experimental trial was established in Bindoon, Western Australia, in 2013, to evaluate the salt tolerance of selected rootstocks. The trees are now productive and four years of data on yield, fruit quality and tree health will be gathered so that recommendations can be made to industry.

A field trial on Italian rootstocks will be established at NSW DPI, Dareton, in collaboration with a commercial partner, Australian Nurserymen's Fruit Improvement Company, to evaluate the performance of rootstocks imported from Italy. The Riverina trial will be evaluated and completed during this project.

HLB is the biggest threat to the Australian citrus industry. There is no cure for this disease, which is destroying citrus industries in affected countries, although progress has been made with identifying rootstocks with some tolerance to HLB. Auscitrus, Citrus Australia (grower representative body) and the Variety Leadership Group are working with NSW DPI and the Queensland Department of Agriculture and Fisheries (QDAF) researchers to identify rootstocks for importation. Field trials to assess the performance of selected HLB-tolerant rootstocks under Australian conditions will be established in New South Wales, Victoria and Queensland in collaboration with the Department of Primary Industries and Regional Development, Western Australia, and QDAF.

Table 4: Horticulture Innovation Australia citrus rootstock project budgets (year ending 30 June)

Year	CT317 (A$)	CT03025 (A$)	CT07002 (A$)	CT13042 (A$)	CT17002 (A$)	Total (A$)
1993	0	0	0	0	0	0
1994	29,991	0	0	0	0	29,991
1995	0	0	0	0	0	0
1996	0	0	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
2003	0	0	0	0	0	0
2004	0	207,653	0	0	0	207,653
2005	0	168,091	0	0	0	168,091
2006	0	168,151	0	0	0	168,151
2007	0	177,483	0	0	0	177,483
2008	0	63,702	48,294	0	0	111,996
2009	0	0	128,783	0	0	128,783
2010	0	0	160,979	0	0	160,979
2011	0	0	128,783	0	0	128,783
2012	0	0	65,059	0	0	65,059
2013	0	0	21,464	0	0	21,464
2014	0	0	0	134,759	0	134,759
2015	0	0	0	340,508	0	340,508
2016	0	0	0	114,049	0	114,049
2017	0	0	0	108,049	0	108,049
2018	0	0	0	87,714	258,068	345,782
2019	0	0	0	0	258,068	258,068
2020	0	0	0	0	258,068	258,068
2021	0	0	0	0	258,068	258,068
2022	0	0	0	0	258,068	258,068
Total	**29,991**	**785,080**	**553,362**	**785,079**	**1,290,340**	**3,443,852**

Note: Total includes contributions from partners including NSW DPI, Queensland Department of Agriculture and Forestry (QDAF), SARDI and CSIRO.

Sources: Hort Innovation project records; Clarke et al. 2010.

3 Project description and timeline

An Australian International Development Assistance Bureau (AIDAB) citrus project completed in Hunan Province, China, in the early 1980s concluded that further ACIAR investment in citrus would be beneficial to both China and Australia.

Subsequently, citrus rootstock improvement was identified as a priority area for further collaborative research, following a visit to China by Ms Patricia Barkley (NSW DPI) and Dr Gabrielle Persley (ACIAR) in 1986. A feasibility study in 1988 by Dr Ken Bevington (NSW DPI), Dr Steve Sykes (CSIRO) and Mr Robert Moore (ACIAR) recommended that a citrus rootstock improvement project should proceed.

The subsequent project, *Citrus rootstock development* (CS1/1987/002), was a partnership between Australia and China, and ran from July 1992 to December 1996.

In both countries, salinity and alkalinity are concerns in citrus producing areas. Researchers have been seeking improved disease-tolerant rootstocks that will adapt to local soil and climatic conditions. Chinese scientists had established arboreta of wild citrus relatives in Hunan and Sichuan provinces, and assistance was required with species identification and evaluation.

Consequently, CS1/1987/002 aimed to collect and exchange citrus rootstock material, local clonal selections and hybrids, and cooperate in their evaluation. Rootstocks were evaluated using isozyme analysis (a rapid method for the species identification of cell cultures), and assessed for disease tolerance, salt tolerance and horticultural attributes. Wild citrus collected in southern China included *Poncirus trifoliata* variants, natural *P. trifoliata* hybrids, several *Fortunella* species, wild mandarins and selections of *Citrus ichangensis* and *C. junos*. *P. trifoliata* is one of the rootstocks on which the Australian citrus industry is currently based.

Following the success of CS1/1987/002, a second ACIAR project, *Evaluation of East Asian citrus germplasm as scions and rootstock* (CS1/1996/076), was completed between July 1997 and June 2002.

This project collected and exchanged citrus rootstocks, clones, public access hybrids and species native to China, Vietnam and Australia. The collection of native species was a priority, as human pressure was affecting the availability of natural citrus species in both China and Vietnam, and the citrus greening disease caused by the bacterium HLB was reducing wild citrus populations in Vietnam.

The project addressed the problem by starting to collect, evaluate and exchange citrus germplasm. Researchers cooperated in the evaluation of rootstock material, and collected and exchanged citrus scion germplasm. The project established source trees for important new citrus scions in each country.

Separately, ACIAR made investments in the citrus industry of Bhutan, and further investment in the citrus industry of Australia between April 2007 and October 2011.

The project *Improving mandarin production in Bhutan and Australia through the implementation of on-farm best management practices* (HORT/2005/142) developed a commercial nursery production system, implemented a sustainable pest and production management program and built capacity in the Bhutanese citrus research sector.

Marketable citrus crop yields are low in Bhutan, at 11 t/ha compared with 35 t/ha in Australia. Poor orchard management results in a lack of control of Chinese citrus fruit fly and the psyllid vector for HLB. The extent of HLB in Bhutan was not known. The use of seedling grown trees without grafted rootstock was limiting fruit yield.

The project aimed to improve the quality and yield of the single mandarin cultivar on which the Bhutanese citrus industry relies.

In Australia, the project aimed to expand work already underway on rootstock/scion compatibility, tree and crop management strategies, assessment of fruit quality characteristics and marketing opportunities. The Australian work focused on mandarin production, as this was the citrus sector with the strongest outlook for growth, is more challenging than oranges to grow and has had the least research investment. The project produced the first mandarin production fact sheets for both Bhutan and Australia.

As a follow-on from HORT/2005/142, ACIAR commissioned a fourth project—*Adapting integrated crop management technologies to commercial citrus enterprises in Bhutan and Australia* (HORT/2010/089).

The project ran from April 2012 to March 2017, building on HORT/2005/142 outputs and focusing on adoption of production technologies.

In Bhutan, the project improved:

- the quality of Bhutanese citrus planting material through germplasm collection, mother-tree establishment and improved nursery practices
- knowledge and management of key citrus pests and diseases
- citrus orchard management practices
- nutrition and evaluation of water supply options
- the citrus research, development and production capacity of Bhutanese scientists, extension agents and citrus farmers.

In Australia, the project enabled the Australian variety evaluation program to be expanded to include more testing and evaluation of the critical management practices needed for successful mandarin production. The project also delivered the Australian Mandarin Production Manual (Hardy et al. 2017) and additional Australian exotic pest and disease management skills.

4 Impact pathways and map

An impact pathway was developed (figures 2–5), which describes the most significant set of potential impacts. For example, the impact pathway for Australia describes the potential contribution of Chinese citrus rootstocks, rather than exploring the secondary impact of new genetics for scions or improved mandarin production practices.

1. ACIAR projects CS1/1987/002 and CS1/1996/076 resulted in the provision of 47 Australian public access varieties and commercial rootstock seeds, including:
   - Late Lane navel (late-season Australian public access navel variety)
   - Ellendale Tangor (mid-season Australian public access mandarin variety)
   - Newhall navel (early season Californian, used to breed two Chinese varieties).
2. Testing and cultivation of Australian varieties in China, with:
   - research work completed by CRI—rootstocks, suitable locations in China, nursery techniques and agronomy
   - Late Lane navel cultivated by China nursery sector.
3. Late Lane navel extensively promoted and propagated, with:
   - China–USA project also introducing Late Lane, and promoting use in southern China
   - local government subsidising the introduction of virus-free trees and new varieties
   - 100,000 Late Lane trees planted in southern China between 2002 and 2005
   - Late Lane area continuing to expand since 2005, and is now a major variety in China (Dr Tahir Khurshid, Plant Physiologist, NSW DPI, Dareton, pers. comm., July 2018).
4. Improved on-farm productivity China, resulting in:
   - Late Lane navel supplies high-value festival/off-season market, and earns more than earlier maturing varieties (Dr Zhao Xiaochun, Director, CRI, CAAS, pers. comm., August 2018).

Figure 2: Major impact pathway for China

1. ACIAR project CS1/1996/076 resulted in the establishment of:
   - techniques for disease-free planting material, including HLB detection
   - a nursery tree certification scheme.
2. Further work by SOFRI included:
   - investment in a new laboratory for detecting HLB
   - techniques taught as part of CS1/1996/076 were used to test samples and eliminate contaminated material that would otherwise have been planted
   - 40,000–50,000 disease-free trees produced each year at SOFRI.
   - Clean planting material supplied through 30 Mekong Delta nurseries.
3. Ongoing HLB control work included removal of infected trees, replanting with disease-free trees and control of HLB vectors, with:
   - the Food and Agriculture Organization of the United Nations/United Nations Development Program investing in HLB control since 1989
   - the Vietnam Government investing in training and production techniques
   - ACIAR investing in CP/2000/043 (Huanglongbing management in Indonesia, Vietnam and Australia)
4. Improved on-farm productivity in Vietnam over long term, from a start of:
   - 55% of 40,000 ha in Mekong Delta affected by HLB, with 27% severely affected
   - HLB reducing farmer income from citrus by 25%–55%.

Figure 3: Major impact pathway for Vietnam

1. ACIAR projects HORT/2005/142 and HORT/2010/089 introduced best-practice farm management to citrus production in Bhutan.
   - Short-term gain: Selective pruning, weed control, basins to retain nutrients, better nutrition, incorporation of irrigation, control of pests and diseases and the use of gibberellic acid (larger farms surrounding project-established demonstration farms are the first to adopt)
   - Medium-term gain: Replacement of seed grown trees with nursery-grown trees on suitable rootstock, introduction of new varieties, industry relocation above 1,200 m to minimise exposure to the psyllid vector of HLB.
2. Bhutan DoA reported:
   - additional capacity to assist farmers through trained staff, demonstration farms, citrus genetics repository, production manuals and training videos.
3. Bhutan Government:
   - provided subsidies for grafted trees, transportation of inputs, irrigation, leasing of land for new orchards above 1,200 m
   - developed a new national five-year plan (2019–2023), which includes the rollout of irrigation systems and further investment in rural access roads.
4. World Bank Food Security and Agricultural Productivity Project:
   - will run from 2018 to 2023
   - has identified citrus as a priority
   - is designed to build on work completed by ACIAR, including area-wide management of Chinese citrus fruit fly and citrus canopy management.
5. National Seed Centre (previously the Druk Seed Corporation):
   - now develops and supplies grafted, nursery-grown trees, although it will be 2023 before enough clean budwood is available in Bhutan to graft all citrus trees (Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, Bhutan, pers. comm., August 2018)
   - is the monopoly supplier of juvenile citrus trees in Bhutan, with backyard nursery production actively discouraged
   - was a partner in ACIAR projects and is now fully government owned.
6. Farmer uptake of production practices and nursery grown trees was as follows:
   - A total of 250 households (out of 22,000 households growing citrus) were targeted during HORT/2005/142, and 2,889 households were trained during HORT/2010/089.
   - ACIAR projects worked with larger farmers with 100–500 trees.
   - Smaller farmers have benefited through ‘spillovers’—that is, observing large farmer practices and adopting affordable interventions (such as canopy management, tree basins)
   - Demonstration farms created during the ACIAR projects now serve as local learning centres, with more established after the end of the projects.
   - Project messages were communicated by extension officers in each sub-district and the Bhutan Broadcasting Service.
7. Improved on-farm productivity and citrus production area includes:
   - significant and immediate positive impact on mandarin yields (11 t/ha rising to 14 t/ha, noting that Australian yield is 35 t/ha, and that 50 t/ha is possible with Afourer mandarin), and on fruit quality (larger, sweeter fruit able to compete in export markets in Bangladesh and India)
   - lower impact of HLB through the gradual relocation of the citrus industry to areas above 1,200 m.
   - scope for significant industry expansion at higher altitudes, with total production area forecast to increase from 37,000 ha to 250,000 ha by 2023.

Figure 4: Major impact pathway for Bhutan

1.	ACIAR projects CS1/1987/002 and CS1/1996/076 collected East Asian germplasm as scions and rootstocks (July 1992 to June 2002), with: • 112 citrus rootstock (77) and scion accessions (35) sourced from China • 44 citrus rootstock and scion accessions sourced from Vietnam.
2.	Repository of Chinese and Vietnamese rootstocks established in Australia (1993), with: • Citrus Program Manager, Hort Innovation recognising the potential value of the rootstock resource, and working with the Australian citrus industry to establish an evaluation program.
3.	Hort Innovation National Citrus Rootstock Improvement Program evaluated Chinese and Vietnamese rootstocks and other Australian hybrid and imported resources, including: • CT0317 evaluation of new citrus rootstocks (1994) • CT03025 rootstock screening and evaluation (July 2003 to February 2008) • CT07002 rootstock short-term orchard trials (April 2008 to May 2013) • CT13042 evaluation and commercialisation of new rootstocks (2014 to 2017).
4	Six Chinese rootstocks released to industry via Auscitrus (who supply citrus nurseries and larger growers) in 2017—four trifoliata and two erythrosa, as: • Zao yang is suitable for navels, Valencia and Eureka lemon, and is superior to current industry standard rootstock (Tri22) • Anjiang hongju is a superior mandarin rootstock that is suitable for both traditional Australian varieties and Afourer whose area is rapidly expanding.
5.	A seventh Chinese rootstock, Barkley, released to industry via Auscitrus following QDAF research. Barkley offers yield, fruit quality and orchard longevity benefits, and is particularly relevant to the Queensland mandarin industry.
6.	Hort Innovation National Citrus Rootstock Improvement Program (CT1702; 2017–2022) is conducting long-term field trials of the: • dwarfing capabilities of non-released Chinese rootstocks • salt tolerance capabilities of non-released Chinese rootstocks.
7.	Improved on-farm productivity in Australia with: • released Chinese rootstocks offering improved yield and fruit quality • non-released Chinese rootstocks having potential for more efficient intensive orchards and citrus production in a future, hotter dryer climate (salt tolerance).

Figure 5: Major impact pathway for Australia

ACIAR impact mapping teases out the important distinctions between project outputs, adoption, outcomes, intermediate impacts and final impacts. Figure 6 shows an impact map, covering each of the countries involved in the four ACIAR projects on which this impact assessment is based.

OUTPUTS			
Technologies	**Scientific knowledge**	**Capacity**	**Policy goals**
• Collection and assessment of germplasm in China, Vietnam, Bhutan and Australia. • Australian molecular analysis technologies transferred to China and Vietnam. • Virus-free progeny established in China, Vietnam, Bhutan and Australia.	• Understanding of the value of native and traditional germplasm from China and Vietnam. • Understanding of the value of domestic germplasm in the citrus industries of other countries. • New knowledge on pests and diseases, including powdery mildew, Chinese citrus fruit fly, the psyllid vectors of HLB, trunk borer, citrus scab, *Phytophthora* root rot and collar rot.	• Understanding of the importance of disease-free budwood and grafted rootstock. • Molecular analysis techniques for germplasm and disease assessment. • Best-practice production and biometrics, Bhutan. • Networks for continuous learning. • Demonstration farms in Bhutan. • Insect-proof houses for mother-trees, China, Vietnam. • Exotic pest management skills, Australia.	• China: extend citrus supply into festival and off-season. • Vietnam: increase citrus from 11,000 t in 1991 to 450,000 t by 2000. • Bhutan: increase exports, extend citrus season, work toward organics, improved access to market (roads), increase production area (land lease) and introduce irrigation. • Australia: new citrus rootstocks to improve on-farm productivity.

ADOPTION			
Commercialisation	**Communication**	**Capacity building**	**Regulation**
• New rootstocks offering improved yield and fruit quality, more tolerant of disease and performing better with mandarins, China, Vietnam, Bhutan, Australia. • Potential dwarfing root-stocks and more efficient production systems, Australia. • Potential salt-tolerant rootstocks China, Vietnam, Australia. • A new orange variety able to fill a specific market window, China. • New scions able to meet the demand for larger, sweeter easy peeling fruit, China, Vietnam, Bhutan.	• Scientific papers on citrus genetics, farm rehabilitation, pests and diseases. • Production/distribution of best-practice production guides China, Vietnam, Bhutan, Australia. • Videos for TV explaining seasonal production activities, Bhutan. • Demonstration farms to show benefits of project recommendations, Bhutan. • Study trips to Australia for extension officers and research scientists, China, Vietnam and Bhutan.	• Scientists selecting improved genetic material for uptake on-farm, China, Vietnam, Bhutan, Australia. • Molecular analysis skills applied to other crops, China, Vietnam. • Stronger institutions able to complete more research and train more scientists, China, Vietnam and Bhutan. • Farmers with improved trees, China, Vietnam. • Implement integrated pest and production systems, Bhutan. • Farmers able to address HLB and continue with more profitable citrus, China, Vietnam and Bhutan.	• China: no regulatory response. • Vietnam: nursery tree standard certification scheme rolled out and supported. • Bhutan: production subsidies (nursery trees, production inputs, land leasing and irrigation infrastructure) and nursery tree standard certification scheme rolled out and enforced. ACIAR projects consistent with Gross National Happiness Index. • Australia: no regulatory response.

(continued over next page)

OUTCOMES AND INTERMEDIATE IMPACTS

Demand	Supply	Environmental	Social
• Demand for larger, sweeter and easy peeling citrus is increasing around the world, especially in Asia. • ACIAR projects help meet increased demand.	• Increased supply for existing production systems, new intensive production systems and production in a hotter dryer environment.	• Conservation of native citrus types, China, Vietnam. • 'Softer' chemicals and use of area-wide freedom. • Negative if misuse of new fertilisers, insecticides and irrigation occurs, Bhutan.	• Income opportunities in poor rural areas (although project outputs sometimes target larger commercial growers in the first instance).

FINAL IMPACTS

Economic	Environmental	Social
• Improved on-farm productivity, China, Vietnam, Bhutan, Australia. • Avoided costs—HLB in Australia.	• No negative impacts, with chemical fertiliser, insecticides and irrigation water correctly managed, Bhutan. • Positive impacts with Chinese citrus fruit fly and powdery mildew controlled with organic solutions, Bhutan.	• Benefits available for men and women. • Some poverty alleviation achieved. • Benefits to smallholders, direct and from spillovers, Bhutan, Vietnam, China.

Figure 6: Impact map for citrus projects, China, Vietnam, Bhutan and Australia

5 What was discovered —project outputs

5.1 Technologies developed and citrus resources accessed

This section describes new technologies developed and citrus resources accessed as a result of ACIAR investment for each of the participating countries.

5.1.2 China

In China, participation in two projects (CS1/1987/002 and CS1/1996/076) resulted in the collection and safe storage of citrus genetic material, including unique native species, old local varieties and sub-wild types.

Mother-trees were grown from this genetic material, and housed in insect-proof screen-houses. ACIAR investment helped restore the National Citrus Germplasm Repository at the CRI in Chongqing.

Virus-free budwood from 47 Australian and international public access varieties was provided to China, along with seed for commercially important citrus rootstocks. Shared budwood focused on late harvest Australian navel orange and mandarin varieties, offering the potential to extend the citrus harvest period into the January festival and off-season market.

Since then, Australian public access variety Late Lane has been extensively propagated and Ellendale Tangor has been trialled. The CRI produced new varieties from the public access Californian Newhall navel supplied by the ACIAR projects, and two new mandarins were bred from Chinese germplasm collected as part of CS1/1987/002 and CS1/1996/076.

Technologies shared with China by Australia enabled molecular analysis of citrus germplasm to determine disease status, rootstock–scion compatibility, and ability to produce ‘true-to-type’ fruit. Using Australian-supplied technology, virus-free progenies of local clonal selections of key cultivars were established by heat treating and shoot-tip grafting at the CRI in China.

5.1.3 Vietnam

In Vietnam, participation in a single project (CS1/1996/076) resulted in the collection and safe storage of citrus genetic material, including native species and variants found in small and isolated orchards.

Genetic material collected included 60 horticulturally superior pummelo, 17 mandarin and 12 lime. These varieties were health tested, and mother-trees were grown, and housed in insect-proof screen-houses built as part of the project at SOFRI.

In 2018, the genetic material remains safely housed at SOFRI, but no commercial releases have been made (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

Virus-free budwood for 20 Australian public access citrus varieties was provided to Vietnam, along with seed for commercially important citrus rootstocks. Virus-free budwood is particularly important in Vietnam, where more than half of all citrus is affected by Huanglongbing (HLB) and experiencing production loss.

The Australian public access Leng navel has performed well in Lamdong province with high yields of good quality fruit. The Australian public access Orlando tangelo was released commercially, and grown in small volumes in the south of the country, until replaced with a superior local variety (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

Technologies shared with Vietnam by Australia enabled molecular analysis of citrus germplasm to determine disease status, rootstock–scion compatibility, and ability to produce ‘true-to-type’ fruit.

Virus-free progenies of local clonal selection of key cultivars were established by heat treating and shoot-tip grafting at SOFRI. A nursery certification scheme was established in southern Vietnam to provide growers with confidence that the trees they were buying were disease free, and better able to resist HLB.

5.1.4 Bhutan

In Bhutan, participation in two projects (HORT/2005/142 and HORT/2010/089) resulted in the collection, safe storage and production of disease-free mother-trees from Bhutan's native citrus stocks.

Bhutan has relied on a single mandarin, known as 'Khasi' in the east and 'Sikkim' in the south-west of the country. The projects introduced, provided safe storage for, and produced Australian public access varieties including navel oranges, common orange, pigmented orange, grapefruit and mandarin.

One navel orange selection (Cara Cara), the internationally popular mandarin Afourer, and processing fruit for juice have been trialled with some success.

The project introduced seven rootstock types to Bhutan's research centres and the National Seed Centre (Druk Seed Corporation). New knowledge was generated on the suitability of Australian rootstocks for mandarin production in Bhutan.

Clean, healthy 'true-to-type' sources of citrus germplasm were developed and provided to demonstration farms and growers from both local and imported cultivars. Improved nursery propagation techniques were demonstrated, including lighter, more appropriate potting mixes. The benefits of replacing seed-grown trees with disease-free, higher-yielding trees grafted to suitable rootstocks was demonstrated. Australian rootstocks were grafted onto local mandarin scions and planted on demonstration farms.

Improved farm management techniques were demonstrated to researchers, extension officers and growers. These included selective pruning (canopy management), weed management, water and nutrient retention basins, nutrition management, irrigation and control of pests and diseases.

Key pests and diseases tackled included Chinese citrus fruit fly, the psyllid vector for HLB and powdery mildew. Knowledge of citrus phenology was created in each production district, enabling management practices to be tailored to agro-ecological zones to improve input use efficiency. The use of gibberellic acid/growth regulators to manage the harvest window and postharvest storage was also demonstrated.

Citrus production guides were produced and distributed. Guides included a pest and disease field guide for Bhutan, a production guide for mandarins in Bhutan and printed nursery irrigation management and soil and water management course materials.

5.1.5 Australia

Australia developed technologies and accessed citrus resources through participation in all four projects. ACIAR project CS1/1987/002 provided access to 77 citrus accessions from China, with the potential to generate new rootstocks that can deliver:

- higher yields
- better fruit quality
- resistance to endemic disease (such as citrus tristeza closterovirus, which has been endemic in Australia since 1870, and *Phytophthora*)
- scion compatibility
- salinity and alkalinity resistance
- dwarfing for more productive citrus orchards.

Genetic material provided by China as part of CS1/1987/002 included 46 rootstock types, including:

- 24 trifoliata (*Poncirus trifoliata*)
- 10 mandarins (*Citrus reticulate*)
- four erythrosa (*C.erythrosa*)
- three ichangensis (*C. ichengensis*)
- three yuzu (*C. junos*)
- two sour orange (*C. aurantium*).

In addition to the 77 Chinese citrus accessions provided as part of CS1/1987/002, a further 35 accessions were provided as part of CS1/1996/076. The second round of genetic material provided by China included both rootstock and scion accessions.

At the time the research was completed, a subset of the Chinese accessions was thought to have potential as scions, including new mandarin varieties to meet Asian export market tastes. To date, none of these accessions have proved to be a commercial proposition (Dr Tahir Khurshid, NSW DPI, pers. comm., June 2018).

Australian mandarin production was given a boost by the ACIAR projects, with new rootstock genetics, additional resources for the national breeding program and evaluation and communication of best-practice production techniques.

Accessions supplied to Australia by China included seeds of crosses made in China to investigate salt tolerance in *P. trifoliata*, a major rootstock in both countries. Among these crosses, new salt accumulation and exclusion germplasm, with commercial potential, has subsequently been identified.

Zao yang, a *P. trifoliata* accession from lemons has shown no indication of yellow-ring incompatibility, a major problem in commercial lemon production. The rootstock shows promise as an alternative replant rootstock for Eureka lemons.

Australian field trials of Chinese rootstocks grafted to Valencia orange—Navelina navel, Late Lane navel, Imperial mandarin, Eureka lemon and Fino lemon scion cultivars—have revealed positive impacts on yield and yield efficiency relative to tree size. Fruit quality, including size and sugar content (measured in brix units), was also improved.

Vietnam provided Australia with 44 new rootstock and scion accessions, as part of CS1/1996/089. This genetic material was incorporated into the Australian rootstock evaluation program. Evaluation of Vietnamese genetic material completed as part of Hort Innovation project CT13042 failed to identify promising rootstock lines for Australia (Dr Tahir Khurshid, NSW DPI, pers. comm., June 2018).

A repository of Chinese and Vietnamese rootstocks and scion material has been established in Australia at the NSW DPI, Dareton Primary Industries Institute. Mother-trees have been grown from this germplasm.

New knowledge on exotic citrus pests and diseases was developed and communicated to the Australian industry (for example, HLB). Improved field- and laboratory-based diagnostics for exotic pests of citrus were developed. Targeted advisory materials on exotic pests and diseases of citrus were developed and distributed.

5.2 Scientific knowledge created

The ACIAR investment created new understanding of the value of native and traditional germplasm, and knowledge of the worth of domestic germplasm in the citrus industries of other countries.

Native and traditional germplasm from China, Vietnam and Bhutan was collected and preserved as a repository of material that might be valuable in both the short and longer term in citrus breeding programs. The repository's value to pure science and conservation is also noted.

The projects resulted in publication of a scientific paper on genetic diversity of *P. trifoliata*. Germplasm from commercial rootstocks and varieties in China, Vietnam and Australia was exchanged. Some of this material was assessed for its immediate applicability to current commercial needs, and new knowledge was created to inform rootstock and scion breeding programs. Scientific papers were produced on citrus rehabilitation in East Asia.

The ACIAR investment also created new knowledge of citrus pests and diseases, including powdery mildew, Chinese citrus fruit fly, the psyllid vectors of HLB, trunk borer, citrus scab, parasitic plants (*Lorenthus spp*.), *Phytophthora* root rot and collar rot. New scientific knowledge created included pest and disease biology, ecology and climatic conditions conducive to pest and disease spread.

Trials completed in Bhutan showed that the virulent form of powdery mildew found in that country can be controlled with sulphur, negating the need to use tridemorph, a particularly hazardous chemical and environmental pollutant. The particularly prolific and damaging powdery mildew species isolated in Bhutan was identified as *Odium citri*, the first report of this species in the country. A scientific paper was written on the discovery, and published in the *Australasian Plant Diseases Notes 2010*.

The ACIAR projects demonstrated that superior control of the psyllid vectors of HLB was achieved with the spraying of insecticides at bud break, rather than during peak psyllid activity. Further, growing in areas above 1,200 m results in lower psyllid activity, and higher citrus survival and production. Relocating the Bhutan citrus industry to altitudes of 1,200–1,800 m offers an opportunity to increase the Bhutanese citrus industry's long-term chances of survival.

Chinese citrus fruit fly has traditionally been controlled with hard chemicals, such as dimethoate, which is now banned in Australia. Project research has developed and tested area-wide freedom for Chinese citrus fruit fly, based on cultural measures (for example, removal and destruction of fallen fruit, which is Chinese citrus fruit fly habitat) and use of softer chemicals (less damaging to non-target and potentially beneficial insect species).

Introducing area-wide freedom measures was only possible thanks to new scientific data on Chinese citrus fruit fly's biology and ecology creation as part of the ACIAR projects. This scientific knowledge was published in the proceedings of the 9th International Symposium of Fruit Flies of Economic Importance held in Thailand in May 2014.

Leaf and psyllid samples collected in Bhutan have been used to update and validate procedures in the national diagnostic standard for HLB. Analysis of the black psyllid (*Diaphorina communis*) showed for the first time that it is a vector of HLB, though not a very effective one.

Up until the ACIAR research, it was thought that the Asiatic citrus psyllid (*Diaphorina citri*) was the sole vector of HLB. A scientific paper detailing the nature of this discovery has been published. Research on curry leaf (*Bergera koenigii*) has also been completed to determine whether it is an alternative host for HLB, and found that it is not.

5.3 Capacity development—people, networks and infrastructure

Capacity development can be thought of in terms of the development of people, networks and infrastructure, as well as their ongoing application to in-country research questions and extension issues. This section describes capacity developed as a result of ACIAR investment for each of the participating countries.

5.3.1 China

CS1/1987/002 began in China in 1993 with the training of CRI research and extension officers, and an understanding of what improvement in citrus is possible with disease-free budwood and grafted rootstock. Capacity built has prompted wider use of nursery citrus with grafted rootstocks in China (Bevington 2006).

Five Chinese CRI scientists were trained in isozyme analysis so they could quickly identify citrus species. Training was also provided in molecular fingerprinting techniques for cultivar identification to be used as an adjunct to isozyme analysis.

Training provided a foundation for the further development of molecular indexing capabilities at the CRI. Subsequently, techniques developed in China as part of CS1/1987/002 have been applied to research questions in citrus and other subtropical plant industries (Dr Zhao Xiaochun, Director, CRI, pers. comm., August 2018).

Dr Deborah Hailstones, Molecular Biologist, NSW DPI, trained seven young Chinese CRI scientists in molecular procedures to detect citrus pathogens, using equipment supplied by ACIAR and not previously available in the CRI. Four of the seven Chinese research scientists were still actively involved in research at CRI 13 years after completing this training (Mr Tang Kazhi, Mr Huang Sen, Mr Yang Fangyun and Mr Jiang Dong).

As a result of the capacity built as part of CS1/1996/076, CRI scientists became highly skilled in using semi-nested polymerase chain reactions to detect citrus tatter leaf virus, HLB and citrus canker, as well as in the use of other sophisticated molecular diagnostic techniques to detect and characterise citrus tristeza closterovirus strains.

For example, Dr (Mrs) Jiang trained in Australia in disease elimination, using polymerase chain reactions. The development of molecular diagnostic capabilities was viewed by the CRI as a significant milestone in its development (Bevington 2006). In 2018, the CRI continues to use these techniques (Dr Zhao Xiaochun, Director, CRI, pers. comm., August 2018).

Chinese scientist Dr Zhou Changyong received a John Allwright Fellowship (JAF) to undertake a PhD in Australia as part of CS1/1996/076. His research focused on the mechanism of cross-protection against severe strains of citrus tristeza closterovirus. The successful control of citrus tristeza closterovirus is a critical aspect of citrus improvement programs in both Asia and Australia. After successfully completing his PhD, Dr Zhou Changyong returned to China, and was appointed Section Leader and Director of the CRI.

Under Dr Zhou Changyong's leadership, and with a significant injection of Chinese Ministry of Agriculture funding for upgrade of laboratories and other facilities, the CRI improved its standing as one of the key citrus research institutes in China.

The ACIAR projects were the stimulus for the establishment of the NCVEC at the CRI. This has had a substantial impact on China's citrus virus analysis and exclusion capacity (Bevington 2006).

In 2018, the NCVEC has an essential role in the supply of virus-free mother-trees. Technologies developed by the NCVEC for virus-free citrus propagation were recognised in the State Scientific and Technological Progress Awards in 2012 (Dr Zhao Xiaochun, Director, CRI, pers. comm., September 2018).

Between 2001 and 2005, Australian-trained Dr Zhou Changyong was actively involved in supervising postgraduate students. Dr Zhou and nine other research staff supervised 27 research projects, valued at RMB15 million. A total of 20 postgraduate students (15 MSc and 5 PhD) were involved, and 42 scientific papers were published (Bevington 2006).

In 2016, Dr Zhou Changyong became a full professor at the CAAS Southwest University. In that same year, the CRI successfully hosted the 20th Conference of the International Organization of Citrus Virologists, and Professor Zhou Changyong was elected chair of the organization (Dr Zhao Xiaochun, Director, CRI, pers. comm., September 2018).

Details of CRI staff trained in Australia and their ongoing work status is shown in the table below.

Table 5: Chinese students trained as part of ACIAR projects

Student trained	Type of training and topic	Work status
Dr Zhou Changyong (JAF)	PhD—citrus breeding to protect against citrus tristeza closterovirus	Research and section head at CRI before moving to a professorial position at CAAS, Southwest University, Chongqing
Dr (Mrs) Jiang	Training in disease elimination in clones entering the CRI budwood scheme	CRI Budwood Scheme
Mr Tang Kazhi	Molecular procedures for detection of citrus pathogens	Research at CRI
Mr Huang Sen	Molecular procedures for detection of citrus pathogens	Research at CRI
Mr Yang Fangyun	Molecular procedures for detection of citrus pathogens	Research at CRI
Mr Jiang Dong	Molecular procedures for detection of citrus pathogens	Research at CRI

Sources: CS1/1987/002 and CS1/1996/076 final reports, Bevington 2006, with a 2018 update from Dr Zhao Xiaochun, Director, CRI.

Basic facilities in the China Department of Germplasm Resources and Breeding, which is responsible for the National Citrus Germplasm Repository, have also been improved following ACIAR project investment. Greenhouses have been upgraded, and a major refurbishment of laboratories has occurred. The repository's primary functions of conservation, evaluation, use and exchange of germplasm has been fully implemented (Bevington 2006).

The China, Department of Germplasm Resources and Breeding is using its additional capacity to develop new cultivars through:

- selection of bud mutations
- selection of nucellar lines
- hybridisation
- irradiation
- genetic engineering
- tissue culture
- study of inheritance patterns, breeding method and the adaptability of new cultivars to different localities (Dr Zhao Xiaochun, Director, CRI, pers. comm., August 2018).

Project research scientists from China attended a citrus germplasm conservation workshop organised by ACIAR and held in Brisbane in October 1997. The workshop included the presentation of papers on:

- the extent of indigenous citrus germplasm in countries throughout Asia
- the risk to its survival
- methods of evaluating its potential.

The workshop also created a new network of Asian citrus researchers. Members of the Asian citrus researchers' network meet regularly at international events, including the International Citrus Congress.

The CRI formed an alliance with the Southwest Agricultural University in 2001, which has since been extended to include the Southwest University in Chongqing. As a result of the alliance, a large number of postgraduate students are working at the CRI, which is having a major impact on citrus research outputs (Bevington 2006).

In 2018, the CRI remains the key centre for the study of citrus virus and virus-like diseases. CRI leads multi-institution consortiums for citrus virus research and the control of HLB. It also provides an extensive set of services to the Chinese citrus industry, including virus and HLB testing (Dr Zhao Xiaochun, Director, CRI, pers. comm., September 2018).

Post ACIAR investment, and subsequent investment by the Chinese Ministry of Agriculture, the CRI is well positioned to continue its key role in citrus research.

5.3.2 Vietnam

ACIAR project CS1/1996/076 began in Vietnam in 1998 with two successful workshops—one in Hanoi and the other at SOFRI in Tien Giang—which were convened at the request of Vietnamese project collaborators.

A total of 37 scientists and horticulturalists attended the Hanoi workshop, and 62 participants, comprising 35 researcher and 27 extension workers, attended the SOFRI workshop. Topics included:

- classification of citrus and implications for citrus improvement programs
- effects of climate on citrus production
- sourcing planting material
- citrus scion and rootstock improvement programs
- pest and disease management
- orchard design and management systems
- canopy management
- nutrition
- nursery management.

The training workshops benefited researchers and extension officers, by providing them with improved knowledge and skills in crop production practices.

Research and extension officers were also trained, and developed an understanding of the improvement in citrus that is possible with disease-free budwood and grafted rootstock. Training and extension resulted in wider use of nursery citrus with grafted rootstocks in Vietnam (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

A nursery certification scheme was established in southern Vietnam, and supplied quality planting material to the Vietnamese citrus industry. In 2018, the certification scheme remains in place, and is enforced (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

Vietnamese scientists at RIFAV and SOFRI were trained in isozyme analysis for the rapid identification of citrus species and the screening of rootstocks. Techniques developed are applicable to research questions in other industries (for example, passionfruit, banana). Scientists in both RIFAV and SOFRI view the ACIAR project as having significantly strengthened the capabilities of their institutes (Bevington 2006).

At SOFRI, improved techniques were developed for detecting HLB and citrus tristeza closterovirus, while improved micro-grafting procedures were developed for 'cleaning up' virus infected material. The training of Dr Le Thi Thu Hong in Australia played a key role in the development of molecular-indexing capabilities, disease detection capabilities and efforts to produce disease-free propagation material at SOFRI.

Dr Hong completed her PhD thesis in Vietnam on the topic *'Investigation of some plant-protection technologies in citrus seedling production in the Mekong delta'* as part of ACIAR project CS1/1996/076. Between completing her thesis in 2002 and 2005, Dr Hong coordinated projects in Can Tho, Vinh Long, Dong Thap and Tien Giang provinces related to the improvement of citrus planting material. She also assisted as coordinator in other HLB research projects. In 2005, Dr Hong was Head of the Division of Research Management and International Cooperation at SOFRI, and has since retired (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

The ACIAR project directly contributed to the successful completion of postgraduate research by Ms Thanh Phong and Ms Tang Mai, both of SOFRI. Ms Phong was awarded a Master of Science from the University of Can Tho for research on the micro-propagation of citrus rootstocks. Ms Mai was awarded a Master of Science for research on screening citrus rootstocks for salinity tolerance. Ms Tran Phuoc Anh Thu completed virus indexing training at the Elizabeth Macarthur Agricultural Institute (EMAI), Camden, New South Wales.

Mrs Nguyen Thi Kim Son (RIFAV) spent three weeks at EMAI training in diagnostic techniques for citrus pathogens with Mrs Patricia Barkley. Dr Do Dinh Ca (RIVAF) and Mr Nguyen Thank Nhan (SOFRI) visited Australia in May 2000 for training in isozyme analysis, salt tolerance screening, assessment of graft incompatibility and research strategies for field evaluation trials with Dr Steve Sykes (CSIRO, Merbein) and with Dr Ken Bevington (NSW DPI, Dareton). This training has been applied to screening rootstock accessions in Vietnam for *Phytophthora* tolerance, salt tolerance and early detection of graft incompatibility, as part of ongoing efforts to identify improved rootstocks for use with local scion cultivars.

In total, the ACIAR project provided postgraduate training for seven SOFRI and RIFAV staff. No JAFs were awarded as part of the project. Five of the seven students were female, and all continued to work in horticulture research after their training (Table 6).

Table 6: Vietnamese students trained as part of ACIAR project CS1/1996/076

Student trained	Type of training and topic	Work status
Dr (Ms) Le Thi Thu Hong	PhD University of Can Tho, plant protection technologies and virus indexing, with training completed at EMAI, Camden	Section head SOFRI, worked to improve citrus planting material and manage HLB, retired in 2018
Ms Thanh Phong	Master of Science from the University of Can Tho, micro-propagation of citrus rootstocks	Director of Agricultural Extension SOFRI 2018
Ms Tran Phuoc Anh Thu	Plant protection technologies, virus indexing, with training completed at EMAI, Camden	Director of Research, RIFAV, retired in 2018
Ms Tang Mai	Master of Science for research on screening citrus rootstocks for salinity tolerance	Director of Research, Tien Giang SOFRI, retired in 2018
Mrs Nguyen Thi Kim Son	Diagnostic techniques for citrus pathogens, trained at EMAI, Camden	Director of Research, RIFAV, retired in 2018
Dr (Mr) Do Dinh Ca	Isozyme analysis, salt tolerance screening, graft incompatibility and research strategies for field evaluation trials in Dareton	Director of Research, RIFAV, retired in 2018
Mr Nguyen Thank Nhan	Isozyme analysis, salt tolerance screening, graft incompatibility and research strategies for field evaluation trials in Dareton	Director of Research, SOFRI, retired in 2018

Sources: CS1/1996/076 final report, Bevington 2006, with a 2018 update from Dr Nguyen Minh Chau.

The ACIAR project provided funds and equipment for propagation facilities, significantly increasing the capacity of SOFRI to index virus and virus-like diseases, and generate virus-free mother-trees for budwood multiplication. As a result of project investment, SOFRI became the first institute in southern Vietnam to use molecular procedures for citrus-disease indexing (Bevington 2006).

Research facilities at SOFRI have improved considerably since the project was completed. The institute is now well set up to continue research on citrus rootstock and scion improvement. The South Eastern Fruit Research Centre is now directly affiliated with SOFRI (Bevington 2006).

Ongoing research at RIFAV since the project finished has included identifying compatible rootstocks for use with local scion cultivars and the further selection of elite clones, as well as maintenance of disease-free mother-trees for budwood multiplication purposes. This ongoing work at RIFAV is evidence of a strong commitment to building on project outputs (Bevington 2006).

Participation in the ACIAR research project and development of new skills in the production of disease-free planting material has allowed SOFRI and RIFAV to develop both domestic and international networks.

SOFRI's ability to generate disease-free planting material has significantly increased its credibility with the local farming community. Cooperation between SOFRI and the provincial government Service of Science and Technology and Environment has also led to more citrus research opportunities.

SOFRI is now linked to international citrus research, through participation and contribution to international conferences, such as the 1997 ACIAR-organised workshop on citrus germplasm conservation attended by representatives of the citrus research community Asia-wide. The network of Asian citrus researchers created at this workshop meet regularly at international events, including the International Citrus Congress.

Since the completion of the project, research on identifying improved rootstocks has continued, but at a reduced pace. Capacity to test for HLB, viruses and rootstock scion compatibility is routinely applied at both RIFAV and SOFRI (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

5.3.3 Bhutan

HORT/2005/142 began in 2007 with a training visit to Australia by three Bhutanese DoA research and extension staff. Capacity building included nutrition, soil, irrigation and canopy management. Practical skills were developed in pruning, budding and top working citrus (grafting a new variety to an established tree).

Students visited commercial citrus nurseries to gain insights into nursery production practices, and a citrus packing company and juicing plant to develop a better understanding of postharvest operations.

Bhutanese students studying in Australia also developed capacity in operating and maintaining a repository of clean citrus germplasm through visits and study at the EMAI, Camden, and the citrus arboretum at the NSW DPI Dareton Primary Industries Institute.

Training was completed in Bhutan for both the local and Australian research and extension teams. Training included nursery-based tree propagation techniques and on-farm citrus management. NSW DPI produced extension materials, including a training video for use in both Australia and Bhutan on top working citrus. The video included best-practice budding and grafting techniques, and remains in use in 2018 (Mr Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, pers. comm., August 2018).

Four Bhutanese DoA research and extension staff received training in Australia in 2008, including in:

- nutrition
- soil
- irrigation and canopy management
- on-farm food safety/quality assurance
- postharvest handling
- laboratory pathology methods
- harvesting
- grading
- fruit quality testing
- the use of gibberellic acid.

Field visits included NSW DPI fruit fly disinfestation facilities, a commercial citrus packing shed, a citrus juice plant, Auscitrus, nurseries, and training in citrus budding and field grafting. Students met with Australian citrus growers.

In 2008, NSW DPI produced training packages on nutrition, establishment, canopy management, phenology (understanding cyclical and seasonal phenomena), leaf/soil analysis and an outline of the Australian citrus industry. Training packages were used in Bhutan to train DoA researchers and extension officers. DoA Bhutan report these packages are still in use in 2018 (Mr Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, pers. comm., August 2018).

Training of 82 DoA research and extension staff in Bhutan took place in 2008 and 2009. Capacity was built in canopy management, soil nutrition, crop phenology, leaf sampling, top working and crop sanitation practices. Training was completed by both Australian project staff and Bhutanese research and extension officers trained in Australia.

Seven Bhutanese staff received training in Australia in 2009, including in:

- soil and irrigation management
- citrus shoot tip grafting
- polymerase chain reactions analysis
- plant diagnostics.

Students visited EMAI, commercial orchards, the plant quarantine station, a citrus nursery, Flemington Wholesale Fruit and Vegetable Markets, a commercial nursery and the NSW DPI Dareton Primary Industries Institute.

In 2011, the National Citrus Repository and an insect proof facility for housing disease-free mother-trees was built at the Agricultural Research and Development Centre (ARDC), Mithun, as part of HORT/2005/142. Dr Nerida Donovan, Citrus Pathologist, NSW DPI, developed an operating procedures protocol for repository management. Plant and equipment bought with project funds were supplied to the repository to establish a citrus pathology laboratory. A second backup citrus repository was built at the ARDC, Wengkhar, and a National Seed Centre at 1,780 m is planned to protect genetic material from psyllids carrying HLB.

HORT/2010/089 built on work completed during HORT/2005/142, and focused on fewer, longer training stays in Australia in more specialised areas. Capacity built in Bhutanese DoA researchers and extension officers included:

- variety evaluation
- horticultural production techniques
- mother-tree maintenance
- disease testing methods
- laboratory techniques
- nursery production
- irrigation design.

Scientific capacity was improved in methods required for variety and rootstock evaluation, nursery production and germplasm maintenance. For example, Dr Kinley Dorji, ARDC, Bajo, trained in Australia in laboratory diagnostics and in maintaining a citrus repository. Dr Kinley Dorji currently manages the National Citrus Repository at Mithun.

Mr Tshering Penjor trained in Australia in citrus variety and rootstock evaluation. Mr Sangay Rinchen trained in Australia in commercial citrus nursery production. Workshops were held at the National Citrus Repository, Mithun, to equip nursery managers, quarantine staff, researchers and extension officers with skills relevant to modern citrus nursery practices.

HORT/2010/089 developed and ran training in biometrical methods for research scientists and extension staff in Bhutan. Mr Loday Phuntsho and Mr Jigme Tenzin, both of the Bhutan DoA, trained in Australia in biometric analysis and trial design. As a result, Bhutan DoA officers were better equipped to carry out statistically valid research trials.

ACIAR projects also built capacity in soil moisture monitoring with Bhutanese district extension officers. Skills developed by extension officers were immediately applied to the introduction of irrigation to citrus orchards. Training meant that extension officers were better able to use project-supplied irrigation and soil moisture monitoring equipment. DoA extension officer Nedrup Tshewang, who trained in soil moisture management in Australia, is now a key officer designing and implementing pilot irrigation schemes for horticultural crops in Bhutan, and is responsible for irrigation design and installation at the King of Bhutan's Palace.

Capacity building in canopy management included the training of a DoA extension officer Mr Phuntsho Wangdi in Australia. Mr Wangdi is now a technical support officer of the repository at Mithun. He and the project team delivered canopy management training to 469 households in the Tsirang district, 320 households in the Dagana district and 86 households and 6 extension staff in the Sarpang and Pemagatshel districts. Citrus growers in many parts of Bhutan have enthusiastically adopted canopy management, with resultant yield and quality increase (Mr Graeme Sanderson, Research Horticulturalist, NSW DPI, Dareton, pers. comm., August 2018).

Pest and disease management training was provided to extension staff and the farm community, focusing on control of HLB, powdery mildew and Chinese citrus fruit fly. For example, 63 households in the Tsirang district trained on Chinese citrus fruit fly biology and management, and 85 households participated in the area-wide pilot study. In the Dagana district, 329 households trained in HLB management and 52 households in Mongar and Lhuentse trained in techniques for fruit fly minimisation. Farmers who participated in the training can now identify pests, are aware of the pests' biology and know the recommended management practices.

Nutrition management training completed as part of HORT/2010/089 included instruction at each of the seven project demonstration farms. For example, 30 households were trained in Punakha, 53 households in Mongar and Lhuentse and 60 households in Sarpang. In total, the project reached 2,889 farmer households, covering all production practices (Mr Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, pers. comm., August 2018).

The ACIAR projects provided postgraduate training for 10 DoA staff. Seven JAFs were awarded and six have been successfully completed. A final JAF student is currently completing his studies. In 2018, all Bhutanese postgraduate students are working in agriculture in Bhutan (Table 7).

Table 7: Bhutanese students trained in Australia as part of ACIAR projects

Student	Training and topic	Status of studies	Working Bhutan	Current professional position
Mr Pema Chofil (JAF)	Master of Health and Community Development	Completed	Yes	Program Director, Agriculture Research and Development Centre
Dr (Ms) Namgay Om (JAF)	PhD, psyllid vectors of HLB	Completed	Yes	Principal Plant Protection Officer, National Plant Protection Centre, DoA, Thimphu
Dr Tshering Dorjee (JAF)	PhD, soil carbon storage	Completed	Yes	Principal Land Management Officer, National Soils Services Centre, DoA, Thimphu
Mr Sonam Gyletshen (JAF)	Masters of Agricultural Science	Completed	Yes	Chief Horticultural Officer, ARDC, Wengkhar
Mr Kiran Mahat (JAF)	PhD, fruit fly survival	In progress	Yes	Chief Plant Protection Officer, National Plant Protection Centre.
Mr Ganja Singh Rai (JAF)	PhD, *Phytophthora* management in Bhutan	In progress	Yes	Chief Research Officer, ARDC, Bhur
Dr Sonam Dechen Dorjee (JAF)	PhD, invasive plants in Bhutan	Completed	Yes	Principal Plant Protection Officer, National Plant Protection Centre, DoA, Thimphu
Mr Lakey	Managerial studies	Completed	Yes	Chief Agriculture Officer, ARDC, DoA, Thimphu
Dr Kinley Dorji	PhD rootstock genetics	In progress	Yes	Chief Horticulture Officer, ARDC, DoA, Thimphu
Mr Jigme Tenzin	Leadership training, Endeavour Leadership Program	In progress	Yes	Chief Horticulture Officer, Agriculture Research and Extension Division, DoA, Thimphu

Sources: HORT/2005/142 and HORT/2010/089 final reports, with a 2018 update from Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA.

The ACIAR projects have created sustained professional networks for previously isolated Bhutan citrus professionals. HORT/2005/142 established the country-wide Bhutan Citrus Coordination Committee, which links extension, research and policymakers.

HORT/2010/089 supported the participation of Bhutanese officials at International Citrus Congresses in Spain (2012) and Brazil (2016), and had representation at the International Nurseryman's Congress in Australia (2017). At the International Citrus Congress in Brazil, Bhutan DoA representatives met with delegates from the Central Citrus Research Institute, Nagpur, India, and have subsequently developed a system of routine information exchange and joint research proposals.

There are now sustained linkages between NSW DPI and Bhutan DoA—information is routinely exchanged, and joint scientific papers are prepared. Bhutanese graduates have networks in multiple Australian universities, and the National Citrus Repository and National Seed Centre (Druk Seed Corporation) receive rootstock seeds from Auscitrus.

Demonstration farms are firmly established across each of the main citrus growing regions of Bhutan—Punakha, Tsirang, Sarpang, Lhuentse, Mongar, Chukha and Dagana. Demonstration farms have created a long-lasting legacy, including venues for both first time and refresher training of district farmers.

Other legacy capital from the projects includes a citrus nursery technical document. The manual standardises technical and regulatory procedures in the production of high health status citrus planting material. A publication—*Citrus pests and diseases management*—was also produced, in partnership with the National Plant Protection Centre. The centre maintains a website that provides information about pests in Bhutan (<http://pestsofbhutan.nppc.gov.bt/2017>) and a database that is relevant to citrus and other crops. A *Production guide for mandarin orchards in Bhutan* was also prepared and updated as part of the ACIAR projects.

After the completion of the ACIAR projects, Bhutanese DoA staff and Bhutanese citrus growers were better able to understand, implement and support modern citrus production.

'Bhutan receives a lot of international aid aimed at its agricultural sector, but only ACIAR and the Japan International Cooperation Agency invest in capacity building. We wish we had the ACIAR funded capacity in place before HLB arrived in our country. Now citrus has a much stronger voice.'
(Mr Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, pers. comm., August 2018).

5.3.4 Australia

All four ACIAR projects built capacity in the Australian citrus industry. Project delivery by Australian research scientists and extension staff in China, Vietnam, Bhutan and in the mandarin industry in Australia included new skills in on-site training and collaboration.

Following project implementation, Australian staff were better equipped with both knowledge and skills to demonstrate, implement, and communicate citrus research techniques to in-country scientists and management practices to farmers.

For example, Australian scientists from EMAI, Camden, and CSIRO Plant Industry provided training to scientists in China and Vietnam in germplasm analysis and in creating disease-free germplasm. Scientists who developed additional skills through delivery of germplasm analysis training included Mrs Patricia Barkley, Dr Debora Hailstones, Dr Ken Bevington and Dr Steve Sykes.

NSW DPI field research and extension officers worked with farmers in Bhutan to identify and communicate the benefits of improved growing practice through, for example, demonstration farms. Citrus research and extension officers benefiting from delivery of production best practice included Mr Graeme Sanderson and Mr Steve Falivene, NSW DPI, Dareton.

Laboratory and field research and extension skills are relevant to the delivery of future international research projects and the training of researchers and growers in Australia.

Through field work in China, Vietnam and Bhutan, Australian scientists have developed additional capacity in field identification, diagnosis and management of exotic citrus pests. This capacity is directly relevant to maintaining the biosecurity of the Australian citrus industry, and detecting and managing exotic pest and disease incursions.

For example, project researchers Ms Sandra Hardy and Dr Nerida Donovan of EMAI, Camden, hosted a national workshop on HLB in Sydney, organised by ACIAR, and attended by key interests in the Australian citrus industry. Dr Nerida Donovan and Dr Malcolm Smith, trained through ACIAR project Improved subtropical citrus production in Sikkim and Australia (HORT/2002/030), were called upon in April 2018 to respond to detection of citrus canker in the Northern Territory. The ACIAR-trained scientists provided strain diagnosis skills as part of the emergency response.

In Australia, capacity was built in the mandarin industry through the production and rapid uptake of the first Mandarin production manual (Hardy et al. 2017), a comprehensive guide to growing and postharvest management of mandarins in Australia. It has been downloaded 330 times, equivalent to once for every mandarin grower and industry advisor in Australia (Mr Graeme Sanderson, Research Horticulturalist, NSW DPI, pers. comm., August 2018).

5.4 Policy goals addressed

ACIAR projects directly targeted government and industry goals in China, Vietnam, Bhutan and Australia.

In China, the central government had set a policy goal of extending the citrus production and harvest window into January to coincide with strong domestic demand generated by the festival season. China sought late-harvest, disease-free and seedless planting material. ACIAR projects delivered Australian Late Lane navel, which has met these requirements. No regulatory response was required by either the central government or provincial authorities.

In 1991, when Vietnamese citrus production totalled 11,000 t per year, the Vietnamese Government set a production target of 450,000 t per year by 2000. Actual production was 440,000 t in 2000, so the policy target was not quite met. But Vietnamese citrus production was 1,130,000 t in 2016, more than double the original policy goal (FAO 2016). ACIAR's investment in improving plant health contributed to this positive outcome.

In 1993, the Vietnamese Prime Minister announced the establishment of the Long Dong South Eastern Fruit Research Centre, which became operational 1994. The centre's mandate is to improve fruit production in the country's southern provinces.

ACIAR investment contributed to the strengthening of the centre and SOFRI's ability to:

- complete fruit tree genetic analysis, disease detection and disinfestation
- create disease-free mother-trees
- tackle HLB, the country's major constraint to profitable citrus production.

Plant health is maintained through to citrus growers with the roll out and enforcement of a nursery tree standards certification scheme. The scheme was developed as part of ACIAR project CS1/1996/076.

In 2005, the Bhutan government set a policy goal of expanding citrus exports. ACIAR project HORT/2005/142 directly addressed this policy goal, putting measures in place to shift current Bhutanese citrus production toward best practice.

The project also established the Bhutan Citrus Coordination Committee to maintain momentum in the citrus industry after its completion. HORT/2005/142 contributed to the Citrus Master Plan for Bhutan, which was prepared in 2009 with support from the EU. HORT/2010/089 was aligned to achieving the master plan's objectives.

Consistent with Bhutan government policy, ACIAR put in place initiatives to lengthen the country's citrus season beyond its current three-month window. Initiatives included demonstrating the use of gibberellic acid to manipulate flowering and maintain citrus postharvest, and the introduction of new varieties to extend the supply period. A longer supply period will help grow export markets.

The Bhutan government has a policy goal of reducing chemical inputs to agriculture, with an ultimate aim of organic production (HORT/2010/089 final report). ACIAR projects worked toward this goal, aiming to increase yields through the careful management of animal manures and the use of retention basins around the base of the tree.

But the DoA reports that the use of chemical fertilisers is increasing in Bhutan, as growers realise an economic return from the addition of chemical fertiliser. Insecticide use has not increased. Cost and availability of insecticides limits their use in Chinese citrus fruit fly control, and growers are working with non-chemical control measures developed during the ACIAR projects—that is, fruit collection and destruction. Sulphur, a powdery mildew control measure consistent with organic production and ACIAR project recommendations, is increasingly being used in Bhutan (Mr Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, pers. comm., August 2018).

In 2018, the Bhutanese government is supporting citrus production by building rural roads that improve grower access to markets and input supplies. Subsidies are also available for the purchase of citrus production inputs, including nursery trees. Land is being leased to citrus growers at concessional rates to encourage their relocation to high altitude areas with fewer HLB causing psyllids.

Regulatory support includes roll out and enforcement of the nursery tree standard certification scheme, which was developed as part of the ACIAR projects. The Bhutan Agriculture and Food Regulatory Authority is effective at regulating nursery tree standards.

Bhutan's 12th five-year plan (2019–2023) includes a major emphasis on developing and installing irrigation infrastructure. HORT/2010/089 established a gravity-fed drip irrigation demonstration at Thangna, which acted as a catalyst for irrigation adoption in citrus and other crops. DoA staff report widespread and significant production increases resulting from the adoption of low-cost, sustainable irrigation.

ACIAR investment in the citrus industry of Bhutan has been broadly consistent with the country's Gross National Happiness Index. The index requires that all national and institutional activities are aligned to the concept's four key principles of:

- sustainable equitable socioeconomic development
- preservation and promotion of culture
- conservation and sustainable use and management of the environment
- promotion of good governance (World Bank 2017).

In Australia, rootstock development and evaluation has been a long-standing industry priority. Industry levies have been used to fund rootstock development since the late 1980s. Industry has committed to funding the ongoing evaluation of Chinese rootstocks identified through CS1/1987/002 and CS1/1996/076 through to 2022.

6 Adoption of research and development outputs

Adoption of research and development outputs includes uptake of new technologies, new scientific knowledge and new knowledge models. It considers research and development uptake by both initial users (for example, researchers) and final users (for example, citrus growers).

6.1 China

Two groups of ACIAR project output were adopted in China—use of virus-free and more productive rootstocks/scions, and introduction of new varieties to lengthen the Chinese citrus season (Bevington 2006).

6.1.1 Virus-free and more productive rootstocks and scions for China

A major adoption achievement of the ACIAR projects has been the impetus given to the further development of citrus-rootstock and scion-improvement programs at the CRI. Comprehensive training of CRI scientists in molecular diagnostic techniques served as a foundation to build improved pathogen-indexing capabilities.

China's Ministry of Agriculture has also established the NCVEC within the CRI to increase the efficiency of virus indexing and virus exclusion, and to promote the planting of virus-free trees.

Associated with the establishment of the NCVEC has been substantial investment in new laboratory facilities, greenhouses and budwood multiplication blocks, which have greatly increased the capacity of the CRI to generate virus-free propagation material.

For example, between 2002 and 2005, 788 candidate mother-trees of 36 local citrus cultivars were virus indexed, and 6% were found to be virus infested. Budwood of trees indexed free of viruses was subsequently used by six regional nurseries to propagate five million trees. Trees were mainly distributed to new citrus orchards in Chongqing. An estimated 6,000–7,000 ha of new plantings were established with virus-free budwood sourced from the CRI (Bevington 2006).

In 2018, the NCVEC is the most important national centre for the supply of virus-free citrus mother-trees. NCVEC supplies almost 100 nurseries in 12 Chinese provinces. Each year since 2005, nurseries operating under the NCVEC-developed 'three levels propagation system' have supplied more than 30 million virus-free trees, resulting in an estimated annual planting of 30,000–35,000 ha. NCVEC's work has had a major impact on the control of HLB in China (Dr Zhao Xiaochun, Director CRI, pers. comm., September 2018).

6.1.2 Introduction of new varieties to lengthen the Chinese citrus season

The marketing period for citrus in China has traditionally been short, and a key goal of China's citrus improvement program is to extend the marketing season by selecting better varieties that mature later and earlier.

Among the scion cultivars introduced to China, Late Lane navel and Ellendale Tangor (a late-maturing mandarin hybrid) have shown good adaptation to the subtropical growing areas of China. Newhall, an early season public access Californian navel introduced as part of the ACIAR projects, was used to develop two new local Chinese varieties. Two late season mandarin varieties were also developed from Chinese genetic material collected during the ACIAR projects (Dr Zhao Xiaochun, Director CRI, pers. comm., September 2018).

Late Lane navel was extensively propagated, and 100,000 trees (400 ha) were planted in southern China between 2002 and 2005. In 2018, there are 6,400 ha of Late Lane navels growing in Chongqing, Hubei and Jiangxi (Dr Zhao Xiaochun, Director CRI, pers. comm., September 2018).

6.2 Vietnam

ACIAR project outputs adopted in Vietnam include the introduction of virus-free and more productive rootstocks/scions and the use of Australian varieties (Bevington 2006).

6.2.1 Virus-free and more productive rootstocks and scions for Vietnam

The project has given impetus to the further development of citrus-rootstock and scion-improvement programs at the collaborating Vietnamese institutions.

RIFAV and SOFRI researchers have used screening methods developed in Australia to screen local and introduced rootstocks for *Phytophthora* tolerance, salinity tolerance and graft incompatibility.

Work on salinity tolerance and graft incompatibility has continued after the completion of the project. Promising rootstock/scion combinations have progressed to the stage of field testing for assessment of horticultural performance (Dr Nguyen Minh Chau, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

Comprehensive training of SOFRI scientists in molecular diagnostic techniques served as a foundation to build pathogen-indexing capabilities, and SOFRI is now equipped with a new laboratory for detecting HLB. The laboratory is being used to test samples from farmers' nurseries to identify infected material that might otherwise be used for propagation of trees. HLB is endemic throughout the citrus growing regions of Vietnam, and has devastated the industry. Key control strategies for HLB are the planting of disease-free trees, rigorous control of vector populations through orchard management and the removal of infected trees.

RIFAV has been actively involved in arranging disease indexing of trees on behalf of farmers, and has been helping producers select elite native citrus clones, in particular local pummelo.

Following indexing, mother-trees are being maintained in a screen-house to be used as a source of budwood for commercial propagation. Some 40 native citrus varieties were collected in northern growing regions and stored in the RIFAV insect-proof screen house. These varieties are gradually being evaluated for use as rootstocks and scions for large-scale commercial production.

In southern Vietnam, 60 horticulturally superior pummelos, 17 mandarins and 12 limes were collected from farmer properties. These varieties have been health tested, and, in time, will be released commercially. They are more productive than current varieties and have the potential to improve orchard productivity and farmer returns.

6.2.2 Introduction of Australian varieties to Vietnam

Post the project, SOFRI has completed further work on evaluating the field performance of mandarin and orange cultivars introduced from Australia. A key result has been the excellent performance of the Leng navel in Lamdong province, with high yields of good quality fruit.

Work has also been completed on the Australian tangelo Orlando, which has been released to growers in the Mekong Delta, who have reported favourable yields of visually appealing fruit (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

6.3 Bhutan

ACIAR project outputs adopted in Bhutan include:

- better production practices communicated through demonstration farms and the training of Bhutanese DoA staff and citrus growers, with recommendations being comprehensive for larger, better resourced growers, and simple for small growers who have few investment resources
- the establishment of a professional nursery sector capable of supplying disease-free grafted nursery trees and new varieties in the medium term, as this, together with an industry shift above 1,200 m offers the opportunity to further narrow the yield gap between Bhutan and Australian production.

Table 8 shows an uptake timeline for research and development outputs in Bhutan.

An unintended positive impact of the ACIAR-funded projects in Bhutan has been the rapid take up of stream powered water pumps for irrigation of non-citrus horticultural crops. Stream powered water pumps, driving gravity-fed drip irrigation systems, have been profiled in project-funded citrus demonstration farms.

Table 8: Uptake of new science and technology, Bhutan

Date	Research output and its uptake
2007	• Establishment of four best-practice citrus demonstration farms in Bhutan. • Training of Bhutanese staff in best-practice production in Australia. • Comprehensive survey of production practices in Bhutan.
2008	• Production of a top working video for use in Bhutan and Australia. • Training of Bhutanese staff in production practices in Australia. • Training 82 research/extension staff in Bhutan. • Survey of citrus tree nutritional status in Bhutan.
2009	• Delivery of a mandarin production guide, and its distribution to extension officers. • Pest and disease survey across production districts. Survey determined distribution of HLB and its vectors, and confirmed that powdery mildew is a major cause of tree loss. • Establishment of the Bhutan Citrus Coordination Committee linking extension, research and policymaking. • Demonstration of the use of gibberellic acid to prolong the harvest season, take advantage of market opportunities and help fruit withstand postharvest handling. Unexpectedly, fruit treated with gibberellic acid did not develop mould. • Continued implementation of improved management practices on project demonstration orchards. • HLB eradicated from citrus orchards in Kamichu, demonstrating that control of the disease in Bhutan is important and possible.
2010	• Continued implementation of improved management practices on project demonstration orchards. Canopy management widely adopted by growers with resultant gains in citrus yield. • Trials of wettable sulphur for powdery mildew control, and use of mineral oils to address any phyto-toxicity effects on mandarins in high altitudes. Sulphur found to be effective and consistent with organic production.
2011	• Establishment of the National Citrus Repository at Mithun. • Statistical analysis of citrus nursery survey based on 56 private nurseries. • Posting of the Production guide for mandarin orchards in Bhutan on the Bhutanese Ministry of Agriculture website. • Value of irrigation during dry winters shown at demonstration farms, and research and extension officers trained in the installation of drip irrigation with stream powered Glockemann water pumps. Glockemann water pumps well received, possibly signalling the beginning of zero energy eco-friendly water supply for both upstream settlements and orchards.
2012	• Repair and upgrade of insect proof greenhouses at Mithun following severe storm damage, with ACIAR and United Nations Development Program funding. • Training workshop in area-wide management of Chinese citrus fruit fly, with 270 farmers trained. Area-wide management implemented, with reduction in damage, increased yields and income.
2013	• A total of 115 citrus accessions collected and propagated in the National Citrus Repository, Mithun, plus commercial varieties introduced from Australia for evaluation. Introductions from Australia included rootstocks supplied by Auscitrus.
2014	• Introduction of a more free-draining potting mix, with a positive and significant effect on citrus seedling growth.
2015	• Nursery irrigation management and soil and water management courses delivered to improve knowledge of Ministry of Agriculture and Forestry staff. • Pathology research done to collect data for a HLB doctorate.
2016	• Seven demonstration orchards established across six citrus production districts. Farmers close to demonstration farms are adopting key recommendations on canopy, nutrient and weed management, which are low/no cost practices and generate a yield and fruit quality gain. • Pathology research done to finalise data for a HLB doctorate. • Introduction of more new varieties, including the navel Cara, the internationally popular Afourer mandarin and selections of processing oranges to support further development of a fruit juice industry in east Bhutan.

(continued over next page)

Date	Research output and its uptake
2017	• Five senior ministry officers trained in Australia on familiarisation with citrus industry, citrus variety evaluation skills, biometrics and trial design.
2018–2022	• Post completion of ACIAR-funded projects HORT/2005/142 and HORT/2010/089: – additional demonstration farms will be established by the DoA – Druk Seed Corporation will develop and supply grafted nursery grown trees – superior production practices and grafted trees will provide a further lift in yield – further testing of Australian varieties will be done to diversify the citrus production base – the production base will be shifted above 1,200 m to avoid HLB psyllids – the professional nursery sector developed as part of the ACIAR projects will be shifted above 1,200 m to avoid HLB psyllids, and ensure new orchards at all altitudes receive clean planting material and the best possible start – gravity-fed drip irrigation systems will be expanded into other horticultural crops and domestic water supply following success on citrus demonstration farms.

Table 9: Uptake of new science and technology, Australia

Date	Research output and its uptake
2008	Production of a top working video for use in Bhutan and Australia.
2009	Production and distribution to industry of mandarin production fact sheets (these pre-dated the Australian mandarin manual, which was prepared in the second project, HORT/2010/089).
2010–2012	Vietnamese scions tested in Australia as potential new mandarin varieties. Scions found not to have commercial prospect (Dr Tahir Khurshid, NSW DPI, pers. comm., June 2018). Chinese scions tested in Australia as potential mandarin, orange and lemon varieties. Scions found not to have commercial prospect (Dr Tahir Khurshid, NSW DPI, pers. comm., June 2018).
2014–2017	Vietnamese rootstocks grafted onto Late Lane navel, Navelina and Eureka lemon without producing a commercial success (Dr Tahir Khurshid, NSW DPI, pers. comm., June 2018).
2017	Incorporation of new knowledge on exotic diseases into biosecurity manuals. Data generated in Bhutan on HLB psyllids and their control are deemed to be particularly relevant to the Australian situation.
2017	Production and release of Australian mandarin manual by NSW DPI, with support from ACIAR, which was acknowledged by Citrus Australia as an output from the two citrus projects completed in Bhutan (Citrus Australia undated).

6.4 Australia

ACIAR project outputs adopted in Australia include the following:

- The first comprehensive guide to mandarin orchard establishment and management, the Australian mandarin manual, was produced specifically for Australian mandarin growers. It covers all aspects of production, and 330 hard copies have been distributed. Distribution of this number of copies is sufficient to cover each Australian mandarin grower and industry advisor.
- Chinese citrus rootstocks show considerable potential to lift citrus fruit yield and quality in the short term. Longer term, Chinese citrus rootstocks might also have a role in creating high productivity and intensive orchards, and managing citrus production in an irrigation constrained saline environment.

Table 9 shows an uptake timeline for research and development outputs in Australia, excluding Chinese citrus rootstocks. Table 10 shows the uptake timeline for Chinese citrus rootstocks.

NSW DPI distributed 330 printed copies of the Australian mandarin manual in the first 12 months following release. Website downloads are in addition to this total. There are 300–330 mandarin growers and industry advisors in the Australian citrus industry.

NSW DPI is aware that the manual is used widely in Australia without negative feedback, and requests have been received for copies from Florida, California and China (Mr Graeme Sanderson, Research Horticulturalist, NSW DPI Dareton Primary Industries Institute, pers. comm., July 2018).

An unintended consequence of the manual's publication is that NSW DPI has been provided with an excellent capabilities marketing document, which they are using to promote their skill set for overseas aid and consultancy work (Mr Graeme Sanderson, Research Horticulturalist, NSW DPI Dareton Primary Industries Institute, pers. comm., July 2018).

Chinese citrus rootstocks brought to Australia through ACIAR-funded projects CS1/1987/002 and CS1/1996/076 have the potential to make a significant contribution to the productivity of the Australian citrus industry.

Table 10: Uptake of Chinese rootstocks in Australia

Date	Research output and its uptake
1992–2002	• East Asian germplasm collected as scions and rootstocks as part of CS1/1987/002 and CS1/1996/076. • Repository of Chinese and Vietnamese rootstocks established in Australia.
2003–2013	• Hort Innovation's National Citrus Rootstock Improvement Program tests Chinese rootstocks. Evaluation based on short-term trials (up to 10 years) in New South Wales, Queensland and South Australia. The program includes glasshouse screening for seed characteristics, seeding uniformity, graft compatibility, disease resistance and salt tolerance. Rootstocks are screened for diseases and tested for tree establishment, growth, chloride uptake, fruit yield and quality (Khurshid et al. 2008). • Four trifoliata and two erythrosa (for mandarins) rootstock types from China show performance superior to existing Australian rootstocks (Khurshid et al. 2008).
2015	• Analysis of 2015 data from trials established in 2010 showed that Valencia trees grafted onto *Zao yang* rootstock had yields of 41 kg/tree compared with 33 kg/tree on industry standard Tri22. *Zao yang* and *Tanghe* (10.9 brix) produced Valencias with higher brix than industry standard Tri22 (10.7 brix). Juice percentage (47%) was higher in Tri22 than *Zao yang, Donghai* and *Tanghe* (45%). There was no change in tree height, but the trunk circumference of *Zao yang* was marginally superior to Tri22. • Conclusion: higher yielding slightly sweeter fruit without loss of other rootstock attributes (NSW DPI 2016).
2017	• Six Chinese rootstocks released commercially—four trifoliata and two erythrosa types. These rootstocks are available through Auscitrus who supply Australian nurseries and large growers with rootstock seeds. Six Chinese rootstocks have been tested on Navelina, Imperial mandarin, Late Lane navel, Eureka lemon and Valencia. • A seventh Chinese citrus rootstock identified by DAF Qld. Named Barkley after NSW DPI citrus pathologist Patricia Barkley, this rootstock has the potential to replace mandarin industry standard rootstock Troyer citrange. Barkley's benefits are expected to include increased orchard longevity, disease resistance (citrus tristeza closterovirus, *Phytophthora*) and improved fruit quality and yield (Mr Malcom Smith, Citrus Breeder, QDAF, pers. comm., August 2018). • The dwarfing effect of Chinese citrus rootstocks tested in field trials at the NSW DPI Dareton Primary Industries Institute (Hort Innovation 2017).
2017–2022	• Hort Innovation's National Citrus Rootstock Improvement Program will complete long-term trials of the six Chinese citrus rootstocks on 16 grower properties across Australia (New South Wales, Victoria, South Australia, Queensland and Western Australia). The major objective of the trial program is to test rootstock performance on a variety of soil types and climatic conditions. Results will be compared to Tri22 (the standard Australian trifoliata rootstock) and Troyer citrange (the standard mandarin rootstock). Tree growth rates, height, canopy diameter, trunk circumference, grafting compatibility, graft union and tree health will be assessed. Once trees bear fruit, yield and fruit quality—including rind texture, juice content, soluble solids and acidity—will be measured. 'The new rootstocks have the potential to drive future citrus industry development. Rootstocks are a major influence on the profitability of citrus orchards. Their impact on fruit size, yield and yield efficiency is critical and will play a significant role in meeting demand from domestic and export markets. Buyers have shown a distinct preference for larger fruit, particularly navels, in recent years.' (Dr Tahir Khurshid, Plant Physiologist, NSW DPI 2018).

7 Assessment of outcomes and impacts

7.1 Economic outcomes and impacts

ACIAR investment in four research projects has created outcomes and economic impacts in China, Vietnam, Bhutan and Australia. This section provides outcomes and impacts qualitatively for China, Vietnam and Bhutan. A qualitative and quantitative assessment is provided for Australia.

7.1.1 Case study: Australian Late Lane navel in China

ACIAR projects CS1/1987/002 and CS1/1996/076 resulted in the provision of 47 Australian public access varieties and commercial rootstock seeds to China. The Australian-developed public varieties that were provided included Late Lane navel and Ellendale Tangor.

Late Lane navel has been successful in China. It was introduced to China as part of CS1/1987/002 in 1993 and again as part of a China–USA citrus project in 1999. Between 2002 and 2005, 100,000 Late Lane navel trees (400 ha) were planted throughout China's southern orange growing areas (Bevington 2006) (Figure 7).

Province accounts for 10-20% of orange production (Jangxi, Guangxi, Chongqing, Sichuan and Hunan)
Province accounts for 5-10% of orange production (Hubei)
Province accounts for 3-5% of orange production (Guangdong & Fujian)

Figure 7: Map of China showing southern citrus growing areas
Source: USDA 2017.

By 2018, 6,400 ha of Late Lane navel had been planted (Dr Zhao Xiaochun, Director CRI, CAAS Southwest University, China, pers. comm., September 2018). Australian Late Lane navel, first introduced through CS1/1987/002, is now a major variety in China (Dr Tahir Khurshid, Research Pathologist, NSW DPI, pers. comm., June 2018).

Adoption of Late Lane navels has been important in southern China, as it has enabled domestic citrus growers to supply a new high-value market window—the January festival season, which previously fell outside the relatively narrow Chinese citrus season (October–December). Harvest of Late Lane navel between January and April also coincides with the off-season for most fresh fruit grown in China (Dr Zhao Xiaochun, Director, CRI, pers. comm., September 2018).

This has earned Chinese citrus growers who supply the festival and off-season fresh fruit market extra profit from higher unit prices for their citrus than would have been possible without ACIAR and follow-up investment. Australian-sourced Late Lane navels are not the only orange available during this period, though, with other Chinese-developed varieties also helping to meet demand.

Producer surpluses generated by Late Lane navel in China are about $38.4 million per year. Table 11 shows derivation of this estimate.

Growth in the Chinese late navel market has come without cost to Australian navel growers who are not in a position to supply China with export fruit until the middle of May. The Australian supply window closes, with no more fruit available for export, in October well before Chinese grown Late Lane navels are harvested.

7.1.2 China economic outcomes and impacts

Ellendale Tangor, a mid-season mandarin, was also supplied as part of the ACIAR projects, and was also thought to have potential to fill a market window in China. This variety has been trialled in China, but passed over for locally developed varieties (Dr Tahir Khurshid, Research Physiologist, NSW DPI, pers. comm., June 2018). Fruit from the Ellendale Tangor proved to be too high in acid for the Chinese palate, as well as seedy. The tree was also prone to dropping its fruit and delivering a low saleable yield (Dr Zhao Xiaochun, Director CRI, pers. comm., September 2018).

Table 11: Producer surpluses generated by Late Lane navel in China

Variable and its source	Estimate
Area of Late Lane navel grown in China 2018 (Dr Zhao Xiaochun, Director, CRI, CAAS Southwest University, pers. comm., August 2018)	6,400 ha
Yield of mature trees in China (Dr Zhao Xiaochun, Director, CRI, CAAS Southwest University) Note: in Australia Late Lane yield 35,000 kg/ha (NSW DPI 2018)	25,000 kg/ha
Price of navels marketed during the Chinese citrus season (October–December) (typically, RMB 6.0/kg or $1.20/kg; USDA 2017).	$1.20/kg
Premium for Late Lane navels marketed during festival and off-season (January–April) • Assumed to be 20% premium reflecting higher willingness to pay and scarcity of alternative fresh fruit. • While no data is available to support this assumption Dr Zhao Xiaochun notes 'the price for this variety (Late Lane) is higher than other navel oranges maturing before January'.	$0.24/kg
Total producer surplus, based on area of production (6,400 ha) by production per hectare (25,000 kg/ha) by premium paid per kilogram ($0.24/kg).	$38.4 million

CRI used Californian early season navel Newhall—provided as part of CS1/1987/002 and CS1/1996/076—to source bud mutations that have been used for the selection and release of two early navel varieties. Some uptake of these varieties by growers has been achieved. Genetic material collected in China as part of the ACIAR projects has also contributed to the development of early maturing mandarin varieties for cool northern Chinese provinces, and late maturing mandarin varieties for southern areas (Bevington 2006). Some uptake of the early maturing mandarin varieties has occurred in northern China, resulting in higher incomes for growers (Dr Zhao Xiaochun, Director, CRI, pers. comm., September 2018).

7.1.3 Case study: disease-free planting material to combat HLB in Vietnam

In Vietnam, SOFRI has continued to use better testing techniques developed as part of CS1/1996/076, and to deliver disease-free planting material for citrus growers. Clean planting material, together with removal of diseased trees and vector control, is an effective strategy for reducing on-farm production and income losses caused by HLB.

Each year, SOFRI produces 40,000–50,000 certified disease-free trees for distribution to farmers, which is enough for about 100 ha of new plantings. If budwood supplied to other certified nurseries is taken into account, then the actual impact is much greater. There are 30 certified nurseries in the Mekong Delta, and total annual impact might be as much as 1.3 million trees planted on 3,000 ha.

SOFRI has also overseen the uptake of a certified nursery scheme, developed as part of CS1/1996/076 to ensure clean planting material is actually disease-free. In 2018, the scheme remains in place, and is actively supported by the Vietnamese nursery sector (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

As a result of ACIAR's investment, a supply of guaranteed disease-free planting material is available to combat HLB in Vietnam, and recovery in grower income can be expected.

At the time the ACIAR research was completed, HLB affected 55% of the 40,000 ha of citrus production in the Mekong Delta, and 27% was severely affected. Farmer income in areas severely affected by HLB was reduced by 25%–55% (Bevington 2006). HLB remains a significant problem in both northern and southern Vietnam, and particularly in the Mekong Delta (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

7.1.4 Vietnam economic outcomes and impacts

Other positive impacts resulting from ACIAR investment in CS1/1996/076 in Vietnam include:

- assessment of Australian citrus varieties
- identification of superior local varieties
- identification of improved rootstocks
- the use of molecular analysis techniques being transferred to other fruit (such as mango, avocado) and vegetable crops.

As part of the project, 20 Australian public access citrus varieties were introduced to Vietnam. One variety, Leng navel, has achieved take up by Vietnamese farmers in the Mekong Delta. Leng navel is an early maturing high-yielding variety that is disease resistant when matched with an appropriate rootstock.

Australian public access tangelo, Orlando, was also released commercially in Vietnam, and was grown in small volumes in the south of the country, mainly in Tien Giang Province. While Orlando was initially favoured by growers for its large fruit size and appealing orange coloured skin, it has fallen out of favour due to 'an unpleasant taste'. Vietnamese growers now favour a local variety, known as Cam sanh. No superior local varieties have yet been identified from indigenous genetic material collected during the ACIAR projects (Dr Nguyen Minh Chau, Director, Long Dinh Research Centre, Vietnam, pers. comm., August 2018).

7.1.5 Case study: impact of ACIAR projects on citrus production, household income, gender roles and the environment, Drujegang, Dagana Bhutan

Dorji et al. (2016) selected the 'gewog' (municipality) of Drujegang for case study analysis because it represents one of the major citrus growing areas in Bhutan, and, before HORT/2010/089, it had not adopted modern orchard management techniques. Drujegang is in the eastern part of the Dzongkhag (administrative district) of Dagana, southern Bhutan (Figure 8).

Dorji et al. (2016) selected 40 Drujegang citrus growers for analysis, dividing the population into small, medium and large growers (Table 12).

A baseline survey of citrus yields, revenues and household incomes was completed in 2012. A second survey was completed 2014, two years after improved management practices had been introduced to Drujegang.

Project intervention

A farming systems extension approach delivered at the community level was used for training Drujegang farmers, the first time that such an approach had been used in the Drujegang gewog.

Improved management practices demonstrated to the community included basin making, farmyard manure application, fertiliser application, use of plant protection chemicals, irrigation, tree canopy management and mulching.

The use of improved management practices rose from 4.5% before the ACIAR project to 16.6% after the training. Not all of the improved management practices were adopted at the same rate. Household citrus growers favoured basin making, farmyard manure application and fertiliser application.

Tree mulching, irrigation and the application of plant-protection chemicals received little support. Many growers resisted applying plant protection chemicals for religious reasons—Bhutanese Buddhists of strong faith are reluctant to harm any living creature.

Figure 8: Map of Bhutan showing administrative districts

Source: <www.bhutanvisit.com/map-of-bhutan>.

Table 12: Drujegang Bhutan citrus grower profile

Characteristics	Small grower (n=20)	Medium grower (n=10)	Large grower (n=10)
Household size (person)	6.3	5.7	5.6
Gender	9 males, 11 females	7 males, 3 females	8 males, 2 females
Labour force (person)	1.3	1.2	1.3
Farm size (ha)	4.4	5.2	15.6
Orchard size (ha)	1.1	2.8	5.9
Number of trees	63	141	210
Level of technology adoption	None	Low	Low

Source: Dorji et al. 2016.

Impact on community

The community worked together to implement laborious citrus management practices, such as basin construction. Basin construction on steep farms required stone walls to be raised so that soil could be levelled. Some improved management practices were not implemented, because there simply was not enough household or village labour (for example, hand watering of citrus orchards during the typical eight-month water deficit). A shortage of agricultural labour is a recognised production constraint in Bhutan (World Bank 2017).

Impact on yield and household income

Adoption of improved farm management practices in Drujegang increased citrus yield and household income. Mean citrus yield rose from 1,900 kg/ha to 2,422 kg/ha (a 27.5% gain), and mean household income more than doubled from A$2,182 to A$4,675.

Impact on women and youth

Mostly women attended ACIAR training, accounting for 60%–70% of farmers trained by the project. Women are responsible for the household, and men often work off-farm, including in construction (Mr Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, pers. comm., August 2018).

The implementation of improved farm management practices meant that all workers, and especially women and youth, were required to complete more work. But women interviewed by the DoA extension team accepted the additional workload, often shared throughout the community, in exchange for additional income. Additional income was used to support items such as household education expenses.

School children aged 12 and over were employed in citrus production, including introducing improved farm management practices. Children worked after school harvesting and grading fruit. Children were pleased to contribute to household income (Mr Jigme Tenzin, Chief Horticulture Officer, Agriculture Production Division, DoA, pers. comm., August 2018).

Environmental impacts

The uptake of plant protection chemicals was low. Use of measures to contain chemical fertiliser—that is, basin making—was high. There were few, if any, negative environmental impacts associated with improved management practices, and the construction of basins helped stabilise soil in orchards with a steep and eroding slope.

Case study conclusions

In the case study gewog of Drujegang, ACIAR investment in extension officer capacity building and household training increased citrus yield and more than doubled household income. Additional work responsibilities for women and youth were offset with additional household income, and there were few impacts on the district environment.

7.1.6 Bhutan economic outcomes and impacts

Other positive impacts for Bhutan resulting from ACIAR investment in HORT/2005/142 and HORT/2010/089 include:

- long-term gain in industry yield from the introduction of grafted nursery stock
- decline in the rate of loss caused by HLB
- gains to other horticultural industries from access to capacity built and the introduction of irrigation.

Longer term, gains in citrus yield and fruit quality, in addition to those described in the Drujegang case study, should be realised by Bhutanese citrus growers.

Roll out of grafted nursery trees, improved varieties including Afourer mandarin and the relocation of the industry above 1,200 m to avoid HLB vectors will all improve the productivity of citrus production in Bhutan.

For example, introduction of grafted nursery stock will reduce the time taken for new plantings to produce a crop. With current seed-grown mandarins, it takes seven years for trees to crop. Grafted trees take four years to crop. In addition, HLB infection is a real risk in seed-grown trees before they produce a crop.

Capacity built through the ACIAR projects has created a professional citrus research and extension team. Members of this team are now available to train younger professionals, and work in other horticultural industries in Bhutan (for example, lychee, mango, avocado, macadamia). Other horticultural industries will also benefit from low-cost streamflow and gravity-fed irrigation introduced to Bhutan by the ACIAR projects.

7.1.7 Case study: economic impact of Chinese rootstocks on Australian citrus production

Rootstock and industry description

ACIAR projects CS1/1987/002 and CS1/1996/076 provided access to more than 50 citrus rootstock types from China. Subsequent investment by Hort Innovation, and project delivery by NSW DPI and QDAF have produced outcomes and potential impacts for Australia. Table 13 shows Chinese rootstocks and their potential Australian on-farm benefits.

Table 13: Chinese rootstocks in Australia and their potential on-farm benefits

	NSW DPI releases—trifoliata types	NSW DPI releases—erythrosa types	QDAF release	NSW DPI research—dwarfing	NSW DPI research—salt tolerance
Names	*Zao yang* *Tanghe* *Ghana* *Donghai*	*Anjiang hongju* *Caoshi xiangju*	*Barkley* (Yuzu type)	85–25 Number 24	*Zao yang* *Anjiang hongju* *Zhoupi Jiangjin*
Suitable scions	Navels Valencia Eureka lemon	Mandarins	Imperial Afourer Other	Navels Mandarins	Navels Mandarins
Types of on-farm economic benefits	• Increased saleable yield • Improved fruit quality (brix, fruit size)	• Increased saleable yield • Improved fruit quality (brix, fruit size)	• Increased saleable yield • Improved fruit quality (brix, fruit size) • Orchard longevity	• Harvest cost-savings • Vigour management • Improved fruit quality (brix, fruit size)	• Production in a future, hotter, drier climate • International sales to Spain, Israel, Pakistan, etc.
Year of commercial release	2017	2017	2017	Not applicable	Not applicable
Comments	• Zao yang has established seed sales • Replacements for industry standard rootstock Tri22	• Anjiang hongju is a superior mandarin rootstock, and the seed is now available for sale	• This rootstock is most relevant to the Queensland mandarin industry	• Planted Dareton, New South Wales in October 2017 • Will be tested as part of CT17002	• Trial established Bindoon, Western Australia, in 2013 • Testing being completed as part of CT17002

Sources: NSW DPI and QDAF literature, with a 2018 update from Dr Tahir Khurshid.

In 2017, NSW DPI commercially released:

- six Chinese rootstocks
- four trifoliata types (*Zao yang, Tanghe, Ghana, Donghai*)
- two erythrosa types (*Anjiang hongju, Caoshi xiangju*).

In 2018, commercial quantities of seed available for sale are *Zao yang*, suitable for navels, Valencias and Eureka lemon, and *Anjiang hongju*, suitable for mandarins including Afourer mandarin. *Zao yang* has already secured meaningful commercial seed sales—60 kg compared to 450 kg of industry standard trifoliata rootstock Tri22 (Mr Tim Herrmann, Manager, Auscitrus, pers. comm., July 2018).

In addition to the six Chinese rootstocks released by NSW DPI, QDAF released a seventh Chinese rootstock in 2017—Barkley—which is particularly well suited to Imperial mandarins, but is also relevant to Afourer and other mandarin varieties (Malcolm Smith, Citrus Breeder, QDAF).

Types of on-farm impact

Chinese rootstocks will offer various potential benefits to growers, including increased output of better-quality fruit, orchard longevity, disease resistance, salt tolerance and orchard intensification via dwarfing. Two potential economic benefits are increased saleable yield and improved fruit quality (fruit size and brix).

Chinese rootstocks have the potential to offer a 15% increase in saleable yield, and an improvement in fruit quality that will lift fruit prices by 5% (Dr Tahir Khurshid, Research Physiologist, and Mr Steven Falivene, Citrus Industry Development Officer, NSW DPI, pers. comm., August 2018).

In addition to the Chinese rootstocks that have already been released, the genetic material supplied through CS1/1987/002 and CS1/1996/076 offers additional production benefits for Australian citrus growers.

Chinese citrus rootstocks will be tested for both their dwarfing ability and their salt tolerance as part of Hort Innovation Project CT17002. Trials began in 2018, and results will not be available until 2022. Dwarfing and salt tolerance benefits from Chinese citrus rootstocks are not yet established, are more speculative and remain unquantified in this analysis.

Valuation of on-farm impact

Fruit grown on Chinese citrus rootstock will start to become available in 2023. Two years are required to grow nursery trees from the time Chinese rootstock became available in 2017, and a further four years are required for farm-planted trees to achieve commercial harvest levels. Commercial harvests that resemble farm financial performance represented in Table 14 would not be until 6 years after planting—that is, 2025.

In 2017, Australia had about 25,000 ha of commercial citrus production. Production was dominated by navel oranges (9,700 ha), Valencia oranges (6,700 ha) and mandarins (6,400 ha). The area of new citrus planted increased by 850 ha per year between 2014 and 2017. New plantings were dominated by mandarins (18% increase in area) and navels (12% increase in area). The increase in Valencia area was a more modest 2% (Citrus Australia 2018).

Current industry forecasts are for ongoing growth of 750 ha per year for five years, followed by much more modest growth (Mr Graeme Sanderson, Research Horticulturalist, NSW DPI, pers. comm., August 2018). In 2023, when the first fruit grown on Chinese citrus rootstocks becomes available, Australia will have a production base of about 28,750 ha. Conservatively, no annual growth in the production base from 2023 is assumed.

To determine the potential on-farm impact of Chinese citrus rootstocks a 'without' and 'with' farm financial performance model was developed. The model uses NSW DPI (2018) farm development data for Afourer mandarins and Washington navel oranges. Purchase cost for trees grafted onto Chinese citrus rootstocks has been assumed to be the same as trees grafted onto conventional rootstock types. The model shows the impact of improved yield and quality for a six-year-old, 1-ha orchard (Table 14).

When mature, new citrus planted on Chinese rootstocks, could account for 50–60% of all new citrus planted in Australia. Maturity is expected to occur 25 years after rootstock release in 2043 (Dr Tahir Khurshid, Plant Physiologist, NSW DPI, pers. comm., June 2018).

Table 14: Potential farm financial performance without/with Chinese rootstocks (A$/ha)

	Farm performance without Chinese rootstocks	Farm performance with Chinese rootstocks
Income (citrus)		
Yield (t/ha)	45	50
Fruit price (A$/t)	625	656
Total enterprise income (A$)	28,125	32,484
Costs		
Site preparation, trees, planting (annualised)	1,042	1,042
Irrigation	1,502	1,502
Herbicide	98	98
Fertiliser	1,083	1,083
Fungicides	108	108
Insecticides	724	724
Crop management sprays	246	246
Pruning	1,687	1,687
Crop management	2,263	2,263
Tractor	1,007	1,007
Harvesting and cartage	8,310	8,310
Levies	158	158
Overheads and fixed costs	1,260	1,260
Total costs	19,484	19,484
Operating profit	**8,641**	**14,022**
Amount of citrus produced (tonne)	45	50
Annual production cost per tonne	433	390
Annual reduction in production cost per tonne (also known as K)	43	
K-shift (cost saving of $43/t divided by citrus price of $625/t)	6.9%	

Source: NSW DPI 2018.

Welfare analysis of ACIAR project benefits

The benefits of ACIAR research outputs are estimated using standard welfare (economic surplus) analysis, as described in detail in Alston et al. (1995).

New citrus planted on Chinese rootstocks could potentially have both a cost reduction and price (quality) impact. As identified by Alston et al. (1995), for the most part, agricultural economists have sidestepped the question of jointly modelling technical changes (supply shifts) and associated changes in production quality. This is because of the difficulty of modelling substitution effects for the product, and substitutions effects in production.

So, to model quality changes formally might require using a model with multiple sources of general-equilibrium type feedback. In any case, 'technical change that leads to a change in product quality is a change in supply conditions not demand conditions, and it would be better to model it as such'. Consequently, the impact of this ACIAR investment has been modelled as a supply shift.

An improvement in saleable yield effectively lowers the unit cost of citrus production from the same sized orchard. An estimate of the reduction in the unit cost of citrus production and the overall supply shift has been added to Table 14.

In a static supply-and-demand model (Figure 9), the impact of Chinese citrus rootstocks is modelled as a reduction in the unit cost of growing citrus ('bc' dollars) at the initial equilibrium level of production, Q_0. The assumption that ACIAR-generated technology results in the same savings in costs at all levels of production gives a downward shift (K), from S_0 to S_1, in the supply of citrus at the farm level. This results in an increase in citrus production from Q_0 to Q_1 and a fall in the farm price of citrus from P_0 to P_1.

The gains (surpluses) to producers (ΔPS) and consumers (ΔCS) are represented by the areas *efcd* and *abfe*, respectively, and described by the equations (Alston et al. 1995):

$$\Delta PS = (K - Z)\, P_0 Q_0 (1+0.5Z\eta) \qquad (1)$$

$$\Delta CS = P_0 Q_0 Z\, (1+0.5Z\eta) \qquad (2)$$

Where:

$K = k/PO_0$

$Z = K\varepsilon/(\varepsilon+\eta)$

ε is the elasticity of supply at the farm level

η is the absolute value of the elasticity of demand at the farm level.

Total industry welfare gains are the sum of the changes in producer and consumer surpluses. The distribution of gains between the two depends critically on relative demand and supply elasticities. However, the total welfare gain is not sensitive to elasticity assumptions.

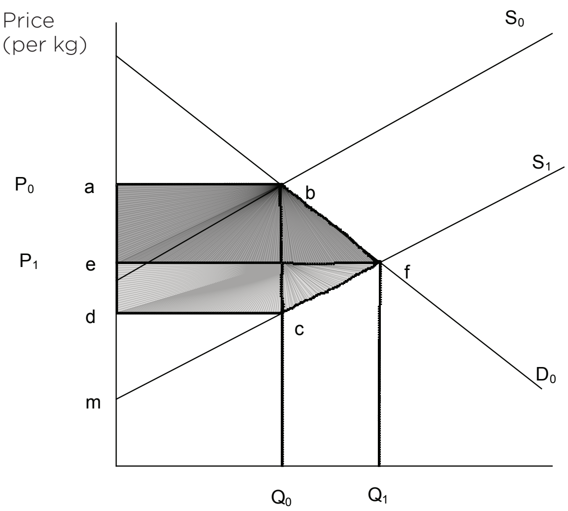

Figure 9: Welfare changes from introduction of Chinese citrus rootstocks

Source: Montes et al. 2008.

An estimate of the k-shift

As identified in Table 14, the k-shift (reduction in production costs per tonne as a proportion of initial price or P_0 is 6.9%—that is, \$43/\$625.

Demand and supply parameters

The supply elasticity of citrus production is likely to be relatively inelastic, given the time it takes for plantings to bear fruit. For the analysis, a supply elasticity of 0.5 is assumed.

Demand elasticity for Australian production is likely to be relatively elastic, given the global citrus and other fruit substitutes available. The financial budgets without and with Chinese citrus rootstocks indicate that with a drop in cost (price) from a shift in supply of 6.9%, there would be an increase in production (from movement along the demand curve) of 11.11%. This suggests demand elasticity of –1.615. This estimate has been used in the analysis.

Equilibrium price and quantity

Equations (1) and (2) indicate that welfare effects are significantly influenced by the choice of product price and quantity. Welfare analysis of the type applied in this section is generally done using prices and quantities judged to be those existing when the industry is close to equilibrium before the technology is introduced (ACIAR research outputs). The prices and estimates of welfare changes are considered as being in real terms (rather than nominal), and projected forward over the period of the analysis, disregarding other exogenous impacts on the industry that will likely qualify the actual benefits accruing (Montes et al. 2008).

Another dimension of the choice of equilibrium price is that, in the approach used in this section, the supply shift K is estimated as the change in unit production costs as a proportion of product price, on the assumption that price in equilibrium is equal to the long-run average cost of production (Montes et al. 2008).

Quantity (Q_0) is the quantity of citrus produced at the steady state area of citrus production, assumed to be 28,750 ha in 2022—that is, 28,750 ha x 45t/ha = 1,293,750 t. Price (P_0) is \$625/t.

Table 15: Change in producer and consumer surplus with Chinese rootstocks

Metric	Quantum	Source/comments
Price of citrus—P_0	$625/t	
Quantity of citrus—Q_0	1,293,750 t	Steady state hectares of citrus production 28,750 ha with 45 t production per hectare
K-shift	6.9%	See Table 14
Elasticity of supply—ε	0.5	See explanation in text
Elasticity of demand—η (absolute value)	1.615	See explanation in text
k	43	See Table 14
Z	0.02	$Z = K\varepsilon/(\varepsilon + \eta)$
ΔPS	A$43,037,574	$\Delta PS = (K-Z) P_0Q_0(1+0.5Z\eta)$
ΔCS	A$13,324,326	$\Delta CS = P_0Q_0 Z (1+0.5Z\eta)$

Producer and consumer surplus estimates

Table 15 summarises the relevant parameters needed to derive changes in producer and consumer surplus.

The levels of producer surplus and consumer surplus in Table 15 is for a single year, assuming 100% adoption of Chinese rootstock. To estimate the changes in producer and consumer surplus likely to be realised, additional assumptions are required, as identified in the following sections.

Articulation of the counterfactual

Typically, in economic impact assessment, the benefit of project investment is the earlier realisation of economic benefits—in this case, increased enterprise income distributed as producer surplus and consumer surplus.

Project benefits are measured for the 'slice of time' between when increased enterprise returns are now realised and when they would have been realised in the absence of project investment. But this is not the case with this particular set of ACIAR investments. If Chinese citrus rootstocks were not brought to Australia as part of the ACIAR projects, they would not have been accessed by the Australian citrus industry, and resultant economic benefits would not have been realised.

Chinese citrus rootstocks were accessed through the ACIAR projects at a particular point in time when China had an interest in foreign citrus genetics, and was willing to exchange native scion and rootstock material for material sourced from Australia.

Subsequently, China has moved away from germplasm exchange and conventional citrus breeding. Requests to China by researchers from other countries to exchange germplasm and access rootstocks have been politely declined. China's citrus research focus has also shifted to genetic analysis at the molecular level, and away from traditional plant breeding. Currently, China is not commercialising, promoting or further developing its native citrus resources.

The gains to Australia from the introduction of Chinese citrus rootstocks are substantial, and will be sustained. Commercial rootstocks take a long time to develop, and have a long economic life—current standard Australian citrus rootstocks have been in use for 50–70 years.

The counterfactual for this analysis is that, in the absence of ACIAR investment, the increase in enterprise income modelled would not have been realised, and the benefits of increased income are sustained over the 30-year analysis period.

Additional research, development and extension required to generate benefits

Positive economic impacts associated with the importation, trialling and commercial release of Chinese citrus rootstocks in Australia is attributable to more than the total investment in CSI/1987/002 and CS1/1996/076.

In addition to the two ACIAR projects, Hort Innovation has funded Chinese rootstock evaluation and communication of results to industry since 1993. Total Hort Innovation investment in rootstock breeding up to and including funds required to secure the release of *Zao yang, Anjiang hongju* and *Barkley* has totalled $2.1 million, and these costs are included as additional research, development and extension required to generate project benefits.

Inclusion of all Hort Innovation costs is an overestimate of the organisation's contribution to Chinese rootstock development. Hort Innovation's program was also directed at other sources of rootstock genetic material, the benefits from which are not considered as part of this analysis.

Summary of assumptions

Table 16 shows a summary of key assumptions made for the valuation of impacts.

Investment return

Investment return was determined over a 30-year period starting in the last year of Hort Innovation investment in the commercialisation of Chinese citrus rootstocks.

Investment return is assessed against total cost, and includes investment in CS1/1987/002 and CS1/1996/076, which was not directed at gains for Australia—it was focused on China and Vietnam. All benefits and costs were discounted to 2018 values, using a discount rate of 5%.

Table 16: Key assumptions—economic impact Chinese rootstocks on Australian citrus

Variable	Assumption	Source/comment
Year of first impact	2025—6-year lag from planting	• Rootstocks released 2017 • Two years to grow nursery tree (2019) • A further six years to achieve the commercial harvest levels shown in Table 14
Area of Australian citrus in year of first impact	28,750 ha	• Base of 25,000 ha in 2017 • Ongoing growth of 750 ha per year until 2023
Annual plantings of citrus	750 ha per year from 2018 to 2022, plus 5% replacement of existing citrus area	• Industry advise that current growth in planting rates will ease after 5 years • It is assumed that a citrus orchard has an economic life of 20–30 years
Share of new citrus plantings using Chinese citrus rootstocks	10% in 2019, increasing by 2.25% per year, and reaching a maximum of 55% in 2029	• When mature, new citrus planted to Chinese rootstock could account for 50%–60% of all new citrus planted in Australia (Dr Tahir Khurshid, Plant Physiologist, NSW DPI., pers., comm. June 2018)
Attribution of impacts to ACIAR investment	90%	• Allowance for funds invested by QDAF and Queensland growers for the development of Barkley • Hort Innovation investment in Chinese citrus rootstock commercialisation has been quantified in the analysis
Probability of output	100%	• Chinese citrus rootstocks released in 2017
Probability of usage	90%	• Consultant assumption, based on discussions with Tim Herrmann, Auscitrus
Probability of impact	90%	• Consultant assumption, based on discussions with Dr Tahir Khurshid and Mr Steven Falivene, NSW DPI

Table 17 shows Australian citrus industry returns from total investment, and returns from ACIAR's share of total investment in CS1/1987/002 and CS1/1996/076.

The total investment of $16.72 million (present value terms) has been estimated to produce gross benefits of $56.28 million (present value terms), providing a net present value of $39.55 million, and a benefit:cost ratio of 3.4:1 (over 30 years, using a 5% discount rate). The ACIAR investment has been successful.

Sensitivity analysis was carried out on three sets of variables, and results are reported in tables 18, 19 and 20. All sensitivity analyses were done for the total investment, and with benefits taken over the life of the investment, plus 30 years from the year of last investment. All other parameters were held at their base values.

Table 18 presents the sensitivity of the results to the discount rate. The results are sensitive to the discount rate used, and reflect the length of time between initial investment, starting in 1993, and the realisation of project benefits, starting in 2025.

Table 19 shows the sensitivity of the investment criteria to the assumed rate of adoption of Chinese citrus rootstocks in Australia. Even at about half the assessed adoption rate, the results of the economic analysis remain positive. If a higher adoption rate is applied, total project benefit:cost ratio is 5.2:1.

Table 20 shows the sensitivity of the investment criteria to the assumed allocation of ACIAR and Hort Innovation project costs to the development of Chinese citrus rootstocks in Australia. If the allocation of costs to development of Chinese citrus rootstocks in Australia is halved, to better reflect other ACIAR and Hort Innovation project activities not relevant to Chinese rootstock development in Australia, then total project benefit:cost ratio is 6.9:1.

While there are no data to support this allocation, it might well be argued that this is an appropriate reflection of investment returns.

Confidence ratings

The results produced are highly dependent on the assumptions made, some of which are uncertain. Two important factors warrant recognition:

- Where there are multiple types of benefits, it is often not possible to quantify all the benefits that might be linked to the investment.
- There is uncertainty about the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 21), with rating categories of:

- high—a good coverage of benefits or reasonable confidence in the assumptions made
- medium—a reasonable coverage of benefits or some uncertainties in assumptions made
- low—a poor coverage of benefits or many uncertainties in assumptions made.

Coverage of benefits was assessed as high—the most important potential benefits from rootstock development, yield and quality improvement were assessed. Confidence in assumptions was rated as only medium, and while data were sourced from the research (NSW DPI) and commercialisation (Auscitrus) community, there remains a level of uncertainty around Chinese rootstock adoption rates.

Lindner et al. (2013) reviewed 27 impact assessment study reports, covering 103 ACIAR research projects, and classified each analysis on the basis of its transparency and economic rigour as being either 'conceivable' 'plausible' or 'convincing'. This analysis is self-assessed as 'conceivable'.

Case study conclusions

Economic analysis shows that the introduction of Chinese rootstocks to the Australian citrus industry has the potential to produce significant benefits.

The total investment of $16.72 million (present value terms) has been estimated to produce gross benefits of $56.28 million (present value terms), providing a net present value of $39.55 million and a benefit:cost ratio of 3.4:1.

The analysis has included the total cost of CS1/1987/002 and CS1/1996/076, even though most of the investment was directed toward China and Vietnam. The analysis also includes the full cost of Hort Innovation's investment in rootstock breeding, even though the development of other rootstock genetics was included in this program. Consequently, the results of a sensitivity analysis that apportions 50% of project costs to Chinese citrus rootstocks in Australia with a resultant benefit:cost ratio of 6.9:1 might well be argued to be an appropriate reflection of investment returns.

Table 17: Summary of returns from Chinese citrus rootstock in Australia

Criterion	Total investment in projects	ACIAR investment in projects
Present value of benefits (A$ million)	56.28	19.16
Present value of costs (A$ million)	16.72	5.69
Net present value (A$ million)	39.55	13.46
Benefit:cost ratio	3.37	3.37

Note: A discount rate of 5% has been used.

Table 18: Sensitivity to discount rate (total investment, 30 years)

Criterion	Discount rate		
	0%	5%	10%
Present value of benefits (A$ million)	177.34	56.28	17.38
Present value of costs (A$ million)	5.99	16.72	45.14
Net present value (A$ million)	171.36	39.55	–27.76
Benefit:cost ratio	29.63	3.37	0.39

Table 19: Sensitivity to assumed rootstock adoption rate (total investment, 30 years)

Criterion	Discount rate		
	1% p.a. peaking at 30%	2.25% p.a. peaking at 55%	4.5% p.a. peaking at 75%
Present value of benefits (A$ million)	37.30	56.28	87.24
Present value of costs (A$ million)	16.72	16.72	16.72
Net present value (A$ million)	20.57	39.55	70.52
Benefit:cost ratio	2.23	3.37	5.22

Table 20: Sensitivity to assumed investment cost (total investment, 30 years)

Criterion	Discount rate	
	50% of total cost	100% of total cost (base)
Present value of benefits (A$ million)	57.85[(a)]	56.28
Present value of costs (A$ million)	8.36	16.72
Net present value (A$ million)	49.49	39.55
Benefit:cost ratio	6.92	3.37

(a) Hort innovation project costs are treated as a 'negative benefit' so that analysis estimates return on ACIAR projects. As a consequence, present value of benefits increases when Hort Innovation's contribution is reduced by 50%.

Table 21: Confidence in analysis of the projects

Coverage of benefits	Confidence in assumptions
High	Medium

7.1.8 Australia—other economic outcomes and impacts

Other key positive impacts for Australia resulting from ACIAR investment in the four projects include mandarin industry production improvements. This has been linked to development and communication of production best practice and critical capacity developed in field and laboratory testing of exotic pests and diseases, especially HLB.

The Australian mandarin industry—producing more than 102,000 tonnes of fruit, of which 38,000 tonnes is exported at a value of $42 million per year—benefited from the development and communication of production best practice. Mandarins are a more difficult citrus to grow than oranges, and less was known about their production requirements. Development and communication of best practice through the Australian *Mandarin production manual* is expected to have a long-term positive impact on industry productivity.

The building of critical capacity developed in field and laboratory testing of exotic pests and diseases has the potential to avoid costs associated with introducing and establishing HLB in Australia. Project documentation notes that, unprepared, a HLB outbreak could wipe $30 million from the farm-gate value of New South Wales citrus. Obviously, impacts in other states would be in addition to this total.

7.2 Environmental outcomes and impacts

The four ACIAR projects have created few environmental impacts. One positive environmental impact is the conservation of native citrus germplasm in China and Vietnam. Germplasm threatened by both human impacts, such as the clearing of native forests for agriculture and disease, such as HLB, has been identified and protected in-country, in repositories.

A second positive environmental impact is the potential for new disease-resistant varieties developed as part of the ACIAR projects to use fewer chemicals. New rootstocks and scions that resist diseases like citrus tristeza closterovirus will require fewer chemical sprays.

A negative environmental benefit might be associated with the modernising of the Bhutan mandarin industry. What was previously low input, low output citrus production is slowly being modernised through the use of inorganic fertilisers, insecticides and irrigation.

The introduction of a regular tree fertilisation program to boost yield and fruit quality with inorganic fertilisers may, in time, create problems with soil acidity and nutrient runoff.

Some Bhutanese citrus growers resist adoption of the technology, because they feel that chemical fertilisers are not natural and deplete the soil. The projects have worked to match fertiliser with plant requirement, to reduce over fertilisation and nutrient leaching. Best practice also recommends that basins be created around trees, to help reduce soil degradation and erosion. Basin making was enthusiastically adopted in Bhutan during the ACIAR projects.

Introduction of 'hard' chemical insecticides to Bhutan to control Chinese citrus fruit fly and HLB vectors, such as dimethoate and cypermethrin, has been balanced with the testing and development of cultural practices (for example, destroying fallen fruit), and the use of 'softer' chemicals that do not interfere with non-pest species.

Again, some Bhutanese citrus growers resist this technology on religious grounds, expressing concern at the killing of living things. HLB control without chemicals will be further improved by the second ACIAR project's recommendation that citrus production be moved to higher altitudes to avoid psyllids and the need for chemical sprays. The control of powdery mildew with sulphur negates the need to use tridemorph, a hazardous chemical and known environmental pollutant. Use of sulphur to control powdery mildew is consistent with organic production techniques.

Introduction of irrigation has the potential to draw down natural streamflow. It is noted that Bhutan is a high rainfall country where irrigation's impact on the environment, when adopted by smallholder citrus growers and other horticultural producers, should be minimal.

On a positive note, recommendations addressing the removal of weeds from citrus orchards in Bhutan will help prevent weed spread to natural ecosystems. HLB control will also prevent the rapid debilitation of citrus orchards and the potential for land degradation on steep and hilly terrain.

7.3 Social outcomes and impacts

Research indicates that the four ACIAR projects have contributed to poverty alleviation, with equal benefits for men and women. No project objectives specifically targeted the empowerment of women.

In China, project outputs have been targeted at both larger commercial citrus farms and smaller family units. China maintains a production responsibility system in which citrus production is the responsibility of both the husband and the wife. A contract to use land for planting citrus is generally made with village authorities.

To finance high initial investment costs, small farmers set up collective agencies, bringing together large groups of individuals managing small orchards of 0.2–0.6 ha. All members of the family are involved in the care of the orchard. In terms of research capacity building, women were well involved in the ACIAR projects. For example, two women came to Australia for training, including Dr (Mrs) Jiang, who originally trained in Australia and has responsibility for disease elimination in clones entering the CRI budwood scheme.

In Vietnam, research outputs were directed to both larger farms and smallholdings. In the Mekong Delta—the focus of ACIAR research activity—citrus is mainly grown in family plots of 0.25–0.33 ha. Women work alongside men, and share production responsibilities.

Poverty is endemic in this region. As in China, women were represented among the Vietnamese scientists who participated in the ACIAR projects. Five of seven Vietnamese students trained as part of CS1/1996/076 were women.

In Bhutan, research outputs targeted larger growers with the financial resources to adopt best-practice production and finance the cost of purchased inputs (for example, chemical fertiliser, grafted nursery trees).

Researchers indicated 'spillover' benefits would be realised by smallholders copying production practices, and participating in pest and disease control. Citrus farms are small in Bhutan, with tree numbers per farm varying between 3 and 900. Production from 50 trees is considered commercial.

About 66% of Bhutan's population are involved in citrus production. About 32% of the Bhutanese population lives on less than A$32 month, and income from citrus provides essential cash for children's education and medical expenses. Children also earn valuable household income from harvesting and fruit grading after school.

Project recommendations for Bhutan to shift the citrus industry to higher altitudes are consistent with sound social policy. Communities at higher elevations are the most likely to experience poverty, and other tree crops can be grown at lower altitudes (for example, lychee, mango, avocado, macadamia).

There appears to be no obvious division in the roles of men and women on-farm in Bhutan. On-farm discussions on citrus management activities are held equally with both men and women, depending on individual farm circumstances. Project demonstration orchards in Bhutan are managed by women, because their husbands worked elsewhere.

Projects used a community-focused approach, which showed some success. Such an approach is seen as a way of encouraging Bhutanese farmers to interact with each other, develop social relationships and work for the benefit of their immediate family and the local community.

Community activities included collecting and destroying fallen fruit to control Chinese citrus fruit fly, developing local gravity-fed irrigation systems and pooling, grading and marketing citrus to maximise total returns.

Capacity building in the Bhutan research sector benefited men and women, with both genders being trained as part of the ACIAR projects—for example, Dr (Ms) Namgay Om completed her PhD in the roles of psyllids in the spread of HLB as part of the ACIAR projects.

In Australia, research outputs will contribute to the long-term profitability of citrus producers. Typically, citrus is grown on family-owned farms, where both men and women contribute to production, fruit packing and financial decision-making. Citrus properties average 20–70 ha, with a 40-ha block required to support a typical farm family (Mr Steven Falivene, NSW DPI, Citrus Industry Development Officer, pers. comm., August 2018). ACIAR research projects were staffed with senior female professionals, including Mrs Patricia Barkley (citrus rootstock breeder) and Ms Sandra Hardy (project leader).

8 Conclusions

This impact assessment has reviewed four ACIAR projects concerned with citrus rootstock, scion and production improvement in China, Vietnam, Bhutan and Australia.

In China and Vietnam, the projects have helped:

- preserve citrus genetics
- transfer technologies from Australia that deliver disease-free planting material
- build science capacity
- introduce more profitable varieties—on its own, the introduction of Late Lane navel to China is thought to be contributing $38.4 million per year to orange grower producer surplus.

In Bhutan, the ACIAR projects have delivered a qualified citrus research and extension team and a package of production improvement measures that are being realised by large and small mandarin growers.

The case study analysis of Drujegang in the eastern part of the Dzongkhag of Dagana has shown that even with partial implementation of ACIAR production improvement measures, smallholder income has doubled. This was achieved without an excessive burden on the hours worked and on the working conditions of women and youth.

In Australia, an economic analysis of the introduction of Chinese citrus rootstocks through the projects has shown significant potential for industry returns.

The total investment of $16.72 million (present value terms) has been estimated to produce future gross benefits of $56.28 million (present value terms), providing a net present value of $39.55 million and a benefit:cost ratio of 3.4:1.

The analysis has included the total cost of CS1/1987/002 and CS1/1996/076, even though most of the investment was directed toward China and Vietnam. It also includes the full cost of Hort Innovation's investment in rootstock breeding, even though the development of other rootstocks was included in this program. Consequently, the results of a sensitivity analysis that apportions 50% of project costs to Chinese citrus rootstocks in Australia with a resultant benefit:cost ratio of 6.9:1 might well be argued to be an appropriate reflection of investment returns.

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10	AACM International 1998	Conservation tillage and controlled traffic	LWR2/1992/009
11	Chudleigh P. 1998	Postharvest R&D concerning tropical fruits	PHT/1983/056, PHT/1988/044
12	Waterhouse D., Dillon B. and Vincent D. 1999	Biological control of the banana skipper in Papua New Guinea	CS2/1988/002-C
13	Chudleigh P. 1999	Breeding and quality analysis of rapeseed	CS1/1984/069, CS1/1988/039
14	McLeod R., Isvilanonda S. and Wattanutchariya S. 1999	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008, PHT/1990/008
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56	Lindner B. and McLeod P. 2008	A review and impact assessment of ACIAR's fruitfly research partnerships—1984–2007	CP/1997/079, CP/2001/027, CP/2002/086, CP/2007/002, CP/2007/187, CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225, CS2/1997/101, CS2/1998/005, CS2/2003/036, PHT/1990/051, PHT/1993/87, PHT/1994/133
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71	Lindner R. 2011	The economic impact in Indonesia and Australia from ACIAR's investment in plantation forestry research, 1987–2009	FST/1986/013, FST/1990/043, FST/1993/118, FST/1995/110, FST/1995/124, FST/1996/182, FST/1997/035, FST/1998/096, FST/2000/122, FST/2000/123, FST/2003/048, FST/2004/058
72	Lindner R. 2011	Frameworks for assessing policy research and ACIAR's investment in policy-oriented projects in Indonesia	ADP/1994/049, ADP/2000/100, ADP/2000/126, AGB/2000/072, AGB/2004/028, ANRE1/1990/038, ANRE1/1993/023, ANRE1/1993/705, EFS/1983/062, EFS/1988/022
73	Fisher H. 2011	Forestry in Papua New Guinea: a review of ACIAR's program	FST/1994/033, FST/1995/123, FST/1998/118, FST/2002/010, FST/2004/050, FST/2004/055, FST/2004/061, FST/2006/048, FST/2006/088, FST/2006/120, FST/2007/078, FST/2009/012
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76	Grewal B., Grunfeld H. and Sheehan P. 2011	The contribution of agricultural growth to poverty reduction	
77	Saunders C., Davis L. and Pearce D. 2012	Rice–wheat cropping systems in India and Australia, and development of the 'Happy Seeder'	LWR/2000/089, LWR/2006/132, CSE/2006/124
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No.	Author(s) and year of publication	Title	ACIAR project numbers
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83	Palis F.G., Sumalde Z.M., Torres C.S., Contreras A.P. and Datar F.A. 2013	Impact pathway analysis of ACIAR's investment in rodent control in Vietnam, Lao PDR and Cambodia	ADP/2000/007, ADP/2003/060, ADP/2004/016, AS1/1994/020, AS1/1996/079, AS1/1998/036, CARD 2000/024, PLIA/2000/165
84	Mayne J. and Stern E. 2013	Impact evaluation of natural resource management research programs: a broader view	
85	Jilani A., Pearce D. and Bailo F. 2013	ACIAR wheat and maize projects in Afghanistan	SMCN/2002/028, CIM/2004/002, CIM/2007/065
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