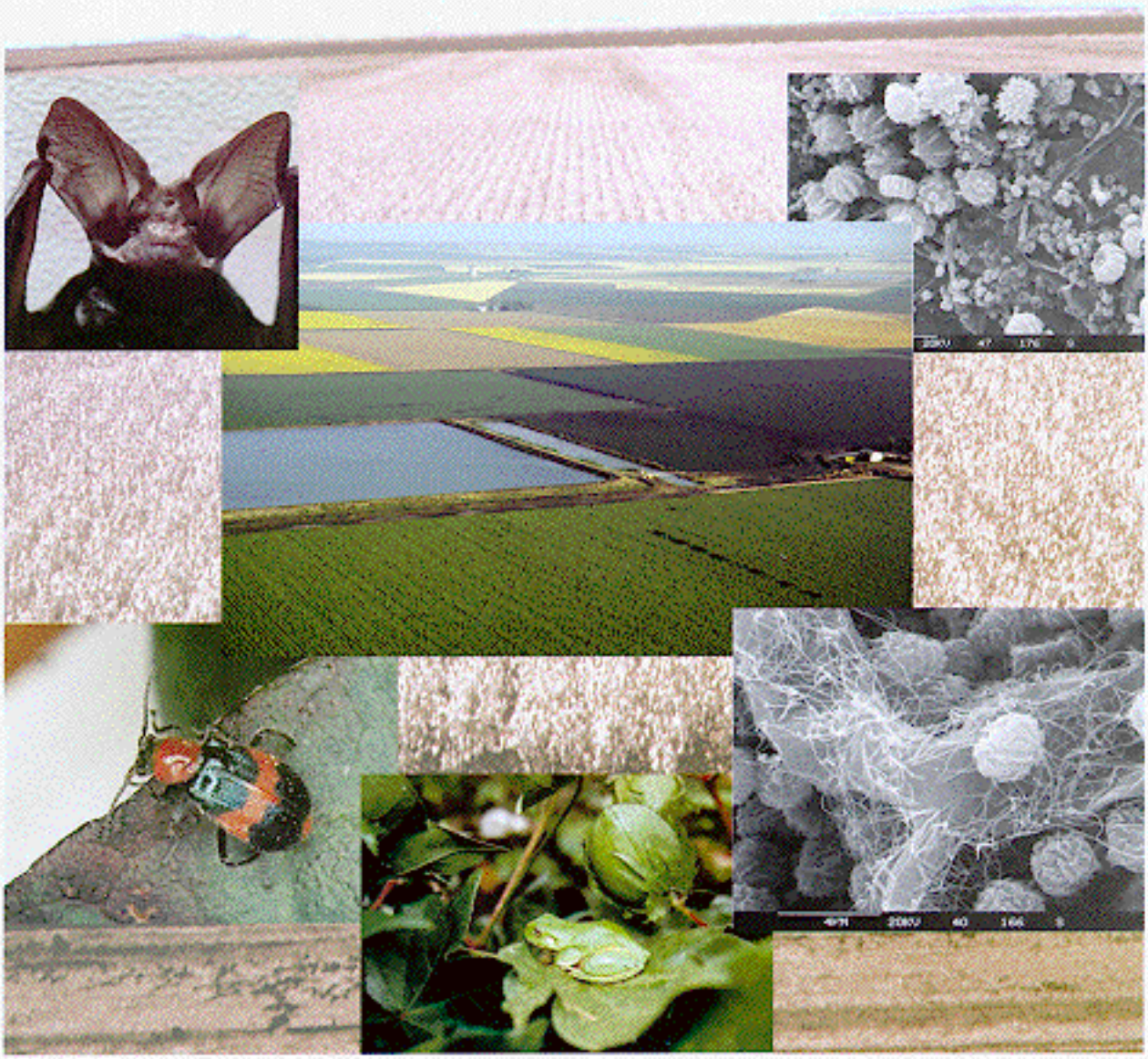
A Review of Biodiversity Research in the Australian Cotton Industry

Executive Summary

Final Report to the Cotton Research and Development Corporation

December 2003



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Cover: Background: Cotton field in the Namoi Valley (Peter Gregg), Photos clockwise from top left: Lesser long-eared bat (*Nyctophilus geoffroyi*) captured over a cotton field in northern NSW (Dave Britton), Aerial view of the Darling Downs agricultural district including cotton fields (Peter Gregg), SEM picture of cotton stubble colonized by a diverse range of fungi spores (VVSR Gupta), SEM picture of cotton stubble colonized with fungi and actinomycete hyphae and spores (VVSR Gupta), Green tree frog (*Litoria caerulea*) on unsprayed cotton on the property of Ken and Lou Platt, near Pilliga, NSW (Martin Dillon), and the beneficial predatory red and blue beetle (*Dicranolaius belulus*) collected from a cotton field in northern NSW (Dave Britton).

Executive Summary

Introduction

'Biodiversity' refers to the diversity of genes, species, ecosystems and ecoregions. Like other sectors in the Australian economy, the cotton industry has a duty of care to ensure its environmental sustainability, including conserving and enhancing the biodiversity upon which it depends and minimising negative environmental impacts. Australia ratified the *United Nations Convention on Biological Diversity* in June 1992. The Convention noted the global loss of biodiversity as a result of human activities, identified the need to conserve biodiversity in viable areas of natural or restored habitat, and recognised the need to mitigate the processes that most threaten biodiversity. Subsequent Commonwealth and State legislation and policies have given effect to the Convention.

Biodiversity is important for ecosystem (life support), ethical, aesthetic and cultural, and economic reasons. The challenge is to balance utilisation of biodiversity on the one hand with its conservation to ensure that present and future human welfare is not compromised. This is not easy due to the value judgements and diversity of private and public interests involved, as well as the incomplete nature of the science of biodiversity and its poor predictive power for decision making.

Report Objectives

This report aims to review the literature, particularly past and current cotton-funded research, to:

1. describe biodiversity and the role of biodiversity in cotton production systems;
2. identify the legislative and policy frameworks for biodiversity that are relevant to the cotton industry;
3. review information about the biodiversity of cotton growing areas;
4. identify gaps and opportunities for further research; and
5. suggest ways in which the industry can embrace a stewardship role in protecting biodiversity in a cooperative partnership with government and the community.

The scope of the project is limited to the main cotton growing areas in New South Wales and Queensland.

Biodiversity and Agriculture

Most biodiversity now exists in human-dominated ecosystems. Human impacts can have positive, negative or neutral effects on different elements of biodiversity. Biodiversity and humans have had a close and mutually supportive relationship for tens of thousands of years. The current western practice of isolating biodiversity management from other human endeavours is a recent phenomenon. While the protection of the characteristic biodiversity of regions in national parks and equivalent reserves will continue, even more important will be steps to safeguard or reintroduce native biodiversity and integrate it within human-dominated and agriculturally productive landscapes over most of the earth's surface.

The three principal threats to native terrestrial biodiversity in Australia are (1) habitat loss due to vegetation clearance, (2) habitat modification (through grazing and cultivation), and (3) exotic species introductions. Nearly 70% of native vegetation in Australia has been cleared or modified by human activity. Vegetation clearance continues, with the NSW and Queensland governments granting clearing permits for 750 000 ha in 1999, most of it in the ecoregions where cotton is grown (although most of this was not for cotton *per se*). Habitat destruction leads to species extinctions: the more habitat cleared, the greater the number of extinctions. Extinctions at regional and continental scales take time, and the full impact of vegetation clearance in Australia will not be felt for decades or centuries. Nevertheless, agriculture and grazing have caused 90% of the plant extinctions in Australia to date, and threaten the survival of most of the nation's endangered terrestrial vertebrates. Although national parks and equivalent reserves can conserve some species, the protected area network is least extensive and least representative of pre-European habitats in agricultural areas. Although cotton occupies less than 5% of the catchments in which it is grown, the industry has the opportunity to consider alternative futures for the flora, fauna and ecosystems that it has replaced. Likewise, the industry has the opportunity to manage the threat posed by livestock grazing, feral animals and weeds on cotton farms, and to conserve and restore remnant ecosystems.

The most extensive loss and degradation of wetlands and impacts on flowing waters in Australia have occurred in agricultural districts. The main threats to aquatic and riparian biodiversity of inland waters and groundwater dependent ecosystems in cotton growing areas are: (1) water extraction and altered timing and quantity of flows due to river regulation; (2) agriculture-related impacts such as grazing, increasing catchment salinity and salt loads in waterways, eutrophication and blue-green algal blooms, pesticide drift, and nitrate and pesticide pollution of groundwater; and (3) the introduction and spread of exotic species. Again, these threats represent opportunities for the industry to restore degraded aquatic, riparian and groundwater dependent ecosystems and protect aquatic biodiversity in cotton growing areas.

While not comparable to the biodiversity of the original undisturbed landscapes, habitat remnants in agricultural areas and modified agricultural environments are able to support some native flora and fauna species. This includes irrigated cotton fields and associated water storages, where many species of bird occur including some resident species. The ability to support flora and fauna assemblages can be enhanced through the retention and active management of remnant vegetation for biodiversity conservation, integration of native vegetation in farming systems, integrated pest and weed management strategies with reduced reliance on broad-spectrum pesticides, and cropping practices such as stubble retention, strip cropping, crop rotations and the planting of refuge crops.

Biodiversity Legislation and Policies

The Federal *Environment Protection and Biodiversity Conservation Act 1999* is the national mechanism for biodiversity conservation and environment protection. This statute requires the environmental assessment of activities (e.g. agricultural activities such as cropping and groundwater extraction) that have a significant impact on flora or fauna species or ecological communities and that involve the Commonwealth. This statute also provides for the identification of key threatening processes, such as land clearance.

The important statutes for NSW cotton growers are the *Environmental Planning and Assessment Act 1979, Threatened Species Conservation (TSC) Act 1995, Fisheries Management Act 1994* and *Native Vegetation Conservation Act 1997*. Together, these statutes mean that large-scale developments in rural areas of NSW generally require development consent and sometimes the development of environmental or species impact statements (the latter are for threatened species, populations or ecological communities). The Catchment Management Boards (CMBs) established under the NSW *Catchment Management Act 1989* are also relevant to cotton growers since their *Catchment Blueprints* specify targets and priority actions for biodiversity, vegetation management, water management, salinity and soils to be implemented over the next 10 years by farmers and government agencies.

The relevant statutes in Queensland are the *Integrated Planning Act 1997, Vegetation Management Act 1999* and *Land Act 1994*. Under these statutes, a development application accompanied by a property vegetation management plan needs to be lodged to clear native vegetation on freehold land, and a permit is required on leasehold land. Regional Vegetation Plans are being developed, and 24 are out for public comment. A moratorium on receipt of new clearing applications has been declared by the Queensland government, with a proposal to phase out broad scale clearing by December 2006.

In its report, *Integrated Catchment management in the Murray-Darling Basin 2001-2010: Delivering a Sustainable Future*, the Murray Darling Basin Commission foreshadowed its plan to set targets for catchment health (water quality, water sharing, riverine ecosystem health and terrestrial biodiversity) throughout the Basin over the next 10 years to guide decision making and monitor progress towards agreed environmental outcomes. One of the main problems hampering the development of catchment biodiversity targets is the lack of information on thresholds of land use intensification that lead to sharp declines in ecosystem function and species.

Biodiversity of Cotton Growing Regions

Most cotton is grown in the Darling Riverine Plain Ecoregion (DRPE, 74% of the 2001-02 crop area) or in the Brigalow Belt South Ecoregion (BBSE, 16%). Relatively small areas are grown in the Murray Darling Depression (Condobolin), Riverina (Lachlan) and Brigalow Belt North (Emerald) Ecoregions. Literature searches revealed varying amounts of information about different taxa in cotton growing areas. While general information about the distribution and abundance of mammals and birds was available for the DRPE and BBSE, the only targeted biodiversity surveys in cotton growing areas were studies (in progress) at Emerald and Moree. Large parts of both ecoregions have never been systematically surveyed for any taxa. Where targeted surveys of the BBSE were conducted for the Regional Forest Agreement process in NSW, surveys were largely conducted on public land. Vegetation mapping by DIPNR in NSW includes sites on private land, but coverage has been limited by landholder cooperation since the introduction of SEPP 46 in 1996. Thus the biodiversity of farmland remains poorly understood.

Mammals

Extinctions of mammal species in Australia account for one-third of the world's mammal extinctions in recent times, and many surviving species have suffered major range contractions. Of the 70 species of mammal recorded in the DRPE, eight species are extinct in the region and 11 species are listed as Vulnerable or Endangered under the *TSC Act 1995*. Of

interest to cotton growing is the occurrence of platypus (*Ornithorhynchus anatinus*) in the DRPE, a species thought to be affected by river regulation. Many mammals declined in eastern Australian cotton growing areas long before cotton was established, though some species continue to decline today. The possible decline of half the bat species in cotton growing areas is a concern, especially given interest in their provision of natural pest control.

Birds

There is reasonable information about the distribution and abundance of birds in cotton growing areas and for wetlands downstream of irrigation areas, but there is little specific information about the linkages between birds and cotton growing. One study of the waterbirds on cotton farm storages in the Lower Gwydir in 1999-2001, recorded 45 species of waterbird (mainly ducks, geese and swans), including four species listed under the *TSC Act 1995*. Waterbirds were more numerous on storages featuring trees in the water, beds of aquatic vegetation, shallow areas and islands, suggesting that irrigation infrastructure can be designed to accommodate waterbirds. The extent of natural wetlands and number of waterbirds in end-of-valley wetlands has declined with the development of irrigation areas and diversion of water for irrigated agriculture.

The habitat loss and fragmentation of woodlands associated with cropping has led to the decline of formerly common woodland birds species in the Wheat-Sheep Zone of south-eastern Australia. In order to safeguard declining woodland birds, it has been suggested that vegetation clearance should cease in areas when 50% of the landscape has been cleared, and that no vegetation communities should be cleared below 30% of their pre-European extent or below an area of 1% of the region (whichever is the larger). Bird surveys of travelling stock routes and reserves in the Gunnedah, Narrabri and Moree Shires have shown that river red gum (*Eucalyptus camaldulensis*) and poplar box (*E. populnea*) woodlands support the largest number of unique and declining woodland bird species, respectively, and that structurally complex woodlands support higher numbers of bird species.

Reptiles, Amphibians and Fish

Reptiles may have survived the past 215 years better than mammals and birds but some species are known to be threatened and the status of most is uncertain. Reptiles in decline in the BBSE in Queensland are mostly associated with grassy habitats and riverine areas that have been used extensively for cotton growing and other crops.

Despite a number of amphibian surveys in cotton growing areas in eastern Australia, little is known of their status. Only two species are listed as rare or threatened in the main ecoregions in Queensland in which cotton is grown but several species may have declined on the Darling Downs over the past 25 years. Current studies of frog ecology in rice growing areas and rice fields in southern NSW provide a model for biodiversity investigations in intensive farming districts.

Native fish populations have declined to 10% of their pre-European levels in the Murray-Darling Basin, and the trend could continue if the impacts of river flow regulation, aquatic habitat degradation, reduced water quality and barriers to fish passage are not reversed. The greatest reductions in fish diversity have occurred in the most heavily regulated rivers.

Invertebrates

While invertebrates predominate over vertebrates in terms of species numbers and faunal biomass in all habitats, relatively little is known about terrestrial or aquatic invertebrates in cotton growing regions. Most of the information is due to agricultural research, given the importance of invertebrates to soil health, as pests and in natural pest control. The invertebrate community in cotton in eastern Australia is reasonably well characterised. However, the lack of centralised databases to capture the results of these invertebrate studies (unlike the case with vertebrate and vascular plants) means that the information is dispersed and difficult to access. Little is known about the impact of different land management practices on terrestrial or aquatic invertebrates, with the conspicuous exception of the impact of pesticides, tillage and crop rotations on invertebrates in cotton. While several studies have attempted to investigate the impact of agriculture on aquatic invertebrates, little conclusive information has resulted to date.

Microorganisms

Soil and aquatic microbes are important components of agricultural and natural ecosystems and are involved in nutrient cycling and the breakdown and decomposition of organic matter, waste products and pesticide residues. Information about soil microbes is largely derived from agricultural research. Although the relationships between soil microorganisms and land management have the potential to affect crop productivity and soil health, little is known. Knowledge of the microbiology of Australian inland waters is worse still despite the fact that aquatic microbes are potential indicators of river health. The catchment blueprints (NSW), strategic catchment plans (Qld) and investigations into river health have largely ignored aquatic microorganisms, to date.

Vascular plants

Unlike the situation with invertebrates and microbes, detailed information about the distribution of vascular (higher) plants is available in electronic databases in both NSW and Qld. In NSW, vegetation mapping by the NSW Department of Infrastructure, Planning and Natural Resources of the main cotton catchments proceeds, but so far is only available for the Upper Namoi and Hillston cotton growing areas and part of the Lachlan Shire (the headwaters of the catchments of the Gwydir and Macintyre Rivers have also been completed). Systematic terrestrial vegetation surveys have been completed for the BBSE and most of the DRPE. Surveys have attempted to focus on both public and private land, but access to private land has often been denied. The Darling River south of Bourke has been identified as a region lacking flora information. In Queensland, the BBSE has been subdivided and mapped into 20 provinces and 163 regional ecosystems, and regional ecosystems have been assigned a conservation status (‘Endangered’, ‘Of concern’ or ‘Of no concern’) based on percent remaining, condition and presence of threatening processes. However, there have been no systematic flora surveys over much of the BBE (this is changing for public land areas), so flora knowledge is poor in many areas.

Vegetation clearance has not been random across the landscape, with vegetation communities on more productive soils experiencing proportionally higher clearing. Most remnant vegetation communities in cotton landscapes have been heavily cleared and are poorly represented in protected areas. Ecological communities relevant to cotton growers and listed as threatened under NSW or federal legislation include brigalow (*Acacia harpophylla*),

bluegrass (*Dichanthium sericeum*) dominant grasslands, grassy white box (*Eucalyptus albens*) woodlands, white box-yellow box (*E. melliodora*) woodland, carbeen (*E. tessellaris*) open forest, and native vegetation on cracking clay soils of the Liverpool Plains. Most regional ecosystems on alluvial soils in cotton growing regions in Queensland are likely to be 'Endangered' or 'Of concern' under the *Vegetation Management Regulation 2000*. Remnant vegetation in cotton areas is likely to contain a high proportion of threatened species.

Non-vascular plants and aquatic vegetation

Non-vascular (lower) plants include algae, lichens and bryophytes (mosses, liverworts and hornworts). Algae can be the basis of food chains in river systems and the cryptogamic soil crusts consisting of these plants in arid ecosystems are important for soil conservation, nitrogen fixation and microbial habitat. Non-vascular plants have not been the subject of systematic regional surveys. In NSW, non-vascular plants are not included in the major vegetation assessments and background reports prepared for different ecoregions. The *NSW State of the Environment 2000 Report* stated that there is virtually no information on the status of and threats to terrestrial and aquatic non-vascular plants. Similarly, the *State of the Environment Queensland 1999* report indicated that there is little information on the biodiversity status of non-vascular plants in Queensland.

Aquatic vegetation includes both floating and rooted vascular plants in addition to algae and non-vascular plants. Aquatic vegetation has been surveyed in several studies of water quality and stream condition in cotton growing regions in eastern Australia although additional work is required on private land. While sampling of some streams and wetlands has been comprehensive, the effects of water quality and flow regimes on aquatic vegetation patterns are not well understood.

Exotic vegetation

Terrestrial and aquatic weeds are a major but understudied problem in cotton growing regions. Although the cotton industry has funded comprehensive research into the management of weeds in cotton fields (e.g. *WEEDpak: A Guide for Integrated Management of Weeds in Cotton*), the threat to dryland agriculture and native biodiversity from 'environmental' weeds such as lippia (*Phyla canescens*), water hyacinth (*Eichhornia crassipes*) and African boxthorn (*Lycium ferocissimum*) in floodplain, riparian and wetland habitats is significant. A coalition of interests including the Cotton RDC recently initiated research into lippia.

Key threatening processes

Both federal and NSW legislation allow for the listing of Key Threatening Processes (KTPs) that lead to a native species or ecological community becoming threatened. The most relevant to cotton growers are land clearance (including infilling of wetlands and drowning of native vegetation), alteration to the natural flow regimes of rivers, streams, floodplains and wetlands, removal of large woody debris from rivers, degradation of riparian vegetation along watercourses, introduction of fish to fresh waters outside their natural range, and the installation and operation of in-stream structures that modify flow.

The biodiversity of cotton fields

Cotton fields in eastern Australia probably contain a surprising amount of biodiversity but most of the biodiversity is likely to be cryptic. Several species of native bat, reptile and frog occur in and over cotton and many species of native bird frequent cotton farming systems, some of them resident in cotton or associated irrigation infrastructure. At least 450 species of invertebrate have been recorded in one cotton field in the Lower Namoi in recent years and the number and biomass of the soil biota is likely to be vast. However, an inventory of the biodiversity of Australian cotton fields has never been undertaken, and we were unable to find published or unpublished information about the diversity or biomass of several major groups of organisms in cotton soils.

Biodiversity and Ecosystem Services

Biodiversity underpins cotton production in many direct and indirect ways. Soil biota is directly responsible for productive soils. Beneficial invertebrates and perhaps vertebrates and the new biopesticides based on naturally occurring viral and fungal pathogens provide a natural pest control service which can be more profitable than reliance on conventional, broad-spectrum insecticides. Aquatic and soil microbes detoxify pesticide residues. Tall vegetation surrounding fields reduces pesticide drift as well as potentially enhancing yields and providing habitat for beneficial organisms. Wild Australian cottons are being investigated for genes that convey resistance to fungal pathogens.

In an indirect sense, the biodiversity of the surface and groundwater catchments upstream of irrigation districts is important in maintaining flows of surface and ground water for irrigation. Upstream vegetation helps control erosion and filters runoff and subsurface flow, maintaining water quality. Deep-rooted vegetation also maintains water tables at depth, preventing the release of stored salts which would otherwise render irrigation water saline or sodic. In turn, the maintenance of upstream ecosystems is dependent on a wide variety of animals and plants and their interactions in terms of pollination, seed dispersal, recruitment and so on. Similar ecological processes operate in cotton growing districts to maintain the native vegetation from whence beneficial organisms are sourced. Soil and aquatic microbes decompose wastes, remove nutrients and break down toxic residues, also helping to maintain soil and water quality.

Indirectly, the biodiversity of the entire biosphere is important in maintaining the gaseous composition of the atmosphere and providing equable climates for agricultural production in cotton growing areas. Similarly, with biotechnology, useful genes from anywhere can be potentially incorporated into cotton, making the world's entire complement of biodiversity valuable to the industry.

The benefits to humans from biodiversity and the ecological processes and conditions generated by it are called 'ecosystem services'. Ecosystem services include the cleansing, recycling and renewal of land and water, the production of raw materials and foodstuffs, and cultural and aesthetic benefits. At least 11 ecosystem services are important for cotton production in eastern Australia:

1. natural pest control;
2. maintenance of soil health;
3. water filtration;

4. prevention of soil erosion;
5. waste absorption and breakdown;
6. maintenance of river flows;
7. maintenance of groundwater levels and groundwater quality;
8. maintenance and regeneration of habitat;
9. maintenance and provision of genetic resources;
10. regulation of climate; and
11. provision of shade, shelter and barrier effect.

Ten of these ecosystem services are important inputs to cotton production and all eleven are affected by it. More ecosystem services are likely to be deleteriously impacted by cotton production than enhanced and most of the positive impacts of cotton production on ecosystem services are likely to be confined to on-farm biodiversity. Major challenges for the industry are to ensure that growers appreciate their dependence on ecosystem services and biodiversity, and manage cotton production to minimise negative impacts and increase positive impacts on both on and off-farm biodiversity.

The 11 most relevant ecosystem services to cotton production in eastern Australia are summarised below.

1. Natural pest control. Insecticide costs of between $800 and $1,000/ha have not been uncommon in irrigated cotton production. Natural pest control can reduce grower reliance on broad-spectrum insecticides through the actions of generalist insect predators, parasitoids, pathogenic viruses and fungi, birds and bats. Despite improved gross margins from adoption of integrated pest management strategies in some areas, more research is required to understand the ecology, movement and manipulation of the common native predatory and parasitoid invertebrates in relation to cotton, other crops and native vegetation, and the impacts of different beneficial organisms on pest numbers. Little is known about the pest control role of vertebrates in cotton growing areas. Certain soil microbes might be instrumental in reducing disease pathogens in cotton soils.

2. Maintenance of soil health. The soil biota maintains healthy productive soils. While the cotton industry has invested in research on soil health, less effort has been directed at understanding the relationship between soil biota and soil health. Production could potentially be increased through better understanding of the response of functional groups of soil biota to management, and their role in maintaining productive cotton soils.

3. Prevention of soil erosion. Given the small rates of soil formation across most of Australia, soil erosion in croplands is unsustainable. Rates of soil erosion under cotton are up to 11 times the level that would have occurred under native vegetation. Soil erosion in cotton fields can be reduced by a variety of means. Prevention of soil erosion leads to the retention of nutrients and pesticide residues in-field, reducing fertiliser requirements and the pollution of irrigation channels and tailwater storages. In some cotton catchments, streambank erosion is responsible for a large proportion of the sediment load in rivers. Dense riparian, fringing and emergent vegetation is important in controlling streambank erosion.

4. Water filtration. Water filtration refers to the capture and removal of sediment and nutrients from overland, subsurface and in-stream flows. This ecosystem service is not particularly important to cotton production per se: the application of nutrient and sediment-laden irrigation water may be beneficial to production, and the closed nature of cotton irrigation systems means that little sediment or nutrient usually escapes. The ecosystem service is important, however, across the rest of the farm in containing sediment and water-borne nutrients from dryland crops and pastures prior to the movement of sediment and runoff beyond the boundaries or into water ways. A lattice work of well vegetated filter strips, water ways and riparian zones is useful in trapping sediment and nutrients, and beneficial for biodiversity.

5. Waste absorption and breakdown. Cotton attracts one of the highest rates of pesticide (insecticide, herbicide and defoliant) application of all broad-acre crops in Australia. Although many new pesticides have short residual activity, pesticides used in cotton have been detected in surface water monitoring over the past 5 years. Pesticide applications need to be matched to the ability of the natural terrestrial and aquatic decomposer chains of microbes to absorb and breakdown these waste products. The efficacy of the key microorganisms might also be manipulated. Recent advances in this area funded by the cotton industry include the use of artificial wetlands in irrigation tailwater systems to reduce pesticide residues, and the isolation of enzymes to detoxify chemical remaining in pesticide containers.

6. Maintenance of river flows. The collection and delivery of river water to cotton growing areas is critical to the industry. The production of adequate quantities of clean river water for use in irrigation is determined by the mosaic of upstream ecosystems and land and water uses. The quantity of river water extraction for irrigation and the reduction in flows and to end-of-valley wetlands is thought to have had a major impact on river health and aquatic biodiversity downstream. The scheduling of water releases for users and the changes to the variability of the natural flow regime is also thought to have affected downstream, aquatic ecosystems. The annual releases for irrigated cotton in summer are an example of how regulation can reduce natural variability, which in turn can benefit non-native organisms such as European carp (*Cyprinus carpio*) that are adapted to more uniform flow conditions.

7. Maintenance of groundwater levels and quality. Groundwater is an important source of irrigation water for some cotton growers. Like river flows, irrigators have little control over groundwater recharge but can affect both the quantity and quality of the local resource. Groundwater use is unsustainable in some regions, with depletion of the high yielding deep aquifers and impacts on shallow aquifers in some areas. The shallow aquifers may be important for groundwater dependent ecosystems such as poplar box (*Eucalyptus populnea*) woodlands on the floodplain of the Upper Namoi. Excessive extraction may also harm hypogeal ecosystems of subterranean aquatic organisms that occur in some aquifers. An isolated example has been reported of rapid drainage of water beneath an irrigated crop when deep aquifers are being pumped. This raises the possibility of the pollution of fresh water aquifers with nitrate, salts or pesticide residues leached from the surface soil.

8. Maintenance and regeneration of habitat. Habitat is the environment in which a plant or animal lives. The health and regeneration of habitat are affected by vegetation clearance and modification, changes in land use, agricultural practices, species extinctions, weeds

and feral animals. The value of different natural habitats for organisms beneficial to cotton production is poorly understood. The replacement of natural habitats by crops and sown pastures has been deleterious to many organisms and beneficial to others. Active management is required to retain and enhance the condition of habitat remnants on cotton farms, restore native vegetation, and maintain or enhance threatened species typical of these habitats.

9. Maintenance and provision of genetic resources. Genetic diversity is responsible for the subtle differences between individuals that allow populations and species to adapt to environmental change and evolve. Cotton breeders are interested in wild Australian cottons as sources of genes conveying resistance to the native fungal disease, Fusarium wilt. Genetic diversity is central to the planned, long-term success of biopesticides being developed against cotton pests because it should be difficult for pest populations to develop resistance to multiple genotypes of pathogenic viruses or fungi.

10. Regulation of climate. Stable predictable climatic patterns benefit farmers. The management of land and water resources throughout the biosphere is important in maintaining atmospheric and climatic stability because land, the oceans and biota act as sinks and sources of greenhouse gases. The mean surface air temperature over Australia increased by 0.8°C in the 20th century, and a further rise of between 0.4°C and 2.0°C is likely by 2030. It is possible that large irrigation areas in the semi-arid cotton growing regions of eastern Australia ameliorate day-time maxima and increase rainfall. On the other hand, the cotton industry may be contributing to Australia's escalating greenhouse gas emissions. Global warming and the increased atmospheric concentration of CO_2 pose various hazards and opportunities for the industry. A baseline assessment of greenhouse gas emissions in cotton based farming systems has recently commenced.

11. Provision of shade, shelter and barrier effect. Windbreaks can ameliorate the crop microclimate, conserve soil, protect plants from wind damage, increase crop water use efficiency, reduce spray drift and provide habitat for beneficial organisms. However, there has been little adoption of windbreak technology in the cotton industry. The maintenance or establishment of windbreaks across cotton farms could have benefits for biodiversity generally, as well as for production.

Conclusions

There are ethical, regulatory, political and economic reasons for the cotton industry to invest in biodiversity research and conservation. Like other sectors of the Australian economy, the industry needs to improve its management of the nation's land and water resources as part of its duty of care to sustainable resource management. The industry can choose to accept the challenge of sustainability and lead by example in achieving new standards of environmental performance. Given the pace of natural resource reforms, the cotton industry should maintain a watching brief on biodiversity regulations and the reform process. Politically, the industry may find it advantageous to lead debate in setting and achieving biodiversity and natural resource targets rather than having others' decisions imposed. The biodiversity that directly sustains the cotton industry is scarcely known in a scientific sense: better understanding of soil biota, beneficial organisms and aquatic microorganisms, in particular, is likely to lead to creative options for sustaining or increasing cotton profits.

The pace of natural resource reform in Australia is unlikely to let up. Despite the remarkable changes in societal values towards the environment in the past 10-15 years, the National Land and Water Resources Audit has established that the nation's natural resource base is in largely poor shape. Times of rapid change can present both hazards and opportunities. Primary producers can play a decisive role in achieving 'public good' outcomes for biodiversity and resource conservation in return for resource security and an acceptable mix of extension services, incentives and regulations to enable them to farm with confidence and flexibility.

Farmers are in a strong position to deliver significant environmental outcomes in a stewardship role negotiated with government and the community. The key factors operating in favour of primary producers are their: (1) ability to manage heterogeneously and at fine-scale; (2) continual presence on the land; (3) strong motivation to manage their own country; (4) practical skills and expertise in adaptive management; and (5) self-interest in sustaining land productivity assuming a conducive decision making environment.

Australia has several international obligations under the *United Nations Convention on Biological Diversity* in relation to biodiversity conservation in agricultural regions: these are (1) integrating the conservation and sustainable use of biodiversity; (2) establishing a system of protected areas and reserves under private ownership for biodiversity conservation in Australia's agricultural heartland; (3) ensuring biodiversity conservation on private land; and (4) providing financial and other incentives for biodiversity conservation on private land. Given the looming extinction spasm, these are key areas in which the cotton industry could work with governments and the community in order to achieve regional environmental and biodiversity conservation targets.

In water sharing, a cooperative approach with government is desirable to develop strategies for water releases to mimic the pre-development patterns of river flow in quantity and timing, delivering water entitlements for industry while ensuring adequate environmental flows. At farm scale, negotiations might focus on storages to increase their value as wetland habitat as well as the enhancement of natural wetlands or creation of artificial wetlands. As part of a negotiated package of environmental reforms with government, the voluntary implementation of private reserves on cotton farms might be traded in exchange for increased resource security. In the light of emerging concepts of environmental best practice in the grazing industries, the cotton industry might negotiate voluntary restrictions on intensive cropping development to a maximum limit of 30-50% of farm area, in return for high security access to water entitlements. The industry could also develop and put to government incentive schemes that target high priority biodiversity outcomes, maximise grower benefits and minimise costs to taxpayers.

Given the inadequate conservation in formal reserves of the regional ecosystems and species characteristic of the riparian and floodplain landforms occupied by the cotton industry, practical on-farm and area wide conservation initiatives include the protection and management in good condition or restoration of small representative areas of regional ecosystems. Area wide management groups of growers might adopt threatened species or threatened regional ecosystems as local flagships, and promote their conservation and restoration on farms and in the area generally.

Many Key Threatening Processes (KTPs) under federal and NSW legislation (such as land clearing, river diversions and regulation, and degradation of riparian vegetation) have been pivotal to agricultural development and are central to further industry expansion. The cotton

industry could instigate threat abatement planning for KTPs of particular relevance to growers, dissuade cotton developers from perpetuating KTPs and develop policies on offsets and compensation to be paid by developers who promulgate KTPs.

Other practical initiatives that cotton growers can take include:

1. retaining stubble to prevent soil erosion and increase the biomass and diversity of soil decomposer organisms;
2. protecting the riparian zone and retaining a lattice work of native vegetation across the whole farm to filter sediments and nutrients and pollutants from runoff using vegetated water ways, filter strips and riparian buffers;
3. planting woody native vegetation around cotton fields as windbreaks, spray drift barriers and habitat for beneficial organisms;
4. using integrated pest management strategies and an area wide pest management approach to reduce pesticide use; and
5. incorporating wetlands and fringing habitat in irrigation infrastructure such as water storages.

A potential vehicle for implementing environmental stewardship and biodiversity conservation is the cotton industry's Best Management Practice (BMP) program. A land and water module is in draft form. Weed management across the whole farm (as an example of duty of care) and protection of threatened species and threatened plant communities in good condition (as an example of voluntary environmental stewardship) are just two issues that might be targeted in further BMP modules. New BMP initiatives should encourage growers to benchmark and document improvements in on-farm biodiversity and management over time, perhaps using simple monitoring and photographic techniques.

Research gaps

There are many biodiversity research gaps for the cotton industry to address. Biodiversity research priorities fall into three categories: (1) research that is likely to lead to profitable outcomes for growers as well as benefit biodiversity; (2) research to clarify the industry's duty of care with respect to possible negative impacts on biodiversity; and (3) 'public good' research to characterise the biodiversity of cotton growing areas and promote biodiversity conservation, particularly on-farm.

Biodiversity research is likely to yield profitable outcomes for growers in four key areas:

1. Beneficial organisms and their role in integrated pest management (IPM). Further research on the diversity, ecology and management of beneficial invertebrates and vertebrates is required to deliver greater certainty to growers adopting IPM strategies, and assist with the design of farm and irrigation development, crop layout and rotations, vegetation plans and revegetation.
2. Soil biology and function. The soil biota underpins productive healthy soils, but the vast majority of the organisms in cotton soils and their functional utility are unknown. Better understanding of the role of soil organisms in contributing to soil fertility, pest control, disease suppression and pesticide bioremediation would be useful.
3. Climate regulation. Recent studies suggest that extensive irrigation developments are capable of ameliorating the regional climate. Moreover, the greenhouse effect could

impact on the industry through changes to catchment water yields and recharge rates, and regional rainfall and temperature regimes, through the fertilizer effect of a CO_2 enriched atmosphere, and through possible changes in the carbon-nitrogen ratio of cotton, with flow-on effects to pest and beneficial insects.

4. Windbreaks and revegetation. Windbreaks offer several potential benefits to growers: increased yields through in-field climatic amelioration, as barriers to spray drift, and as habitat for beneficial organisms. Given the lack of adoption of windbreaks on cotton farms, further research might investigate the impact of different windbreak designs on cotton profits and the best species to use in revegetation for multiple benefits.

Further research is required to clarify the cotton industry's environmental impact in five key areas:

1. Impact of pesticide residues on non-target organisms and ecosystems. The health of remnant eucalypt trees in some cotton growing areas is poor, and traces of pesticides used in cotton have also been detected in water monitoring programs in recent years. The industry has already invested in drift minimisation strategies and the impact of pesticides on non-target organisms. Further efforts aimed at quantifying the impact of pesticides on non-target aquatic and terrestrial ecosystems are warranted, in order to judge the levels and types of pesticide movement off field that are acceptable. Further investment in pesticide bioremediation would be valuable, particularly for the treatment of pesticide residues in water and soils (both in cotton farming systems and off site) and chemical containers.
2. Impact of groundwater extraction on groundwater dependent ecosystems. In groundwater zones where deep and shallow aquifers are connected, extraction for irrigation from deep aquifers can lead to the lowering of water levels in shallow aquifers. This potentially imperils terrestrial ecosystems dependent on the shallow groundwater as well as hypogeal ecosystems of groundwater-dwelling organisms. Research is required to ensure that groundwater use for irrigated cotton is not damaging groundwater dependent ecosystems.
3. Pollutants in deep drainage beneath cotton fields. The industry has recently invested in deep drainage research in order to understand the phenomenon. One aim should be to determine the quantity and destination of contaminants (salts, nitrate and pesticide residues) that drain below cotton fields and develop mitigation strategies.
4. Maintenance of natural river flows. The two major concerns about the impact of the cotton industry on river flows are the quantity of water diverted from inland rivers to irrigation and the reduction in river flow variability in order to meet irrigators' seasonal requirements for water. The challenge for the industry is to understand how these impacts have affected downstream wetland health in each catchment and to develop water sharing strategies with government that allow river flows to more closely mimic the natural regime.
5. Greenhouse emissions. The loss of native vegetation to cotton industry development since 1990 and ongoing farming practices may have contributed to Australia's escalating greenhouse gas emissions. The industry has begun to benchmark its emissions, and needs to develop mitigation strategies with the ultimate aim of demonstrating greenhouse neutrality.

Whether cotton levy payers should continue to fund 'public good' research into biodiversity conservation where the research application exceeds the duty of care, is a decision for the industry. However, a striking conclusion of this report is our ignorance of the vast majority of the biodiversity that sustains cotton production, and of the biodiversity on private land in the agricultural heartlands of inland NSW and Queensland. The industry has the opportunity to encourage establishment of terrestrial and aquatic biodiversity survey and monitoring sites on farms in all cotton growing regions. The industry occupies a disproportionate amount of the most productive and valuable ecosystems, both in an agricultural and biodiversity sense, in inland eastern Australia. Due to the combination of fertile soils and water, the remnant ecosystems in these areas are likely hotspots for native biodiversity, but they are also the least represented in the protected area network. These ecosystems and their characteristic flora and fauna are also among the most impacted and threatened. The cotton industry could thus contribute to knowledge of biodiversity of these threatened ecosystems, and to determining thresholds to land use intensification for biodiversity conservation in agricultural regions.

Neither terrestrial nor aquatic invertebrates, lower plants or microorganisms have been systematically surveyed in the two principal ecoregions in which cotton is grown. Given that most of the research on invertebrates and microbes in Australia is conducted by the agricultural industries and supporting agencies, the cotton industry might want to collaborate with other agricultural agencies in establishing databases in which distributional data for invertebrates and microbes are systematically collated.