6.0 Conclusions

In this chapter, we conclude our review of biodiversity literature pertinent to the Australian cotton industry. We first summarise the economic, regulatory, political and ethical reasons why the cotton industry needs to maintain a biodiversity focus in its activities. We outline a series of practical opportunities for the industry in terms of growers embracing an active on-farm and area-wide role in biodiversity conservation. Finally, we identify biodiversity research gaps and opportunities under three headings: (1) the opportunities for profitable research on biodiversity, where investment is likely to lead to favourable returns for the industry; (2) gaps in understanding where the industry needs to clarify and, if necessary, minimise its on and off-farm environmental impact, in recognition of its environmental duty of care; and (3) research in biodiversity conservation where the industry or groups of growers may judge they have special responsibilities or opportunities to conserve native biodiversity in an environmental stewardship role.

6.1 Why the Cotton Industry Needs to Know About Biodiversity

The cotton industry needs to invest in understanding and managing biodiversity for ethical, regulatory, political and economic reasons. All sectors of Australian society need to accept responsibility to continuously improve their management of the nation's land and water resources, as part of a duty of care to sustainable resource management (Industry Commission 1998). Cotton may prefer to be in the vanguard of reform and lead by example in the development and achievement of improved standards of environmental performance. Cotton Australia's Best Management Practice program (Williams and Williams 2002) is an excellent example of the industry's performance in this regard.

The pace of natural resource reform in Australia has quickened in recent years. Government regulations and consultative processes in natural resource administration are evolving quickly as state and federal governments attempt to reverse the environmental degradation identified in recent state of the environment and natural resource audit reports without unduly hampering agriculture and regional development. The cotton industry needs to maintain a watching brief on biodiversity regulations and reforms because these have, and will likely continue to have, major consequences for growers' routine activities as well as industry development and expansion. Politically, the cotton industry may find it more advantageous to be pro-actively involved in developing new regulatory approaches and processes and to lead debate in setting and achieving biodiversity and natural resource reform targets, than reacting to regulators' demands. Finally, biodiversity underpins productive ecosystems and productive ecosystems sustain biodiversity. However, there remain large knowledge gaps about (1) the relationships between soil biota and soil health and the management of soil biota, (2) the ecology and management of beneficial organisms responsible for natural pest control, and (3) the microbes responsible for pesticide bioremediation and the practical implementation of this technology. Further advances in these areas could deliver significant boosts to production or reductions in variable input and remediation costs.

6.1.1 The importance of biodiversity to sustaining cotton production

The preceding chapter demonstrates that biodiversity directly sustains cotton production. Soil biota are responsible for productive soils. Productive soils are chemically fertile, structurally sound and have a high diversity and biomass of soil organisms. Soil organisms decompose organic matter, cycle nutrients, break down wastes and pesticide residues, suppress pathogens,

and aerate soil and maintain its permeability. Beneficial invertebrates on the soil surface and in the canopy and surrounding vegetation, and perhaps bats and birds, naturally control pests and can significantly improve cotton gross margins. Naturally occurring viruses, bacteria and fungi are being employed in new generation 'soft' biopesticides. Aquatic microbes in tailwater and irrigation reticulation systems detoxify pesticide residues in runoff and may reduce yield depressions when tailwater is re-applied. Their utility can be magnified through the appropriate design of tailwater systems incorporating aquatic vegetation for phytoremediation. Tall remnant and planted vegetation surrounding fields reduces pesticide drift and dust blown from fields, in addition to potentially increasing yields through increased water use efficiency and productivity via the windbreak effect and providing habitat for beneficials. Wild native cottons are being investigated as genetic sources of disease resistance, and useful genes from potentially any organism may be incorporated into new varieties using gene technology in the future.

Indirectly, biodiversity at much broader scales than the cotton farm is responsible for key ecosystem services to cotton. Off-farm activities affect the area-wide populations of pests and beneficial organisms that impact greatly on cotton yields and costs. Management throughout the surface and groundwater catchment affect the delivery of irrigation water of an acceptable quality. Land, water and energy use decisions globally affect regional climates conducive to agricultural production in eastern Australia. Uninformed decisions about the management of ecosystems and their biodiversity remote from cotton farms could have major impacts on growers' livelihoods in future.

6.1.2 Mounting social and regulatory pressure

The pace of natural resource reform in Australia is extraordinary. The past 15 years have witnessed the arrival and broad acceptance of the concepts of 'ecologically sustainable development', 'biodiversity' and greenhouse-induced 'climate change'; the rise and, in some respects, the extraordinary success of landcare; the advent of threatened species and threatened plant community legislation in all jurisdictions; mounting financial allocations by governments to conservation and natural resource stewardship programs; and despite this, the National Land and Water Audit's largely bleak findings of the state of the nation's natural resources.

Australian governments have signalled their intent to continue natural resource reform given evidence of the degraded condition and deteriorating trend of most of the natural resource base. The Murray-Darling Basin Ministerial Council is committed to improving the health of rivers within the Basin and to introducing its integrated catchment management framework of targets for salinity, water quality and biodiversity over the next decade. An environmentally sustainable Australia is the nation's primary research and development priority. It seems unlikely, therefore, that the pressure for environmental reform will wane.

6.2 Practical Opportunities

The severity of the impacts of land and water development to date, and the pending consequences for native biodiversity, provide a significant opportunity for farmers, as natural resource stewards (Morton et al. 1995), to negotiate with governments and the wider community in relation to improved outcomes for biodiversity.

6.2.1 Farmers as land stewards

There are several key characteristics of primary producers that place them in a powerful position to negotiate 'public good' outcomes for biodiversity conservation: these are farmers' (1) fine-scale and heterogeneous management of the environment; (2) constant managerial presence on the land; (3) strong motivation to manage their own country; (4) practical skills and expertise in adaptive ecosystem management; and (5) self-interest in sustaining land productivity in the long-term (i.e. across generations), assuming a conducive decision making environment.

Farmers tend to manage land and water resources on a finer scale and in a much more heterogeneous way than the natural disturbance regimes and physical gradients in soils and landforms that shape landscapes. The basic units of farm management are fields or paddocks, roads, laneways, storages and channels generally covering areas of less than 1 ha up to 200 ha in cropping zones. A floodplain that might have been dominated by one vegetation type prior to farming may be subdivided into a number of farms, many fields and paddocks and a wide range of different vegetation states, both semi-natural and exotic (sown crops and pastures). Provided a whole of landscape approach is taken and some of the semi-natural areas are managed primarily for conservation while other areas are managed for native biodiversity to some degree, it is feasible for such a landscape to cater for much of the pre-existing native biodiversity (Barrett et al. 1994, McNeely et al. 1996). This is possible because the large changes in vegetation state and disturbance regime at a fine scale resulting from human management permit a greater range of habitats and therefore opportunities for a wider range of species, than the pre-existing vegetation. There are invariably some species, particularly large vertebrates and disturbance-sensitive plants that require areas of original habitat and disturbance regimes; the protected area network must cater for this subset of species (Barrett et al. 1994). However, much of the original biota may be catered for in a variegated landscape under largely private ownership with an appropriate range of resource use intensities and management goals (McIntyre et al. 2002).

Being present on the land on a continuing basis affords primary producers the opportunity to manage with a high degree of control and to specific objectives. In theory, at least, fires can be controlled before they burn large areas, pests can be managed before they reach uncontrollable numbers, habitats can be managed and modified to achieve specific objectives, environmental performance indicators can be monitored on a continuing basis, and both reactive and proactive management can be undertaken in a timely fashion.

A feature of Australian primary producers is their love of the land, the sense of place they derive from it, and the sense of fulfilment they gain from managing it well, despite the large and accelerating social and environmental changes occurring around them. Society could count on a dedicated workforce of resource stewards if it were to engage primary producers to manage biodiversity. Farmers are experts in managing ecosystems and many are both practical and flexible, choosing pragmatic, effective, low-cost options to achieve management goals. Society could therefore also count on a skilled, efficient workforce.

Assuming a conducive decision making environment that allowed primary producers to manage for the long term out of self-interest, few would deliberately degrade their property and the value of its natural capital. On the contrary it would be in their interest to sustain and enhance the natural resource base and its economic value.

Thus there are good reasons why governments, on behalf of society, should be interested in employing primary producers as resource stewards to conserve native biodiversity on farms. Given the predicted numbers of extinctions and Australia's international obligations to conserve biodiversity in agricultural regions, governments should be keen to engage farmers, negotiate schemes to conserve biodiversity in agricultural districts, and provide resources (e.g. extension programs) to facilitate positive change.

6.2.2 Stewardship opportunities for cotton growers

There are many opportunities for the cotton industry to take on a leadership role in implementing sustainable agriculture in Australia and developing and meeting environmental targets negotiated with government and the community.

Meeting Australia's international obligations

Among the requirements placed on Contracting Parties to the *United Nations Convention on Biological Diversity*, Australia is required to (Anon. 1992a):

- *integrate conservation and sustainable use of biodiversity, as far as possible and appropriate;*
- *establish and manage a system of protected areas and other special areas (e.g. reserves under private ownership) for biodiversity conservation;*
- *ensure biodiversity conservation in situ by taking appropriate measures across all tenures, not just within protected areas and other special conservation areas; and*
- *provide financial and other appropriate social and economic incentives for in situ biodiversity conservation.*

The cotton industry has the opportunity in partnership with government and the community to develop policies that better integrate the conservation and sustainable use of biodiversity in cotton growing districts. In the critical area of water resources management for the industry, a cooperative rather than a combative approach with government over water sharing across catchments at a State or whole of Basin scale could lead to plans for releases of water for irrigation to better mimic the pre-development patterns of river flows in quantity and timing, and ensure water entitlements while maintaining adequate wetland areas for bird breeding events and other biodiversity values across a catchment, state or the Murray Darling Basin as a whole. At farm scale, further research and development into the design of storages could greatly increase their value as wetland habitat with minimal costs to growers or society (Jarman and Montgomery 2001).

As part of a negotiated package of cooperative environmental reforms with government, the cotton industry might negotiate voluntary implementation of private reserves on cotton farms of, say, up to 10% of farm area, in return for increased resource security in relation to water entitlements. In the same spirit, and in the light of emerging concepts of environmental best-practice in the broad-acre grazing industries (McIntyre et al. 2002), the cotton industry might negotiate voluntary adoption of farm-scale thresholds of development, restricting intensive cropping development to just 30% of farm area in return for appropriate concessions from government.

There are many ways in which government could provide financial, economic and social incentives to cotton growers to conserve biodiversity. The industry is in the best position to develop proposals for incentives that maximise grower benefits, minimise the cost to

taxpayers, and best achieve priority biodiversity conservation targets. Economic incentives might include government subsidies or tax rebates for the use of 'soft' insecticides to enhance the efficacy of natural pest control, and an environmental tax on damaging broad-spectrum insecticides and the most hazardous herbicides.

Practical on-farm and area wide initiatives

In terms of the ten priority outcomes to be pursued between 2001-05 for the *National Strategy for the Conservation of Australia's Biological Diversity*, the cotton industry has the capacity to work with governments to help achieve most:

1. protect and restore native vegetation and terrestrial ecosystems;
2. protect and restore freshwater ecosystems;
3. control invasive species;
4. mitigate dryland salinity;
5. promote ecologically sustainable grazing (in so far as many cotton growers also run a grazing enterprise);
6. minimise impacts of climate change on biodiversity (through research into the greenhouse gas emissions from cotton farms and the development and extension of greenhouse friendly management practices); and
7. improve scientific knowledge and access to information (e.g. through encouragement of biodiversity research and survey on cotton farms).

Again, prior to negotiations with government and community, the industry might develop proposals that target the above and are easiest to deliver.

The protected area network of national parks and equivalent reserves is least extensive and least representative of pre-European habitats in the heavily cleared and altered wheat-sheep belt. This represents a large and important opportunity for the cotton industry to negotiate alternative futures to the pending mass extinctions in the agricultural heartlands of Australia. Cotton growers are also able to effectively deal with the threats to biodiversity posed by grazing livestock and feral animals and weeds on their land. Thus, the industry is in a key position to enter into partnerships with government and the community to better manage the major threats to biodiversity in Australia's agricultural heartland where the extinction spasm is predicted to be most severe, in return for negotiated concessions in matters of importance such as resource security.

With regards the main threats to native biodiversity of wetlands, flowing waters and groundwater dependent ecosystems, growers have many opportunities to improve the situation for native biodiversity in cotton growing areas with appropriate R&D and industry concessions from government. Opportunities include:

- improving the water use efficiency of irrigated enterprises with a focus on minimising deep drainage and tailwater runoff, and reducing water diversions from rivers and groundwater;
- working with government to reschedule water delivery at times and in quantities that better mimic the natural flow regime;

- maintaining healthy, weed-free, well vegetated riparian buffers on streams and rivers to filter runoff from adjacent dryland crops and pastures;
- implementing wetland-friendly grazing regimes;
- continuing to reduce or eliminate the use of environmentally hazardous pesticides that are detected in off-farm water quality monitoring;
- monitoring and reducing nitrate leaching beneath crops and in runoff and making more efficient use of applied nitrogenous fertilisers; and
- managing weeds and feral animals across the whole farm to a high degree of commitment and efficacy.

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 therefore been heavily cleared and are poorly represented in protected areas. They are likely to contain a high proportion of threatened plant and animal species, as extinction processes in highly fragmented remnants take their toll. Again, this presents an opportunity for the cotton industry to be pro-active in the identification and conservation of endangered ecological communities and threatened species in cotton growing areas.

Threatened species and communities in cotton growing areas offer special flagship opportunities to provide area wide groups of growers with a united focus for environmental restoration, as well as providing a highly visible focus for the wider community to appreciate the industry's environmental commitment. The number of individuals of an endangered species in a district or the area of restored habitat of a threatened community are performance indicators that are readily communicated to and understood by the general public. The industry might help growers identify the endangered species and communities in each cotton catchment and work with area wide groups to develop recovery plans for each area. The floodplain and alluvial landforms occupied by the industry are among the most productive in eastern Australia and the most heavily modified, and the most heavily regulated and diverted rivers have suffered the greatest losses of native fish. Thus, there is no shortage of threatened species and communities to choose from. Flagships might be chosen on the basis of the species and ecosystems that have experienced the greatest changes. Charismatic and important umbrella aquatic flagships might include platypus (*Ornithorhynchus anatinus*), native fish communities and threatened waterbirds, as well as natural wetlands and riverine communities. The rare species and the grassland, shrubland and woodland communities typical of riparian, floodplain and alluvial areas in cotton growing districts are the obvious candidates for terrestrial flagships. Declining and threatened woodland birds are charismatic umbrella species on which to focus, particularly since their numbers remain higher in the northern temperate and subtropical woodlands of northern NSW and southern and central Queensland, where broad scale agricultural development is of more recent origin and the chances of maintaining viable populations are better, than in the south. However, there are other umbrella and charismatic species to choose from.

Perhaps the most sensitive issue for the cotton industry is that of Key Threatening Processes (KTPs), as some are pivotal to its continuing development. The KTPs of principal concern are:

- land clearance (including infilling of wetlands and drowning of native vegetation);
- alteration to the natural flow regimes of rivers, streams, floodplains and wetlands;
- degradation of riparian vegetation along watercourses; and
- installation and operation of in-stream structures that modify flow.

The Commonwealth and NSW legislation allows for the preparation of threat abatement plans to reduce the impact of KTPs. The industry might therefore consider developing threat abatement plans for each relevant KTP, either unilaterally or in cooperation with government and the community, in order to minimise the environmental impact of future cotton developments. It would be desirable if the industry were to encourage growers to avoid new developments that involved KTPs. However, where the environmental impacts of new developments involving KTPs are defensible, the industry should develop minimum standards for the implementation of environmental offsets or for compensation payable by the developers.

In terms of future, over-the-horizon environmental issues, KTPs provide a clear signal to all sectors of Australian business and society as to how damage to the nation's biodiversity has occurred. While the present focus of the environmental debate is to ensure that governments, industry and society now accept responsibility for putting their respective houses in order, there may come a day when all sectors are required to look retrospectively at the actions of their predecessors and begin to repair or pay for restoration of the damage. Thus, minimisation of KTPs now is likely to be in the industry's best long-term interests.

Incorporating environmental stewardship into the industry's BMP land and water module

The cotton industry's development and extension of an accredited and audited Best Management Practice (BMP) program in the area of pesticides and petro-chemical handling and occupational health and safety is laudable. The proposed development of a land and water BMP module offers the industry with multiple opportunities to promote growers' duty of care and environmental responsibility. Whether the BMP program should be restricted to issues relating to growers' duty of care to sustainable resource management (i.e. minimising negative environmental and social impacts, or externalities) or expanded to promote growers' environmental stewardship role (e.g. 'public-good' biodiversity conservation) is debatable. Two examples below, targeting environmental weeds and threatened species and ecological communities, indicate the difference between duty of care and environmental stewardship.

The cotton industry has been proactive with excellent research and extension in the area of weeds in cotton fields (e.g. *WEEDpak*). The industry might consider extending this commitment through the BMP program to tackle environmental weeds across the whole farm, for instance in floodplain, riparian and wetland habitats where weeds such as African boxthorn (*Lycium ferocissimum*), lippia (*Phyla canescens*) and water hyacinth (*Eichhornia crassipes*) pose a major threat to primary production as well as the ecological integrity of natural and semi-natural ecosystems. Progressive BMP levels of performance in environmental weed management might consist of the following: (1) identify species, assess and record the extent of the problem across the whole farm, and identify highest priority species to deal with; (2) tackle and eliminate highest priority weeds in areas where they are only now spreading to and are in low density; (3) contain and suppress high priority weeds in areas of dense infestation; and (4) reduce extent and abundance of high priority weeds to minimal levels. An analogous BMP and levels of performance for managing threatened species and communities as part of a whole farm conservation plan might consist of the following: (1) identify and record which threatened species or plant communities occur on the farm and where, and identify management priorities; (2) protect the most critical habitats and populations by managing threatening processes; (3) manage to increase the size of the

population or extent of the remnant plant community through habitat restoration; and (4) tackle successive conservation priorities so that representative areas of all threatened habitats are conserved on farm. These actions, though laudable in terms of biodiversity conservation, arguably exceed the duty of care of growers to minimise obvious negative impacts of their actions on others or on the wider environment.

Practical initiatives to conserve biodiversity in an ecosystem services framework

Further practical initiatives that growers can take that will increase biodiversity on their farms include:

1. Prevention of soil erosion - increasing in-field trash and retaining stubble to reduce or minimise soil erosion is also good for the biomass and diversity of decomposer organisms in the soil (Pimentel et al. 1992).
2. Water filtration - retention of a lattice work of filter strips and water ways permanently vegetated with dense native perennial vegetation across the dryland cropping and pasture zones of cotton farms, and encouragement of dense, weed-free riparian vegetation to control streambank erosion will have several benefits. The vegetation will not only filter runoff of sediment, nutrients and pollutants prior to them leaving the farm, but will contribute to on-farm biodiversity, as riparian habitats are naturally rich in species. The development of a whole-farm erosion and filtration strategy, employing native vegetation beyond the irrigated cotton section of the farm, could form part of the new land and water BMP module.
3. Maintenance and regeneration of habitat – management of representative areas of each remnant habitat type in good condition on the farm.
4. Provision of shade, shelter and barrier effect – planting of woody native vegetation around cotton fields as windbreaks, spray drift barriers and habitat for beneficial insects.

6.3 Gaps and Opportunities for Future Research

In addition to the practical initiatives that cotton growers can begin or continue to implement immediately (Section 6.2), there are many research gaps and opportunities that the cotton industry may wish to address. Biodiversity research priorities are arranged below in terms of three priorities:

1. research that is likely to lead to profitable outcomes for growers;
2. research that is designed to clarify the impact of cotton production on biodiversity where there is reason to believe that the industry could have a negative environmental impact; and
3. research to better characterise the biodiversity of cotton growing areas and help ensure its conservation in such areas.

6.3.1 Biodiversity research to benefit grower profits and the environment

There are four key areas of biodiversity research where a greater knowledge of the native biodiversity and ecosystem function of cotton production systems is likely to have production benefits for growers. These are (1) beneficial organisms and integrated pest management strategies, (2) soil biota, soil health, disease suppression and pesticide breakdown, (3) impact of irrigation zones on climate regulation, and (4) windbreak technology.

Beneficial insects

The reliance on natural pest control in some areas of the cotton industry is already being rewarded by higher gross margins for growers adopting integrated pest management (IPM) strategies reliant on native beneficial insects. As Johnson et al. (2000) pointed out, this has come about largely in ignorance of the ecology, movements and habitat preferences of the native invertebrates and vertebrates responsible for delivering pest control. Further research in these areas is likely to deliver greater certainty to growers adopting IPM strategies based on beneficial invertebrates, and assist with the design of crop rotations, crop layout, farm development and revegetation plans, and area-wide habitat management to support IPM. Bats are often abundant over cotton crops (L. Mackinnon and M. Dillon, pers. comm., 2003) and insectivorous woodland birds consume large quantities of insects. Further research would clarify the role of vertebrates in natural pest control in and adjacent to cotton fields.

Soil biota

Soil biota underpin soil health but most research into conservation farming methods has ignored the soil biota and concentrated on soil chemical and structural fertility. Better understanding of the role of the different components of the soil biota in contributing to soil fertility might assist with the development of soil management strategies to improve soil health and production. Research might also focus on the soil biota that contribute to disease suppression in cotton soils, and that detoxify or are resistant to otherwise harmful pesticide residues.

Climate regulation

A recent report that large surface irrigation developments can ameliorate regional climate over tens of kilometres suggests that similar investigations may be warranted in the larger cotton growing catchments in eastern Australia. It is possible that cuts in water allocation may have as large or larger impact on local rainfall and temperature extremes than those predicted under global warming scenarios, due to the loss or reduction in size of extensive irrigation areas.

With the predicted changes in regional climate under global warming scenarios, research into the impact of changing temperature, rainfall regimes and a CO_2 enriched atmosphere on irrigated cotton production is also warranted, given the potential impacts on river flows, salinity levels, evaporative demand, relative growth rates, foliar carbon to nitrogen ratios, and pest and beneficial insect populations.

Windbreak technology

Windbreaks offer several potential benefits to cotton growers: increased yields through climatic amelioration and less physical damage downwind, as barriers to chemical spray drift, and as habitat for beneficial organisms. Given these benefits, the widespread adoption of windbreaks in other parts of the world, and the promotion of tree planting on cotton farms by the cotton industry, the lack of adoption of windbreak technology on Australian cotton farms is curious. Research might find out why most growers have not planted windbreaks around cotton fields. CSIRO Land & Water has developed high level skills in modelling the micro-meteorological impact of windbreaks. Additional research might focus on the likely impact of

windbreaks on irrigated and dryland cotton production in different regions in eastern Australia.

Assuming growers are receptive to the idea of establishing habitat dominated by perennial plants for beneficial organisms near their cotton fields, research might also focus on the plant species most suitable for planting in different cotton regions as habitat for beneficials?

6.3.2 Biodiversity research to clarify the industry's environmental duty of care

There are several areas of potential environmental impact that the cotton industry needs to address. These are (1) the impact of chemical drift on non-target organisms and ecosystems; (2) the impact of groundwater extraction on groundwater dependent ecosystems; (3) the impact of deep drainage beneath cotton fields on the quality of groundwater resources or river water quality in the case of lateral rather vertical drainage; and (4) the impact of water scheduling on river health.

Impact of agricultural chemical drift on non-target organisms and ecosystems

The health of trees and woody vegetation in cotton growing districts is often poor, notably the health of poplar box and river red gum woodland in NSW cotton growing districts (Sections 5.3.7 and 5.3.8). Given the groundwater-dependent nature of these ecosystems and the close association of dieback of these trees with irrigated farming in some areas, the possibility remains that groundwater extraction or drift of pesticides is responsible for poor tree health. The cotton industry has recognised the problem and is currently funding research into the impact of defoliant drift on native trees. Drift of herbicides and broad-spectrum insecticides may also be problematic, and requires evaluation. Although broad-spectrum insecticides are unlikely to affect tree health directly, the area-wide impact of broad-spectrum insecticides in cotton growing areas is such that the abundance of beneficial predatory and parasitoid insects could be disrupted in nearby woodland remnants, allowing pest insects such as gall-formers largely protected from occasional episodes of drift to outbreak. Gall-forming insects are abundant on poplar box in poor health in intensive farming districts in the Upper Namoi catchment (V. Banks, pers. comm. 2003).

The health of trees is perhaps just the visible evidence of a spray drift problem. It could be that many ecosystem components are affected by small quantities of chemical drift, but little research on impacts on non-target organisms has been done to date. Some of the promising avenues of research recently funded by the cotton industry concern the isolation of enzymes for detoxifying the pesticides that remain in chemical containers after use, and the development of artificial wetlands to assist with the bioremediation of pesticide residues in tailwater. Further efforts aimed at quantifying the impact of pesticide drift on non-target aquatic and terrestrial ecosystems is warranted in order to judge the levels and types of pesticide application and movement off field that are acceptable, and the requirements for enhancing the bioremediation capacity of terrestrial and aquatic ecosystems in cotton districts.

Impact of groundwater extraction on groundwater dependent ecosystems and neighbours

In groundwater zones where shallow and deep aquifers are connected, extraction from deep aquifers for irrigation can lead to the lowering of water levels in shallow aquifers. This can potentially imperil groundwater dependent ecosystems such as groundwater dependent trees and hypogeal ecosystems of groundwater dwelling organisms. Neighbouring users of shallow groundwater for livestock and domestic purposes are also affected. Simply blaming the groundwater licensing authority for breaching its duty of care may not be in the industry's long term interest. Research is required to identify the zones in which groundwater use is damaging groundwater dependent ecosystems and neighbouring users of the shallow aquifer resource, and to implement mitigation strategies.

Pollutants in deep drainage beneath cotton fields

The impact of deep drainage beneath cotton crops and the contamination of shallow groundwater or adjacent river water with contaminants such as salt, nitrate and pesticide residues is a major issue, with reported drainage figures of 0.5-3.0 ML/ha beneath irrigated cotton crops (Hood 2002). The cotton industry has recently commenced a large investment into deep drainage through the Australian Cotton CRC in partnership with the Murray-Darling Basin Commission. One aim should be to determine the quantity and destination of pollutants that drain below cotton fields and to develop mitigation strategies.

Maintenance of river flows

The two major concerns about the impact of the irrigated cotton industry on river flows are (1) the diversion of large proportions of annual flow to irrigation and the impacts on downstream riverine systems and the reductions in area of end-of-valley wetlands, and (2) the reduction in variability of river flows in order to meet mid-summer irrigation scheduling requirements. The challenge for the industry is to better understand how these impacts have affected downstream river and wetland health and develop strategies to reduce impacts. Research is required to understand the impacts of reduced flow on aquatic processes and biodiversity. Further investigations into strategies to reduce water use would also be beneficial.

Climate regulation

The loss of native vegetation during the development of the industry is likely to have involved a net increase in greenhouse gas emissions with the loss of perennial vegetation and the decline in soil organic matter in the transition from native vegetation to cotton fields. The magnitude of these emissions might be computed, and the industry should consider whether it is feasible to develop proposals to make up the difference over time in order to be able to claim greenhouse neutrality. This approach could be promoted via the industry's land and water BMP module.

6.3.3 Research to characterise the biodiversity of cotton areas

One of the striking conclusions of this report is our ignorance of the vast majority of the diversity and biomass of native species that sustain cotton production and, more generally, cotton farms and regions. Invertebrates have not been included in the major conservation

assessments of ecoregions in which cotton is grown, and neither terrestrial nor aquatic invertebrates have been systematically surveyed in these ecoregions. We know next to nothing about the microbes in cropping soils or inland waters with little or no research on aquatic fungi, viruses or aquatic protozoans. Even for taxa such as higher plants and vertebrates where systematic surveys have been undertaken of regions in which cotton is grown, little information has been collected on private land in some areas, so there are knowledge gaps about the regional ecosystems and species that characterised the riparian, floodplain, alluvial and wetland landforms and habitats now occupied by cotton farms. The industry could contribute in large measure to knowledge of biodiversity if it were to encourage the establishment of terrestrial and aquatic biodiversity survey and monitoring sites on cotton farms. Given the extent of development of these ecosystems in the agricultural heartland of Australia, the biodiversity agencies might be persuaded that surveys in cotton districts warrant a higher priority than elsewhere.

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 major declines in the integrity of ecosystems and species loss. Cotton growers might therefore wish to encourage biodiversity surveys in their districts in order to elucidate what biodiversity exists in these areas, how much occurs in different habitats on farms, and to identify putative thresholds of land use intensification in terms of species retention and loss.

Given the absence of database facilities for storing distributional data about lower plants, invertebrates, lower plants and microbes in NSW and Queensland, the cotton industry in association with other agricultural industries might consider supporting the biodiversity agencies in developing appropriate databases. At the present time, applied research funded by the research and development corporations and agricultural and natural resource agencies are likely to be the primary sources of information deposited in such databases.

Modelling might also be done on the threatened plant communities and species in cotton growing areas to determine whether climate change is a threatening process for species of interest to the industry.