

4.0 The Biodiversity, Threatened Species and Communities, and Key Threatening Processes in Cotton Growing Regions in Eastern Australia

4.1 Introduction

This Chapter provides an overview of the range of species or higher order taxa present in cotton growing areas in inland eastern Australia, details species and communities which are listed as threatened and the processes threatening biodiversity in those areas, and makes specific references to cotton growing where appropriate. No attempt is made to provide exhaustive species lists, and it was impossible to include every reference relating to each species.

Information on research relating to the main biological taxa found in cotton growing areas was obtained by:

- searches of electronic databases;
- general internet searches and focused searches of government department sites, government authorities (e.g. Natural Heritage Trust, Australian Research Council) and university sites;
- checking reference lists in relevant reports;
- contacting people likely to have details of relevant information; and
- a search of the Cotton Research and Development Corporation library.

We attempted to obtain data on all biological taxa in all of the major cotton growing areas. The data found varied enormously in its coverage leading to the presentation of information from a variety of scales (e.g. from ecoregion to paddock scale). Comprehensive reports were found for two key ecoregions, the Brigalow Belt South Ecoregion (BBSE) (although a lot of Queensland data relates to the whole Brigalow Belt Ecoregion [BBE]) and the Darling Riverine Plains Ecoregion (DRPE). Relatively small areas of cotton are also grown in the Murray Darling Depression Ecoregion and the Riverina Ecoregion. Many references have been found relating to these areas, and have been included in the tables for each taxon.

Lists of recorded (vascular plant) flora and (vertebrate) fauna species for nominated areas (e.g. a key cotton growing area) can be purchased through government departments in each state. For general information on the status of flora and fauna taxa, threatening processes, threatened ecosystems, physical resources (e.g. soil and water) and agricultural activity on an ecoregion basis, the National Land and Water Resources Audit's (NLWRA) Atlas and Data Library is an ever increasing source of useful information (<http://www.nlwra.gov.au>). The Atlas and Data Library provide easy access to large volumes of information in a variety of useful formats. The NLWRA has also been responsible for the recent production of the *Australian Terrestrial Biodiversity Assessment 2002* (Sattler et al. 2002). In Queensland, Biodiversity Planning Assessments (BPAs) have been completed for most sub-regions of the BBE. BPAs combine a variety of natural resource data to assess biodiversity values at a landscape scale, and are useful in identifying areas of biodiversity significance. Maps produced through this process can be used by decision makers (e.g. when assessing development applications). Updated information on BPAs can be obtained from: http://www.epa.qld.gov.au/cgi-bin/w3-msql/environment/environment/conservation/msqlwelcome.html?page=bio_planning.html

The NSW and Queensland state governments hold large quantities of natural resource information and have many current projects that will be useful in future biodiversity research. A NSW example is Soil Landscape Mapping (<http://www.dlwc.nsw.gov.au/care/soil/ssu/nswssu.htm>). This project merges soil and landscape information useful in understanding linkages between natural processes. To date, mapping has only been completed for the far north west and part of the Upper Namoi cotton growing areas. In Queensland, NR&M's Queensland Landuse Mapping Project (<http://www.nrm.qld.gov.au/science/lump>) aims to map land uses such as cotton growing. This will provide base information useful for analysing other datasets such as regional ecosystem mapping. Mapping completed so far of interest to cotton growing include the Fitzroy, Upper Condamine and Balonne catchments. State government department websites provide directories outlining available datasets.

4.2 Ecoregions and Cotton Growing

Figure 4.1 shows Thackway and Cresswell's (1995) map of ecoregions in relation to the main cotton growing areas in inland eastern Australia. It should be noted that cotton crops comprise a small percentage of the areas shaded in Fig. 4.1. Table 4.1 shows the ecoregions in which the main eastern Australian cotton growing areas occur. Cotton is principally grown in five ecoregions: the 'Murray Darling Depression' (Tandou and Hillston), 'Riverina' (Lachlan), 'Darling Riverine Plain' (Macquarie, Lower Namoi, Gwydir, Bourke, Macintyre, St George/Dirranbandi), 'Brigalow Belt South' (Upper Namoi, Darling Downs and Dawson/Callide) and 'Brigalow Belt North' (Emerald). Most of the cotton acreage in eastern Australia is located on the Darling Riverine Plain (74% of the 2001/02 crop) and Brigalow Belt South (16%). Biodiversity information about these ecoregions is pertinent to the corresponding cotton growing area(s), even if the information comes from outside an irrigation or farming district.

Ecoregions in both states have been divided into smaller units based on landscape scale variations in climate, soils and landform. In NSW these smaller units are known as provinces, described by Morgan and Terrey (1992). In Queensland they are referred to as sub-regions (they were formerly known as provinces). Province boundaries have not yet been mapped in NSW, but sub-region boundaries have been mapped in Queensland.

4.3 Mammals

Extinctions of mammal species in Australia account for around one third of the world's mammal extinctions in recent times (Maxwell et al. 1996). Eight percent of marsupial species and subspecies and 12% of Australian rodent species present at the time of European settlement are extinct (Lee 1995, Maxwell et al. 1996). In addition to extinctions, many remaining species have experienced major reductions in their range and abundance. Historical causes of declines are discussed in a number of references (e.g. Morton 1990, Dickman et al. 1993, Short and Smith 1994). Dickman et al. (1993) described mammal declines in the Western Division of NSW (including part of the Darling Riverine Plains Ecoregion) and identified predation by feral cats (*Felis catus*) and introduced red foxes (*Vulpes vulpes*), overgrazing by livestock and rabbits (*Oryctolagus cuniculus*), vegetation clearance, hunting and trapping, and altered fire regimes as the main causes. McFarland et al. (1999) investigated threatening processes for vertebrate fauna in the BBSE in Queensland: habitat loss or degradation is the main known or suspected threatening process for remaining priority species.

Table 4.1. Main cotton growing areas in eastern Australia and the IBRA ecoregions in which they occur (Anon. 2002; Thackway & Cresswell 1995). Cotton acreages were down by 50% of maximum planted area in some of the main cotton growing areas in the Darling Riverine Plains, Brigalow Belt South and Brigalow Belt North in 2001/02, due to low prices.

Cotton Growing Area	IBRA Ecoregion	Cotton Acreage 2001/02 (ha)
Southern NSW (Lachlan)	Riverina Subregion: Lachlan	– *
Southern NSW (Hillston)	Murray Darling Depression Subregion: Darling Depression	15 400
Southern NSW (Tandou)	Darling Riverine Plains Subregion: Menindee	6000
Macquarie	Darling Riverine Plains Subregion: Bogan-Macquarie	53 000
Lower Namoi Valley	Darling Riverine Plains Subregion: Castlereagh- Barwon Brigalow Belt South Subregion: Pilliga Outwash	53 100
Upper Namoi Valley	Brigalow Belt South Subregion: Liverpool Plains	13 300
Gwydir	Darling Riverine Plains Subregion: Castlereagh- Barwon Brigalow Belt South Subregion: Northern Outwash	91 000
Bourke	Darling Riverine Plains Subregion: Castlereagh- Barwon	12 000
Macintyre	Darling Riverine Plains Subregion: Castlereagh- Barwon	63 500
Darling Downs	Brigalow Belt South Subregion: Eastern Darling Downs	44 000
St George-Dirranbandi	Darling Riverine Plains Subregion: Warrambool- Moonie	25 000
Dawson-Callide (Theodore-Biloela)	Brigalow Belt South Subregion: Banana-Auburn Ranges	5900
Central Highlands (Emerald)	Brigalow Belt North Subregion: Isaac-Comet Downs	21 800

- The Hillston acreage includes that of the Lachlan.

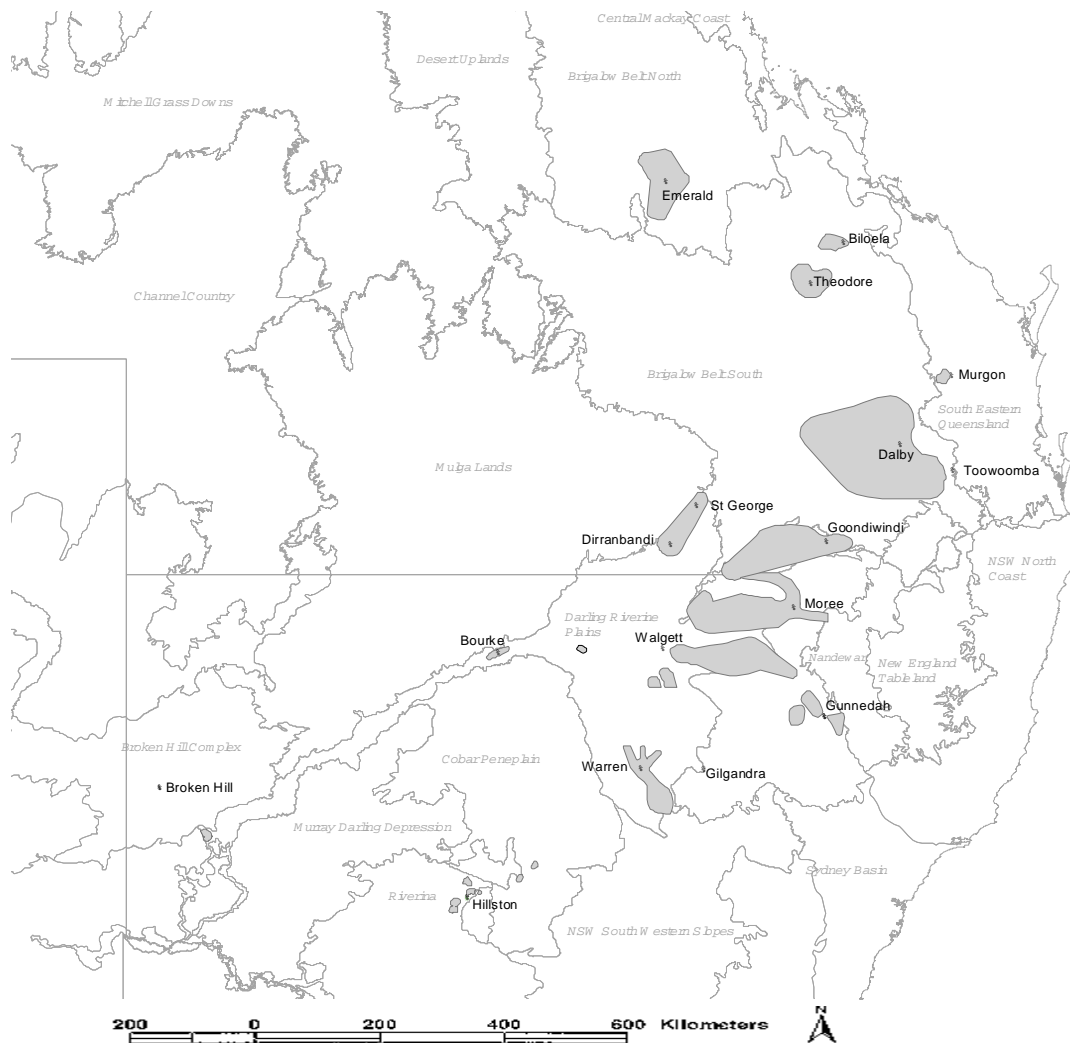


Fig. 4.1. Boundaries of the main areas within which cotton is grown in eastern Australia, and the IBRA ecoregions (Anon. 2002c)

While bats appear to have survived European settlement better than other mammal groups with no species having become extinct, human activities such as habitat clearance and roost disturbance threaten bat populations. Almost half of all bat species are considered to be of conservation concern, and many species are listed as threatened under national and state legislation (Duncan et al. 1999). The potential role of mammals such as insectivorous bats in natural pest control is discussed in Section 5.3.1, but research on bat dietary patterns is limited, and it is not currently possible to quantify their beneficial role.

4.3.1 New South Wales

Lists of all mammalian fauna reported in the BBSE and DRPE are contained in NSW NPWS (2002a) and Kearle et al. (2002), respectively. Fourteen mammal species have become extinct in the BBSE. During fauna surveys of the BBSE conducted as part of the Western Regional Assessments in the past 5 years, 29 and 17 mammal species were detected, including the delicate mouse (*Pseudomys delicatulus*), a new species for NSW (NSW NPWS 2002c). When combined with records from other surveys, a total of 18 species of mammal known from the BBSE are listed as threatened under the *TSC Act 1995* (Appendix 3, Table A). A summary of existing fauna knowledge for the BBSE prior to the Western Regional Assessments is contained in NSW NPWS (2000a).

Seventy species of mammal have been recorded in the DRPE, including 17 bat species (Kearle et al. 2002). Floodplains important for cotton growing in the northern part of the ecoregion, have been the focus of a number of fauna surveys cited in the *Darling Riverine Plains Bioregion Background Report* (Kearle et al. 2002). Table 4.2 contains details of these and other relevant references. Eleven species are listed under the *TSC Act 1995*, two as Endangered and nine as Vulnerable (Appendix 3, Table A). A further eight species of mammal once occurred across the ecoregion, but have since become extinct. No threatened populations of mammals have been recorded in the DRPE, but populations of swamp wallaby (*Wallabia bicolor*), common brushtail possum (*Trichosurus vulpecula*), koala (*Phascolarctos cinereus*) and an unidentified *Petaurus* glider found in the northern floodplains, are considered to be regionally significant (Kearle et al. 2002). Of interest to cotton growing is the presence of platypus (*Ornithorhynchus anatinus*) in the DRPE. This species is considered to be of conservation concern in the Western Division of NSW, and is affected by river regulation activities.

4.3.2 Queensland

Until recently there had been no systematic survey of fauna across the BBE of Queensland, and large parts of the ecoregion remained unsurveyed (Young et al. 1999). However, the results of a systematic fauna survey have just been published as part of an assessment of forest values within the Western Queensland Hardwood Region (EPAQLD 2003). This survey work was largely restricted to forests and woodlands of conservation reserves, leasehold lands and state forests, so a gap remains in the availability of survey data from freehold forests, woodlands and grasslands (Teresa Eyre, pers. comm. 2003).

McFarland et al. (1999) examined the fauna of the BBSE (including mammals), through a combination of analysis of historical records and a preliminary systematic survey. Table 4.2 lists relevant mammal surveys in all cotton growing areas. McFarland et al. (1999) found some 104 native mammal species had been recorded in the BBSE. Under Queensland's *Nature Conservation (Wildlife) Regulation 1994*, at least two mammal species once found in the BBE are presumed to be extinct, three are listed as Endangered, three as Vulnerable and four as Rare (Appendix 3, Table B). Strategic plans for the catchments in which cotton is

grown give some idea of threatened species that occur within these catchments (Appendix 3, Table B), but lists within these plans are generally given as examples rather than exhaustive lists. Young et al. (1999) cited Gordon (1978) as containing information on localised extinctions and range reductions of Queensland mammal species. More recently, McFarland et al. (1999) analysed the extent of changes in priority vertebrate species from pre 1975 levels to 1999, and examined vertebrate species distributions and associations in relation to spatial (land tenure) and environmental (regional ecosystems or broad vegetation groups) variables. In regard to species distributions, McFarland et al. (1999) found that vertebrate fauna in this ecoregion occupy broad habitat niches, evidenced by 80% of species using more than one broad vegetation group.

Table 4.2. Mammal surveys and other research undertaken in cotton growing areas of NSW and Queensland

Reference	Location of Survey	Type of Information
Briggs (1996)	Cropped lake beds in DRPE, NSW	Targeted fauna surveys.
Coles (1995)	Cypress/ironbark forests of north west NSW	Bat survey
Crossman and Reimer (1986)	Taroom Shire, Qld	Mammal survey as part of broader fauna survey
Date and Paull (1999)	Cypress/ironbark forests of north west NSW	Vertebrate fauna survey
Dick and Andrew (1993)	Culgoa and Birrie River floodplains, NSW	Mammal survey as part of broader fauna survey
EPA QLD (2003)	Western Queensland Hardwood Region, BBE	Mammal survey as part of broader fauna survey for assessment of forest condition
Eyre et al. (2001)	Forested land south central Qld	Mammal survey as part of broader fauna survey and assessment of vegetation condition exercise
Finlayson (1931, 1934)	Dawson & Fitzroy Valleys, Qld	Mammal records from 1930s
Kerle (1998)	Trangie Agricultural Research Centre, NSW	Faunal biodiversity survey
Kirkpatrick (1966)	Warwick district, Qld	Mammal survey records
Kirkpatrick and Amos (1977)	Millmerran Shire, Qld	Mammal survey records
McFarland et al. (1999)	BBSE, Qld	Mammal surveys and compilation of historical data, and assessment of conservation status of each species
NSW NPWS (1993)	Macquarie Marshes, NSW	Details of mammal records
NSW NPWS (2000a, 2002c)	BBSE, NSW	Detailed fauna surveys focussed on forested areas, including an analysis of distribution patterns and associations with different vegetation communities
Sattler et al. (2002)	National Land & Water Resources Audit	Analysis of status of mammals on ecoregion basis
Smith (1993)	Narran River floodplain, NSW	Mammal survey as part of broader fauna survey
Smith et al. (1998)	Northern floodplains of NSW	Mammal survey as part of broader fauna survey
Spark (1998 unpubl.)	Gwydir Watercourse, NSW	Mammal survey as part of broader fauna survey
Bill Wilkinson, NR&M, Qld	Emerald Irrigation Area, Qld	Recording, analysing and mapping of biodiversity in cotton areas of Emerald Irrigation Area
Wilson et al. (1993)	Macquarie Marshes, NSW	Bat observations

4.4 Birds

Few research projects have focussed on birds on cotton farms or birds in cotton growing areas (Peter Jarman, pers. comm. 2002), although bird surveys and research projects have included cotton growing areas as part of a broader region. Therefore while there is a reasonable level of information on the distribution of bird species over broad areas in which cotton is grown and for downstream wetlands, there is little information on linkages between birds and cotton growing activities (e.g. the role of birds in natural pest control or the off-site impacts of broad-spectrum insecticides on the dietary requirements of insectivorous (insect eating) birds). Table 4.3 provides details of bird research in cotton growing areas.

The Action Plan for Australian Birds 2000 (Garnett and Crowley 2000) included Recovery Outlines for all bird species listed as threatened under the federal *Environment Protection and Biodiversity Conservation Act 1999*, and information on species of conservation concern. These outlines provide references relevant to specific species. In addition to records available from databases held by the State Government departments, data is also available from the Birds Australia Database (atlas@birdsaustralia.com.au).

4.4.1 New South Wales

Jarman and Montgomery (2001) studied waterbirds on irrigation storages in the Lower Gwydir Valley, NSW. On-farm wetlands on nine irrigated cotton farms were surveyed between September 1999 and July 2001, to investigate use by waterbirds. Over 45 species of waterbirds were detected, dominated by ducks, geese and swans. All of the species detected had been recorded on natural wetlands in the Lower Gwydir, and several of the rare species known from natural wetlands in the region were not detected. Four waterbird species listed under the NSW *TSC Act 1995* were recorded: magpie goose (*Anseranas semipalmata*), blue-billed duck (*Oxyura australis*), freckled duck (*Stictonetta naevosa*) and Australasian bittern (*Botaurus poiciloptilus*). These species were infrequent and in low numbers. Variations in the numbers of waterbird species observed over the 2-year period suggested that the waterbirds were highly mobile, using on-farm wetlands as part of a wider network of wetlands in the region.

Jarman and Montgomery (2001) found waterbirds were significantly more numerous on wetlands featuring trees in the water, beds of aquatic vegetation and shallow areas that periodically formed mud islands. Very few waterbirds bred in the on-farm wetlands. The authors suggested that if their results were extrapolated to the whole Lower Gwydir Valley, on-farm wetlands probably only support 1-5% of the Valley's waterbird community, and support less than 0.5% of the number of nesting waterbirds. They suggested that if on-farm wetlands were modified to make them more suitable for use by birds, these wetlands could contribute substantially more to the conservation of bird species in cotton growing areas.

The long-term impacts of changes in river flow volumes on nesting waterbirds downstream of a cotton growing area were investigated for the Macquarie River (Kingsford and Thomas 1995, Kingsford and Johnson 1999). Dam building and water diversions on the Macquarie River led to significant reductions in the area of land flooded in the Macquarie Marshes (by at least 40-50% between 1944 and 1993). The number and density of waterbirds found in the Macquarie Marshes declined during this time. In the Gwydir River catchment, a 70% reduction in flows has led to reduced flooding of the Gwydir floodplain wetlands (the

Lower Gwydir and Gingham watercourses), with flooding of the core wetland area of 20 000 ha being reduced from a natural level of 17% of the time to 5% of the time (Kingsford 2000).

The NSW National Parks and Wildlife Service commissioned a review of threatened and declining birds in the NSW sheep-wheat belt (SWB) (Reid 1999). Included in the study were most of the major cotton growing areas of NSW. The study focused on birds of dryland habitats (wetlands and waterbirds were largely excluded), and identified bird species that fell into two categories, 'Threatened' (including Endangered and Vulnerable birds listed under federal and state legislation), and 'Declining' (based on a review of the literature, expert opinion and the results of regional avifauna surveys). Table 4.3 provides a list of regional avifauna surveys in cotton growing areas. Some 38 species of landbird found in the SWB were listed as 'Threatened', and 20 species as 'Declining' (Appendix 4, Table B). Two species were identified as being of 'Special Concern': black-chinned honeyeater (*Melithreptus gularis*) and white-browed treecreeper (*Climacteris affinis*).

Reid (1999) observed the following in relation to the characteristics of Threatened and Declining species, and threatening processes:

- insectivores predominated amongst the 20 Declining species;
- fewer insectivores were represented in the Threatened species list;
- threatened species are typically of low abundance or restricted range;
- Declining species have large Australian ranges, but in the SWB, have experienced dwindling populations and are at risk of local extinction across extensive parts of the landscape;
- selective clearance of certain types of vegetation on fertile soils is probably the ultimate cause of the declining numbers of Threatened and Declining species;
- in a highly fragmented landscape (such as the SWB), the interaction between drought and fragmentation is likely to be a threat for birds with poor dispersal capabilities; and
- the ongoing decline of the habitat quality of the remaining vegetation further threatens bird numbers.

These findings may be useful to cotton growers planning vegetation conservation and restoration works.

Reid conducted a further investigation into the habitat and threats to birds in the SWB (Reid 2000). This second study was a modelling exercise looking at the links between vegetation cover and bird atlas data. Reid (2000) made several recommendations for landscape reconstruction to halt the declines documented in the original study. In areas where vegetation clearance for agricultural development continues, Reid (2000) recommended the following stopping rules:

Stopping Rule 1. Habitat rarity principle: defined vegetation communities should not be cleared below 1% of the total landscape area (e.g. 3 km²). This applies whether the community is locally rare or if it has become rare through past clearance.

Stopping Rule 2. Habitat conservation and ecosystem function principle: defined vegetation communities should not be cleared below 30% of their original extent in the landscape.

Stopping Rule 3. Landscape and regional conservation principle: in toto, all broad-acre clearance should cease if 50% or more of the landscape is cleared.

In landscapes where broad-acre land clearance is no longer an issue, Reid (2000) recommended that landscape reconstruction efforts focus on:

- prevention of the deterioration in habitat quality of existing remnant vegetation, particularly remnants in the small to medium size class (15-250 ha);
- targeting revegetation works that incorporate existing remnant vegetation, including isolated old trees, rather than starting from scratch, and using these works to increase the size of small remnant vegetation patches; and
- natural regeneration processes that can be facilitated by activities such as fencing and changed management, rather than planting activities.

CSIRO conducted a bird survey on wooded travelling stock routes (TSRs) of the Northwest Slopes and Plains, including the Narrabri, Gunnedah and Moree areas. Some 32 TSRs were selected for the survey based on vegetation type, and 30 Stock Reserve sites dominated by a range of box species of eucalypts were also included in the survey. Many of the sites were in cotton growing areas and the woodland types surveyed occur on many cotton farms in these areas. Some of the findings of the survey included (Freudenberger and Drew 2001):

- there was no significant relationship between the number of bird species and TSR size;
- there was a strong relationship between the structural complexity of the tree-dominated vegetation types and the number of bird species observed;
- grasslands with a shrubby vegetation layer had the same average number of bird species as grasslands with no shrubs;
- each of the vegetation sites had bird species that were unique (i.e. not found in other vegetation types), with the river red gum (*Eucalyptus camaldulensis*) vegetation type supporting the highest number of unique species (this is important for cotton growers given that cotton is often grown on land that once supported red gums);
- different bird species were classified from 'tolerant' to 'rare and sensitive' to habitat modification based on the vegetation structural complexity and the frequency of occurrence;
- 6 Declining woodland bird species based on Reid (1999) were recorded on the TSRs, and the poplar box (*E. populnea*) routes had the highest number of Declining bird species; and
- 11 Declining woodland bird species were found in the Stock Reserves.

The study found that TSRs were of high conservation value for birds in these extensively cleared landscapes. The relatively large size, connectivity and vegetation diversity of the TSRs meant that they supported a more diverse range of bird species than extensively cleared and grazed areas.

Systematic bird surveys were part of the general fauna surveys undertaken in the BBSE (NSW NPWS 2000a, 2002c) and the DRPE (Kearle et al. 2002) funded by the NSW Biodiversity Strategy. Threatened bird species recorded in these ecoregions are shown in Appendix 4, Table A.

4.4.2 Queensland

As with mammals, there has been no systematic survey of birds across freehold forests, woodlands and grasslands of the Queensland portion of the BBE, and large parts of the

ecoregion remain unsurveyed (Young et al. 1999). On an ecoregion scale, rare and threatened birds of the BBE in Queensland listed under the *Nature Conservation (Wildlife) Regulation 1994* are detailed in Young et al. (1999) and are shown in Appendix 4, Table C (note that some of listed species would not be found in cotton growing areas). Bird surveys that have been undertaken within the BBE and including cotton growing areas, are shown in Table 4.3. A review of historical records and field surveys by McFarland et al. (1999) found that some 383 species of bird had been recorded in the BBSE in Queensland.

Table 4.3. Bird surveys and other research undertaken in cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Barnard and Barnard (1925)	Duaranga, Qld	Historical bird records
Brooker (1992)	Macquarie Marshes, NSW	List of waterbird species
CFNC (1988)	Chinchilla, Qld	Bird records of Chinchilla Field Naturalist Club
EPA QLD (2003)	Western Queensland Hardwood Region, BBE	Bird survey as part of broader fauna survey for assessment of forest condition
Eyre et al. (2001)	Forested land south central Qld	Bird survey as part of broader fauna survey and assessment of vegetation condition exercise.
Freudenberger and Drew (2001)	Travelling Stock Routes and Stock Reserves, northern NSW	Bird surveys and analysis of results
Heron (1973)	Goonoo State Forest, NSW	Bird survey
Jarman and Montgomery (2001)	Lower Gwydir Valley, NSW	Survey of waterbirds on water storages on cotton farms
Kingsford and Thomas (1995), Kingsford and Johnson (1999)	Macquarie Marshes, NSW	Report on waterbird numbers and diversity, and the impact of water diversions on nesting
Kirkpatrick (1968)	Warwick, Qld	Bird survey
Kirkpatrick and Amos (1977)	Millmerran, Qld	Bird survey
Longmore (1978)	Rockhampton, Qld	Bird survey
Major et al. (1998 unpubl.)	Forbes (sheep-wheat belt), NSW	Assessment of the value of remnant vegetation for birds in the sheep-wheat belt
McCosker (1997)	Gwydir Wetlands, NSW	List of birds recorded by NSW Bird Atlasers from 1982
McFarland et al. (1999)	BBSE, Qld	Bird surveys and compilation of historical data, and assessment of conservation status of each species
NSW NPWS (2000a, 2002c)	BBSE, NSW	Bird surveys and analysis of distribution and conservation status
Reid and Masters (no date, unpubl.)	Condobolin, NSW	Bird survey
Reid (1999, 2000)	Sheep-wheat belt of NSW	Review of regional avifauna studies and habitat modelling exercise
Sattler et al. (2002)	National Land & Water Resources Audit	Analysis of status of birds on ecoregion basis
Schrader (1987)	Parkes	Bird survey
Seddon and Briggs (no date, unpubl.)	Forbes, NSW	Bird survey
Smith et al. (1994)	Western Division of NSW (including part of the DRPE)	Assessment of bird species of conservation concern
Whitmore et al. (1983)	Meandarra, Qld	Annotated list of bird records
Young et al. (1999)	Entire BBE, Qld	Summary of data relating to threatened species

4.5 Reptiles

The Action Plan for Australian Reptiles (Cogger et al. 1993) suggested that reptiles have survived the last 200 years better than mammals and birds. However, there is no room for complacency given the conservation status of some species, and the lack of information on others which makes it impossible to know if they are declining. The life histories of fewer than ten species have been studied with any degree of completeness. There are some 765 reptile species in Australia, and of these, *The Action Plan for Australian Reptiles* recommended that 11 species be classified as Endangered, 41 species as Vulnerable and 152 species as Rare or Insufficiently Known status (Cogger et al. 1993). As part of this Plan, Recovery Outlines (covering distribution, habitat, threats, current research, management actions, references and gaps in the knowledge to effectively manage these species) have been prepared for Endangered and Vulnerable species.

Sadlier and Pressey (1994) identified reptiles of concern in the Western Division of NSW which includes some cotton growing areas, and listed conservation threats. These included loss of habitat from clearing, habitat modification from changed fire regimes (affecting important habitat characteristics such as the litter layer, fallen timber and perching sites), possible negative impacts of stock grazing associated with changes in the shrub and litter layers (though these are uncertain) and introduced predators. McFarland et al. (1999) investigated the distribution and conservation status of reptiles in the BBSE in Queensland. Patterns of decline in reptiles were linked to grassy habitats and riverine areas, sites used extensively for cotton growing. Details of reptile research in cotton growing areas are provided in Table 4.4.

4.5.1 New South Wales

Reptile species listed as threatened in the BBSE and the DRPE are shown in Appendix 5, Table A. Some 106 reptile species have been recorded in the BBSE in NSW (NSW NPWS 2002c). Reptiles of the BBSE had not been systematically surveyed prior to recent surveys as part of the NSW Western Regional Assessments of the BBSE (Stage 1 and 2) for the Resource and Conservation Assessment Council (NSW NPWS 2000a, 2002c). These surveys focussed on the distribution and abundance of vertebrates within forest and woodland vegetation on public land, particularly in areas where there were knowledge gaps.

In the Stage 1 assessment, 39 reptile species were detected including one threatened species, the pale-headed snake (*Hoplocephalus bitorquatus*) which is listed as Vulnerable under the NSW *TSC Act 1995* (NSW NPWS 2000a). This species was detected in the poplar box (*Eucalyptus populnea*) vegetation association which has been extensively cleared for cotton growing. In Stage 2, 61 species of reptiles were detected including the border thick-tailed gecko (*Underwoodisaurus sphyrurus*) listed as Vulnerable. The survey also recorded a new species for the state, the zig zag gecko (*Oedura rhombifer*). The five-clawed skink (*Anomalopus mackayi*), listed as Endangered, is also reported in the ecoregion (NSW NPWS 2002a). An analysis of reptile records on a mapsheet basis indicated that reptile species across the BBSE could be classified into three groups (NSW NPWS 2002c):

Group 1: this group of species is located on the western and north-western margins of the BBSE, including parts of the western and northern Pilliga State Forest. More frequently recorded species include several species more typical of inland NSW (e.g. *Egernia striolata*, *Cryptoblepharus carnabyi* and *Pseudonaja nuchalis*).

The occurrence of cracking clays (used extensively for cotton-growing) is associated with the more frequent records for *Denisonia devisi*. *Diplodactylus steindachneri* was the only species unique to this part of the BBSE.

- Group 2: this group covers the largest portion of the ecoregion, mainly relating to central parts of the ecoregion (from south of Dubbo through the foothills of Mt Kaputar north to Yetman). More frequently recorded species are typical of woodlands and open forests (e.g. *Diplodactylus vittatus*, *Ctenotus robustus*, *Varanus gouldii*, *Oedura robusta* and *Lerista bougainvilli*). Many species are unique to this group.
- Group 3: mainly restricted to mapsheets in the coolest and wettest parts of the ecoregion (e.g. the Liverpool Ranges and Mt Kaputar area).

Some 104 reptiles species are recorded as occurring in the DRPE, with 77 species recorded from the northern floodplains region where cotton is grown (Kearle et al. 2002). Kearle et al. (2002) cited a number of surveys that have focussed on floodplains and wetlands of relevance to cotton growing, and these are included in Table 4.4. Six of the reptile species are listed as threatened under the *TSC Act 1995*. A further 22 species are of conservation concern, based on work by Cogger et al. (1993) and Sadlier and Pressey (1994).

4.5.2 Queensland

Reptiles in the Queensland portion of the BBE had not been studied extensively until recently. The review by Covacevich et al. (1998) of reptile distribution and conservation status in the BBE is the most extensive study available and included field work and a review of museum and literature records. This review found that the maintenance of reptile biodiversity in the BBE appeared unlikely with further clearance of native vegetation. *Lerista allanae* is Critically Endangered and may be extinct, and *Aspidites ramsayi* is Vulnerable in the southern portion of the BBE. In the Emerald district, despite extensive clearing, a highly diverse array of small reptiles survives in a disturbed native pine (*Callitris*) forest (Covacevich et al. 1998). However, due to a paucity of data, the authors could not say whether or not small areas of native vegetation supporting high reptile species numbers are sustainable in the long term. Systematic reptile surveys as part of the recent assessment of forest condition in the Western Queensland Hardwood Region, have improved reptile knowledge.

Some 148 species of reptile have been recorded in the BBE in Queensland (Covacevich et al. 1998). The ranges of 13 of these species are virtually confined to the BBE, and for a further 14 species, the BBE forms a significant portion of their range (Covacevich et al. 1998). Appendix 5, Table B, lists 17 reptile species occurring in the BBE which are regarded as threatened under Queensland's *Nature Conservation (Wildlife) Regulation 1994* (Young et al. 1999).

Table 4.4. Reptile surveys and other research undertaken in cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Ayers et al. (in press)	Darling River Basin	Summary of reptile information
Briggs (1996)	Cropped lake beds in DRPE, NSW	Targeted reptile surveys which investigated the impacts of lake bed cropping
Bustard (1968)	Pilliga, NSW	Survey of reptiles in Meeriwindi State Forest (plus this author has published a number of articles on individual species)
Covacevich (1996), Covacevich et al. (1998)	BBE, Qld	Review of reptile records
Date and Paull (1999)	Cypress/ironbark forests of north west NSW	Reptile surveys as part of broader fauna surveys
Dick and Andrew (1993)	Culgoa and Birrie River floodplains, NSW	Reptile survey as part of broader fauna survey
EPA QLD (2003)	Western Queensland Hardwood Region, BBE	Reptile survey as part of broader fauna survey for assessment of forest condition
Eyre et al. (2001)	Forested land south central Qld	Reptile survey as part of broader fauna survey, and an analysis of the impacts of forest condition on reptiles found in surveyed areas
Kirkpatrick (1968)	Warwick district, Qld	Reptile survey
McFarland et al. (1999)	BBSE, Qld	Reptile surveys and compilation of historical data, and assessment of conservation status of each species
Metcalfe et al. (1994)	Macquarie Marshes, NSW	Reptile survey as part of broader fauna survey
NSW NPWS (2000a, 2002c)	Forested public land, BBSE	Reptile surveys as part of broader fauna surveys
Sadler and Pressey (1994)	Western Division of NSW (including part of the DRPE)	Compilation of data on distributions and habitat preferences of reptiles
Smith (1993)	Narran River floodplain, NSW	Reptile survey as part of broader fauna survey
Smith et al. (1998)	Northern floodplains of NSW	Reptile survey as part of broader fauna survey
Spark (1998 unpubl.)	Gwydir Watercourse, NSW	Reptile survey as part of broader fauna survey

4.6 Amphibians

There are more than 210 species of frogs in Australia, from 29 genera and 4 families (Campbell 1999). There have been very few frog population studies, and the habitats of frogs have rarely been described and are not well understood (Tyler 1997). This lack of information has made assessment of the conservation status and needs of Australian frogs difficult (Tyler 1997).

In *The Action Plan for Australian Frogs* (Tyler 1997), human activities with the potential to affect the viability of frog populations have been summarised as including (Tyler 1997):

1. *Insecticide use in agricultural and horticultural areas, particularly aerial spraying.*
2. *Land reclamation by drainage in wetland areas, resulting in loss of breeding sites.*
3. *The conversion of temporary ponds to dams for stock use resulting in the destruction of peripheral sheltering sites.*
4. *Introduction of the Mosquito Fish *Gambusia holbrooki* which preys on frog eggs and tadpoles.*

Other factors being considered as potentially implicated in frog declines include: global changes to air and water quality, increased exposure to ultra-violet radiation caused by depletion of the ozone layer, habitat modification, impacts of introduced species, pollution, hormonally active pesticide residues, pathogens and disease, acidification and climate change, including changes in climatic extremes.

Due to the use of agricultural chemicals in cotton growing, and perceptions that these may be related to declining frog numbers, it is worth discussing chemicals and their potential impacts in more detail. The most likely chemical pollutants to which amphibians are exposed are agricultural and pest management chemicals (Mann and Bidwell 1999). However, until the last decade, amphibians were not included in routine toxicological assessments, and most of the toxicological data available relates to overseas species whose genera are not well represented in Australia (Mann and Bidwell 1999). An excellent summary of the threats that agricultural chemicals pose to Australian frogs is contained in *Toxicological Issues for Amphibians in Australia* (Mann and Bidwell 1999) (Table 4.5), which reviews the literature. General amphibian research in cotton growing areas is outlined in Table 4.6.

Amphibians in irrigated rice and ‘natural’ habitats in rice growing areas are currently being studied by Skye Wassens, Johnstone Research Centre, Charles Sturt University. Irrigation and pesticide use make this study of interest to cotton production. Findings so far are as follows (Skye Wassens, pers. comm. 2003):

There are only five frog species that appear to be associated with rice in NSW: southern bell frog (Litoria raniformis), Peron’s treefrog (Litoria peronii), Tasmanian froglet (Lymnodynastes tasmaniensis), barking marsh frog (Lymnodynastes fletcheri), and Eastern sign-bearing froglet (Crinia parainsignifera). The later three can reach very high abundances in rice bays. While the southern bell frog and Peron’s treefrog have a more patchy distribution and tend to have fairly small populations (probably because of their more specialised habitat requirements).

As rice bays have pooled water across summer (late October to April), with good vegetation cover and high nutrient levels, they seem to make quite good breeding habitat for frogs. They also tend to have a lower abundance of predatory species like (Gambusia spp) and cray fish (Cherax spp) than irrigation canals where the water is more permanent. Tadpoles of all of these species have been found in rice bays. Tadpoles do not appear to be heavily affected by chemicals, possibly because most of the pesticides are applied to rice early in the season, before the bays have been colonised (and hence before breeding commences). Tadpole dieoffs as a result of copper sulfate application have been observed, but there appeared to be a temperature interaction, with die offs occurring in bays with higher water temperature.

There appears to be a relationship between fringing vegetation in bays and canals and the abundance of southern bell frogs: southern bell frogs tend to spend April-November in irrigation canals and storages and colonise rice bays by early December once there is a bit of vegetation cover in the bays. They also tend to over-winter under vegetation along the edges of canals. Regular burning along levees and removal vegetation from canals to assist flow appear to have negative impact on frog populations but this has not been tested.

This study may be useful in designing a future research project into the impacts of cotton production on frogs.

Table 4.5. Current Australian research into the impacts of agricultural chemicals on frogs (Source: Mann and Bidwell 1999)

Chemical	Does research indicate that this chemical could have deleterious effects on amphibians?	Australian studies
Insecticides – organochlorines	Yes	A number of overseas studies have investigated negative impacts of endosulfan on amphibians, including one review that rated endosulfan as second most acutely toxic chemical (of those tested to date) to amphibians, after heavy metal mercury. In only known Australian study, Broomhall (2002) found sublethal levels of endosulfan significantly adversely affected <i>Litoria citropa</i> tadpole survivorship, and water temperature variability at time of endosulfan exposure increased tadpoles' vulnerability to predation by odonates 24 days later
Insecticides – organophosphates	Yes	No Australian studies on potential risks to frogs.
Insecticides – carbamates	Yes	No Australian studies on potential risks to frogs.
Insecticides – pyrethroids	Yes	Only one study known (Millen 1995).
Herbicides and fungicides	Yes (but there are many different compounds in this category and none have been adequately studied)	Three published studies, including two on south-western Australian species with information on the toxicity of glyphosate formulations to tadpoles and adult frogs) (Johnson 1976, Bidwell and Gorrie 1995, Mann and Bidwell 1998 (in press), 2001).
Pesticide mixtures, and solvents, carriers and surfactants	Yes	No Australian studies on potential risks to frogs.
Fertilisers	Results are equivocal	One Australian study (Baker and Waights 1993, 1994) on two frog species, reported reduced feeding and weight loss in tadpoles exposed to sodium nitrate. These results are not consistent with findings of two overseas studies.
Salinity	Wide variation in salt tolerance reported in amphibians, but if water salinities reach greater than 25% of concentration of seawater, amphibians face an osmotic challenge.	One published (Tyler 1972) and three unpublished studies (Baumgarten 1991, Quincy 1991, Ferraro 1992) on Australian species.

4.6.1 New South Wales

Thirty species of frog have been recorded in the BBSE since 1972 (NSW NPWS 2002c). There are no records in the ecoregion for species listed under the *TSC Act 1995*.

Twenty-five frog species have been recorded in the DRPE. There are no records in the ecoregion for species listed under NSW's *TSC Act 1995*, but there has been no detailed assessment of the status of amphibians (Kearle et al. 2002). Several species of concern as defined by Sadler and Pressey (1994) may occur. There has been no assessment of the status of amphibian populations in the DRPE, but areas such as the Gingham Wetlands on the Gwydir River may be worthy of assessment (Kearle et al. 2002).

4.6.2 Queensland

In the Brigalow Belt Bioregion, two species of frog are listed as rare or threatened under the *Nature Conservation (Wildlife) Regulation 1994*: McDonald's frog (*Cophixalus mcdonaldi*) and rough frog (*Cyclorana verrucosa*) which are both listed as Rare (Young et al. 1999). The rough frog is known to occur in the Border Rivers Catchment (BRCMA 2001).

McFarland et al. (1999) found that there was insufficient information to identify changes in frog fauna, but that several species (e.g. *Adelotus brevis*, *Limnodynastes salmini*, *Cyclorana brevipes*, *C. verrucosa* and *Litoria lesueuri*) appeared to have experienced reduced distributions from pre-1975 levels to 1999, especially in the Darling Downs (an important cotton growing area).

4.7 Fish

The magnitude of the impact of human activities on freshwater fish biodiversity is evident from the recently released *Draft Native Fish Strategy for the Murray-Darling Basin, 2002-2012* (MDBMC 2002). The top four key threats to fish in the Basin were largely related to agricultural activities, particularly irrigated agriculture (Table 4.7). Native fish populations in the Murray-Darling Basin were estimated to be approximately 10% of their pre-European settlement levels, and could decline to 5% over the next 40-50 years if no action is taken. It has been estimated that returning environmental flows could help fish to recover to 25% of their pre-European settlement levels (MDBMC 2002).

Many research recommendations are made in the *Draft Native Fish Strategy for the Murray-Darling Basin, 2002-2012* (MDBMC 2002). Recommendations cover the areas of rehabilitating fish habitat, protecting fish habitat, managing riverine structures, controlling alien fish species, protecting threatened native fish species and managing fish translocation and stocking.

Table 4.6. Amphibian surveys and other research undertaken in cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Dick and Andrew (1993)	Culgoa and Birrie River floodplains	Amphibian survey as part of broader fauna survey
Eyre et al. (2001)	Forested land south central Qld	Amphibian survey as part of broader fauna survey
Henderson (1999 unpubl.)	Narran Lake Nature Reserve	Targeted amphibian survey
Marshall et al. (no date)	Condamine-Balonne Catchment, Qld	Work still in progress. Includes sampling of frog communities at each monitored site, investigating impacts of flow modification and land use
McCosker (1997)	Gwydir Wetlands, NSW	Annotated list of frogs recorded in wetlands
McFarland et al. (1999)	BBSE, Qld	Amphibian surveys and compilation of historical data, and assessment of conservation status of each species
Metcalf (1994)	Macquarie Marshes, NSW	Results of a preliminary frog survey
NSW NPWS (2000a, 2002c)	Forested public land, BBSE	Amphibian surveys as part of broader fauna surveys
Ian Oliver, DLWC, unpublished work	Pilliga Burren Junction area, NSW	Biodiversity field research, including frog surveys, of 43 native vegetation sites (<i>E. populnea</i> communities) in varying condition and in varying landscape contexts (e.g. adjacent to crops, adjacent to forests)
Sadler and Pressey (1994)	Western Division of NSW (including part of the DRPE)	Compilation of data on the distribution and habitat preferences of amphibians
Smith (1993)	Narran River floodplain	Amphibian survey as part of broader fauna survey
Smith et al. (1998)	Northern floodplains of NSW	Amphibian survey as part of broader fauna survey
Spark (1998 unpubl.)	Gwydir Watercourse	Amphibian survey as part of broader fauna survey
Straughan (1966 unpubl.)	Eastern Darling Downs, Qld	Investigation of frogs from the eastern Darling Downs

Table 4.7. Key threats to native fish management in the Murray-Darling Basin (MDBMC 2002).

Threat	Threatening process
Flow regulation	Loss of water to other uses, critical low flows, loss of flow variation, loss of flow seasonality, loss of low to medium flows
Habitat degradation	Damage to riparian zones, removal of in-stream habitats, sedimentation
Lowered water quality	Artificial changes in water temperature, increased nutrients, increased turbidity, salinity, pesticides and other contaminants
Barriers	Impediments to fish passage caused by dams, weirs, levees and culverts etc., and non-physical barriers such as increased velocities, reduced habitats, water quality and thermal pollution (changes in water temperature)

The impacts of river regulation on fish communities in the Murray-Darling Basin was studied by Gehrke et al. (1995), including detailed investigation in the Darling River. A significant trend of reduced species diversity was found in increasingly regulated river systems.

While river regulation and habitat degradation have been major factors in the decline of fish, pesticide impacts have also attracted a high level of attention. The behaviour of pesticides in the riverine environment and fish toxicology was investigated in detail by Bowmer et al. (1996). There are many gaps in the understanding of the impacts of pesticides in riverine systems (Bowmer et al. 1996): (1) some pesticides have not been subjected to detailed study; (2) factors such as vegetation affecting the bioavailability of pesticides and the complex pattern of intermittent spikes and chronic pesticide residue exposure, are not fully understood; (3) the effect of mixtures of different pesticides requires further work; and (4) improved understanding of food webs in cotton growing areas is required. Further work is required not just to understand the in-stream impacts, but also the impacts on higher order predators such as waterbirds. Table 4.8 gives details of general fish research in cotton growing areas.

4.7.1 New South Wales

The biodiversity background reports for the BBSE and DRPE cite Llewellyn (1983) and Harris and Gehrke (1997) as the main sources of fish survey information. Appendix 6, Table A, details the fish recorded in the two ecoregions from these reports, and provides details of their conservation status. Some fish recorded in an earlier survey were not found in a more recent survey, suggesting the possible decline of some species (NSW NPWS 2002a).

Recommendations for future work from the biodiversity background reports include:

- collation of existing information and an audit be undertaken regarding invertebrates, aquatic vertebrates, macroinvertebrates and fish within the BBS (NSW NPWS 2002a); and
- an assessment of information relating to fish, and the determination of priorities for further work in relation to terrestrial vertebrate conservation strategies (Kearle et al. 2002).

4.7.2 Queensland

Some 41 species of fish have been recorded in rivers that flow through cotton growing areas in the BBE (McFarland et al. 1999) (Appendix 6, Table B), though this number is inflated by species recorded from estuarine areas of the Fitzroy River. None of these species are listed under the *Nature Conservation (Wildlife Regulation) 1994*. Noble et al. (1996) and Noble (2001) provide information on several studies into the effects of land use on general river health including fish, in sub-catchments of the Fitzroy River where cotton is grown. Current and upcoming projects in the Condamine-Balonne and Border Rivers catchments (Table 4.8) will improve knowledge of the conservation status of fish in cotton growing areas, including efforts to understand how conservation status relates to land use and river regulation.

Table 4.8. Fish surveys and other research undertaken in cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Andrew Berghuis, DPI Fisheries, Bundaberg	Border Rivers Catchment, Qld and NSW	Current project monitoring use of fish ways by native fish in Macintyre River
Gehrke and Harris (2000)	Namoi, Gwydir, Lachlan, Macquarie and Darling Catchments, NSW	Fish surveys and analysis of species richness and fish communities
Gehrke et al. (1995)	Darling River, NSW	Analysis of fish communities in several rivers in Murray-Darling Basin, including Darling River
Harris and Gehrke (1997)	All cotton growing areas, NSW	Fish surveys
Harris and Silveira (1999)	All cotton growing areas, NSW	Analysis of river health using Index of Biotic Integrity (IBI) and data from NSW fish survey (Harris and Gehrke 1997)
Llewellyn (1983)	All cotton growing areas, NSW	Fish surveys
Tim Marsden, DPI Fisheries, Mackay	Fitzroy River Catchment, Qld	Current project monitoring pre and post installation of two fish ways
Marshall et al. (no date)	Condamine-Balonne Catchment, Qld	Work still in progress. Includes sampling of fish communities at each monitored site, investigating impacts of flow modification and land use
Noble et al. (1996), Noble (2001)	Fitzroy River Catchment, Qld	Several projects investigating health of the Fitzroy River and its tributaries, effects of land use, and providing summary data on a range of species including fish
Swales and Curran (1995 unpubl.)	Macquarie Marshes, NSW	Fish survey
Wager (1993)	Qld	Report on distribution and status of freshwater fish in Queensland
Glenn Wilson, Cooperative Centre for Freshwater Ecology, Goondiwindi	Border Rivers Catchment, Qld and NSW	Upcoming L&WA project investigating patch dynamics and connectivity ramifications for fish along Macintyre River

4.8 Terrestrial invertebrates

While invertebrate species may be the predominant fauna in every habitat both in terms of number of species and in total biomass, knowledge of invertebrates is poor and only a small percentage of invertebrates has been catalogued (EPAQLD 1999). In regard to agricultural systems generally and cotton specifically, many projects have included invertebrates as one of the studied parameters. However, as this information is not accessible via centralised electronic databases as with vertebrates and vascular plants, it is not readily useable in biodiversity assessments. Consequently, our understanding of invertebrate biodiversity is poor. Very little is known about terrestrial invertebrate diversity, and invertebrates were not considered in the major conservation assessments in the main ecoregions in which cotton is grown (Young et al. 1999, Kearle et al. 2002, NSW NPWS 2002a) until recently. This is starting to change with the recent completion of the *Darling Riverine Plains Bioregional Scoping Study: Terrestrial Invertebrates* (Wilke 2002). The aims of this project included completion of a baseline inventory of terrestrial invertebrates from selected taxonomic groups (all ground-dwelling invertebrates), and an initial analysis of biodiversity patterns across the DRPE, focussing on patterns associated with broad vegetation type and land use. Wilke (2002) included findings of interest to cotton growing:

1. Measures of the diversity of many invertebrate ‘taxocenes’ (discrete groups based on taxonomic affinity) showed there was a clear distinction between sites on public land and those on private or leased land, although not in terms of species richness (number of species). The author suggested that this may mean that while the number of species present on land of different tenures may not vary greatly, there are differences in the structure and composition of the invertebrate populations and these differences warrant further investigation.
2. The diversity of many invertebrate taxocenes varied between vegetation categories. The river red gum (*E. camaldulensis*), poplar box (*E. populnea*) and myall (*Acacia pendula*) communities stood out as having high overall diversity and a distinctive fauna. The diversity levels were lower for native grasslands, but they had a distinctive fauna for many taxocenes.
3. Some of the measures of habitat complexity were important in explaining the differences in invertebrates between sites. The various taxocenes also reacted strongly to different microhabitat variables.

4.8.1 Ground-active and soil invertebrates

Details of recent work including ground-active and soil invertebrates is contained in Sections 4.16, 5.3.1 and 5.3.2. In relation to cotton growing, most of the work has focussed on the presence of beneficial invertebrates within cotton fields or nearby. Some examples of surveys not related directly to cotton were found (e.g. Oliver, Nkem, Doherty, Chilcott in Tables 5.5 and 5.6). The impact of land management practices on soil invertebrate biodiversity is very poorly known, although recent work on the impacts of crop rotation, cultivation and pesticides in cotton is noteworthy (e.g. Hulugalle et al. 1997, Lytton-Hitchins 1998, Lytton-Hitchins 2000). More is known about the impact of mining activities (Ian Oliver, pers. comm. 2002).

4.8.2 Invertebrates in vegetation

Studies of beneficial insects for cotton production have mainly involved sampling exotic vegetation (e.g. cotton, other summer crops such as sorghum, winter crops, lucerne and weed species). Johnson et al. (2000) reviewed this work in detail. Some recent projects have included native vegetation. Research directly related to cotton involving invertebrate sampling of native vegetation includes Silberbauer (2001), Walker (1998b), Stanley (1997) and Yee (1998), as well as current postgraduate research by Rencken. Work not related to cotton includes L&WA (new project) and Banks (current postgraduate research, Tables 5.5 and 5.6).

4.9 Aquatic invertebrates

As with terrestrial invertebrates, knowledge of aquatic invertebrates is poor and many species remain uncatalogued. In cotton growing areas, several studies have sampled aquatic invertebrates, mostly related to water quality studies and the assessment of the impacts of pesticide contamination. These studies are shown in Table 4.9.

When commenting on studies that attempted to assess the effects of pesticides on aquatic invertebrates in the major cotton growing areas of central and north western NSW, Thoms et al. (1999) concluded that changing assessment methods from year to year, the sampling of a small number of sites over a large area, and the confounding effects of multiple land uses, led to inconclusive findings. Marshall et al. (no date) found that there were similar problems with attempts to assess the effects of changed flow regimes on the ecological condition of rivers (including impacts on aquatic invertebrates). Therefore results from existing invertebrate surveys are limited in their usefulness in assessing the interactions between agricultural activities such as cotton growing and aquatic invertebrates.

At least one study in Queensland is attempting to address these concerns. Marshall et al. (no date) are in the second year of a minimum 3-year project measuring multiple indicators of riverine ecosystem health and their responses to changes in flow regime, landscape disturbance and other anthropogenic influences in the Condamine-Balonne catchment. The project is a pilot study that will sample multiple indicators of river ecosystem health along a well defined gradient of flow modification, with secondary impact sources quantified and controlled for, where possible.

4.9.1 New South Wales

The scoping report for the BBSE did not include information on aquatic invertebrates (NSW NPWS 2002a). The background report for the DRPE stated that little is known about the diversity of aquatic invertebrates in the ecoregion, but lists several relevant studies that have been included in Table 4.9.

4.9.2 Queensland

Aquatic invertebrates were not included in the assessment of the conservation status of the BBE in Queensland (Young et al. 1999), and the *State of the Environment Queensland 1999* (EPAQLD 1999) stated that invertebrate knowledge is poor. Known aquatic invertebrate research is included in Table 4.9.

4.10 Microbes

Soil and aquatic microbes are an important component of agricultural systems. Soil microbes are involved in processes such as organic matter decomposition, the supply of nutrients to plants and the absorption and breakdown of waste products such as pesticides. Aquatic microbes affect water quality through their roles in nutrient cycling and the absorption and breakdown of waste products and pesticide residues. These roles make soil and aquatic microorganisms indispensable components of ecosystems.

Table 4.9. Aquatic invertebrate surveys and other research undertaken in cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Boddy and Bales (1996)	Border Rivers, NSW & Qld	Three year survey and monitoring of aquatic macroinvertebrates
Bray (1994)	Macquarie Marshes, NSW	Baseline survey of aquatic invertebrates
Brooks (1998)	Central and North West regions, NSW	Monitoring of aquatic invertebrates as part of water quality monitoring
DNR and DLWC (1999)	Border Rivers Catchment, NSW & Qld	Assessment of ecological condition of streams in Border Rivers, including macroinvertebrate sampling
Duivenvoorden (2002a, 2002b)	Fitzroy Basin, Qld	Pilot study of the effects of irrigation on macroinvertebrates (through pesticide residues and impacts on water quality parameters). Phase 2 of study has just commenced
Jenkins and Boulton (in press)	Teryaweynya Creek, Lower Darling River Catchment	Investigation of short-term aquatic microinvertebrate recruitment following floodplain inundation
Jenkins and Boulton (1998)	Teryaweynya Creek, Lower Darling River Catchment	Investigation of effects of time since last flood and flood frequency on community dynamics of invertebrates emerging from reflooded lake sediments
Jenkins and Briggs (1997)	Darling River Catchment, NSW	Wetland invertebrates in cropped lakebeds along Anabranche of Darling River
Jenkins et al. (2002)	Barwon-Darling River Catchment, NSW	Study of colonisation pathways of microinvertebrates in floodplain lakes following flooding
Leonard et al. (no date)	Namoi River Catchment, NSW	Investigation into links between riverine endosulfan levels and macroinvertebrates in Namoi River
Marshall et al. (no date)	Condamine-Balonne Catchment, Qld	Work still in progress. Includes sampling of macroinvertebrate communities at each monitored site, investigating impacts of flow modification and land use
Noble et al. (1996)	Fitzroy Basin, Qld	Study of effects of land use on riverine environment, including macroinvertebrates
Royal and Bales (1994)	Central and North West regions, NSW	Monitoring of aquatic invertebrates from artificial substrates and then natural habitats as part of water quality monitoring
Sheldon (1995)	Darling River, NSW	Survey of macroinvertebrates in main channel, billabongs and in microhabitats such as substrates and snags
Glenn Wilson, CRC for Freshwater Ecology (Current)	Border Rivers Catchment, NSW & Qld, Upper Condamine Catchment, Qld and Upper Gwydir Catchment, NSW	River health investigation including macroinvertebrate sampling
Glenn Wilson, CRC for Freshwater Ecology, (Upcoming)	Macintyre River, Qld and NSW	L&WA funded investigation into patch dynamics and implications for plankton

4.10.1 Soil microbes

Soil microbes are discussed in detail in Section 5.3.2 Soil Health, and Table 5.6 in that section outlines recent relevant research. Information on soil microorganisms is largely derived from agricultural research, but the level of knowledge of soil microorganisms is poor. The relationships between soil microorganisms and land management practices are

important to cotton farmers as they have the potential to directly affect crop productivity and long-term soil health, and they can be directly influenced by the everyday management decisions of farmers. Dalal (1998) summarised research into the effects of soil type, land use, crop rotations, fertilisers, soil amendments and tillage practices on soil microorganisms.

4.10.2 Aquatic microbes

Aquatic microorganisms (viruses, bacteria, fungi and protozoans) are responsible for some of the ecosystem services provided by rivers (e.g. pollution absorption), and play an important role in nutrient transformation (Veal 1998b). As aquatic microbes are numerous and easy to sample they have the potential to be used as indicators of river health, but with the exception of faecal indicators, they have not been used extensively for this purpose (Veal 1998b). The limited study of microorganisms and limitations associated with sampling techniques (e.g. techniques for culturing bacteria), mean that the understanding of the role of organisms such as bacteria in key ecological functions like nutrient cycling, is based on a very small information base (Sly et al. 1998).

In aquatic environments, microorganisms can be either produced in the water body (autochthonous) or derived from the surrounding terrestrial environment (allochthonous). Generally allochthonous microorganisms do not survive or multiply in aquatic systems, but both types of microorganisms may be useful indicators of river health (Veal 1998a). For example, allochthonous microorganisms may be useful in assessing soil erosion processes.

There has been very little study of the native microbes of Australian inland waters. Boon (1998) reviewed what is known about the microbiology of freshwater systems in Australia.

Planktonic environments (microorganisms in water bodies)

There have been several studies of paired river-billabong sites in the Murray-Darling Basin (Boon 1998). These have shown that there are major differences in the abundance of bacteria in rivers and wetlands (wetlands have been recorded as supporting higher bacteria abundances). However, the turbidity of some rivers makes it difficult to accurately sample bacteria. Different relationships between bacterial abundance and other aquatic variables such as the level of suspended solids have been found between rivers and billabongs (Boon 1998).

In the 1990s, largely molecular techniques were developed to describe the types of bacteria present. The few studies that have been made tend to focus on select groups of microbes. Boon (1998) could find no work on the viral components of natural waters in Australia. He found only one study on aquatic fungi, and didn't find any work on aquatic protozoans.

Benthic environments (microorganisms associated with the beds of rivers and wetlands)

There has been little research in this area, possibly due to the greater difficulty of studying benthic bacteria than planktonic bacteria (Boon 1998). The one exception is an attempt to quantify carbon transformations in wetland sediments (particularly methane consumption and production processes by bacteria). Fungi have not been found in sediments, and viruses and protozoans are largely unstudied.

Biofilms (microorganisms on submerged surfaces)

Biofilms are assemblages of algae, fungi, bacteria and unicellular animals that cover submerged surfaces. They are a major energy source in aquatic food webs (Burns and Ryder 2001a). Biofilm research in Australia was reviewed by Burns and Ryder (2001a), who indicated that knowledge of biofilm function had made recent rapid advances. While there has been a lack of study of biofilms in cotton growing areas (except for the Macquarie River upstream of Dubbo), several recent projects involving lowland rivers are relevant. An Australian Research Council, Department of Land and Water and NSW Environment Protection Authority funded project, *Developing Indicators of River Health: the Response of Biofilms and their Consumers to River Flow Management* (Robertson et al. unpubl.), investigated biofilms from the Macquarie, Murrumbidgee and Ovens Rivers. While these rivers had varying hydrological regimes and biofilm assemblages, the biofilms in each river were functionally quite similar. This indicates that research findings from selected lowland rivers may be of broader relevance (including to lowland rivers in cotton growing regions) (Darren Ryder, pers. comm. 2003). An upcoming CSIRO Land and Water funded project, *Interactions Between Biofilm Production and Water Quality – Nutrients and Suspended Sediments* (Table 4.10), involving the Macquarie and Murrumbidgee Rivers, will further improve the understanding of biofilm assemblages and functions, with potential relevance to cotton growers given the influence of suspended sediments on riverine nutrient and pesticide bioavailability (Section 5.3.5).

Table 4.10. Aquatic microbe research relevant to cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Bunn et al. (1997)	Lowland stream, Qld	Investigation into contributions of sugar cane and invasive pasture grasses to aquatic food webs
Burns and Ryder (2001b)	Murrumbidgee River, NSW	Investigation into effects of flooding on bacterial activity
Marshall et al. (no date)	Condamine-Balonne Catchment, Qld	In progress project investigating river flow and land use, including collection of bacteria
Robertson et al. (unpubl.)	Macquarie, Murrumbidgee and Ovens Rivers, NSW & Victoria	Investigation in to functioning and diversity of biofilm assemblages in lowland rivers
Darren Ryder, Ecosystem Management, UNE, upcoming CSIRO project	Macquarie and Murrumbidgee Rivers, NSW	Upcoming investigation into interactions between biofilm production and water quality
Scholz and Boon (1993a, 1993b)	Murray-Darling Basin	Investigation into biofilm activity in billabongs
Watts et al. (2001)	Murrumbidgee River, NSW	Development of model for using biological indicators for assessing river flow management (potentially useful to other lowland rivers)

In regard to cotton growing areas, catchment blueprints (NSW), strategic catchment plans (Queensland), and other investigations into aspects of river health such as flow regimes and water quality, have largely failed to consider the aquatic microorganism component of biodiversity. The *Condamine-Balonne Integrated Monitoring Pilot Project* (NR&M no date) includes the collection of bacteria from planktonic and benthic environments (along with algae, macroinvertebrates, fish and frogs). Bacteria will be studied to determine how they respond to changes in stream flow and land use over the coming years. Some 30 sites for sampling have been selected in the catchment. Flow conditions were used as the primary selection criterion, with land use being a secondary criterion. Several sites are situated

within parts of the catchment where cotton is grown. A L&WA funded project will soon commence investigations into patch dynamics and the connectivity ramifications for plankton (and fish and carbon flows) along the Macintyre River (Glenn Wilson, pers. comm. 2003).

4.11 Native Vegetation

4.11.1 Terrestrial vascular plants

Clearance of native vegetation has not been equally distributed across the landscape, with vegetation communities on the more productive soils experiencing proportionally higher rates of clearing (Ford et al. 2001). The implications for agriculture are that many vegetation communities within agricultural landscapes have been heavily cleared, are poorly represented within conservation reserves and contain high numbers of threatened species. This is true of cotton growing areas which are often located on floodplains with few sizeable conservation reserves. This presents challenges to the conservation and management of native vegetation in farming environments. Ecosystem services related to native vegetation are discussed in more detail in Section 5.3.8.

Recovery outlines or plans have been prepared for many species listed as threatened under federal and state legislation, and these plans describe the threats facing each species. The greatest threat to most remnant vegetation is continued vegetation clearance, listed as a major threat to biodiversity in both NSW (Bedward et al. 2001) and Queensland (Young et al. 1999). Regional Vegetation Management Plans (RVMPs), provided for under both NSW and Queensland legislation, will give direction to landholders on how clearing proposals within regions will be handled. RVMPs are under preparation in both states, although the interdiction of the native vegetation proposals of the Wentworth Group of Concerned Scientists has put the NSW process on hold.

Research into vascular plants in cotton growing areas is contained in Table 4.11. In both NSW and Queensland, detailed flora records for any selected site (such as a cotton growing area) can be purchased from electronic databases managed by the NSW National Parks and Wildlife Service and the Queensland Herbarium.

New South Wales

Vascular plant surveys undertaken within small areas of the BBSE and the DRPE are numerous, but until recently there had been very few extensive surveys. Recent work is improving this situation. Vegetation mapping in the BBSE has been enhanced by the completion of two studies as part of the Western Regional Assessments (NSW NPWS 2000c, McCauley et al. 2002). Appendix 7, Table A, shows species in the BBSE listed as threatened under NSW's *TSC Act 1995*. (Note that flora information in Appendix 7 includes a 15 km buffer zone around the BBSE, so some of the species listed are unlikely to actually occur in the BBSE. Known anomalies have been highlighted.) Surveys have focussed on forested areas on public land, with a list of systematic flora surveys in the BBSE listed in NSW NPWS (2002a). A systematic flora site gap analysis was completed, and recommendations made regarding how knowledge of native flora distribution, ecology and conservation status could be improved (NSW NPWS 2002a). The recommendations are extensive, but include recommendations relevant to cotton growing, such as the need to undertake further systematic flora surveys of non-woody vegetation such as wetlands and

grasslands on private land, and the need for monitoring sites to be established across all land tenures to fill in gaps in the information base.

Vegetation mapping (at 1:100 000 scale) being undertaken by the NSW Department of Infrastructure Planning and Natural Resources is addressing the lack of systematic surveys on private land. Survey sites completed as part of the mapping project are largely selected without regard for land tenure (there are at least 100 survey sites per map sheet). A refusal rate of between 60-70% of requests to visit private land has influenced the location of sampling sites. Additional surveys on the properties of landholders who grant access and on public land sites, mean that environmental variation across the landscape is being adequately considered for the purposes of vegetation mapping (Graham Watson, pers. comm. 2003). In the BBSE, mapping for the Upper Namoi has been completed. Mapping is also available for the upper catchment areas of the Gwydir and Macintyre Rivers.

Vegetation maps and associated reports are, or will soon be, available at:

<http://www.dlwc.nsw.gov.au/care/veg/mapsynopsis/index.html>.

Kearle et al. (2002) provided detailed plant community descriptions for the DRPE. Species in the DRPE listed as threatened under NSW's *TSC Act 1995* are shown in Appendix 7, Table B. In recommending future work to improve flora knowledge, Kearle et al. (2002) stated that the northern floodplains have been the subject of the most detailed surveys, and priority should be given to the Darling River south of Bourke (including the Lake Tandou area) where there are very few records. Kearle et al. (2002) found that systematic surveys were also generally lacking in the DRPE, but DIPNR's vegetation mapping project will change this in the near future. A survey of the grasslands of the Moree Plains by Hunter and Earl (1999) with follow up PhD research by Lewis (UNE) is relevant to cotton growing areas. Broad areas of vegetation are also being mapped in the Moree Plains Shire as part of the Moree Biodiversity Landuse Audit (reference details to come).

Vegetation mapping has been completed by DIPNR for Condobolin and parts of the Lachlan Shire, covering the Hillston and Lachlan cotton growing areas.

In addition to being used for vegetation mapping, the results of flora survey sites are added to electronic databases and can be used for other purposes (e.g. investigations into understanding the links between land use and selected vegetation species). These other uses would benefit from the inclusion of more survey sites on private land, and the lack of information from some areas of private land is a gap in the knowledge base.

Queensland

The BBE in Queensland is divided into 36 sub-regions, 20 of which are located in the BBSE where most cotton is grown. Each sub-region has a distinctive pattern of landform, soils and vegetation. The subregions have been divided into 163 regional ecosystems largely based on land systems mapping in combination with vegetation and geological maps. Regional ecosystems provide useful smaller units for considering patterns of flora and fauna distribution across an ecoregion, and when assessing landscape change such as the extent and impacts of activities such as clearing.

Regional ecosystems have been assigned a conservation status ('Endangered', 'Of concern' or 'Of no concern') based on the extent remaining in the landscape, their condition and the presence of threatening processes. Young et al. (1999) described each ecosystem and its conservation status. This information is indicative of areas of biodiversity concern. For

example, in the Eastern Darling Downs province, several regional ecosystems supporting grassland on alluvial plains are listed as endangered. The survey and mapping of vegetation communities (both pre-clearing and remnant vegetation) and regional ecosystems has been completed for the BBE (at 1:100 000 scale) and can be purchased through the Queensland Herbarium. This mapping is based on aerial photo interpretation, field sampling and surveys.

Young et al. (1999) provided details of flora species listed as threatened under Queensland's *Nature Conservation (Wildlife) Regulation 1994* (Appendix 7, Table C), but stated that there had been no systematic flora field surveys of much of the BBE. Table C covers the entire BBE, and some of the species listed would not occur in cotton growing areas. The *Assessment of Forest Values within the Western Queensland Hardwood Region* (EPAQLD 2003) which included systematic flora surveys, has recently improved the flora information available for forests and woodlands on public land. The *Condamine Catchment Strategic Plan* (CCMA 2001) stated that there has been no systematic survey of flora, but that several listed threatened species of plants occur (Appendix 7, Table D).

The vegetation of the Darling Downs has been the subject of detailed investigation. Fensham and Fairfax (1998) used Land Survey Records to reconstruct the pre-European vegetation patterns across the Darling Downs including cotton growing areas. This showed that blue grass (*Dichanthium sericeum*) grassland communities which originally covered 390 000 ha (or 42.5%) of the Darling Downs, have been reduced to 1.25% (Goodland 2000). Recognition of this depletion prompted a survey of significant grassland sites which were mapped as part of a report *Grassy Ecosystem Significant Sites of the Darling Downs, Queensland: Locations and Management Recommendations* (Goodland 2000). Threatened species located through this process are shown in Appendix 7, Table E. Survey work has now been extended to the poplar box (*E. populnea*) grassy woodlands (focussing on public land). No written report is available at this stage, but an electronic database and a set of maps of all of the significant species and their locations has been created as part of this project, and will shortly be available through the Queensland Parks and Wildlife office at Toowoomba (Alison Goodland, pers. comm. 2002). It is hoped that this work will be extended to include private land in the near future.

Flora and fauna surveys were undertaken in remnant forests to the south, east and north of the cotton growing areas around St George and Dalby as part of a project to assess forest condition by the Forest Ecosystem Research and Assessment section of the Department of Natural Resources and Mines (Eyre et al. 2001). Work on this project is ongoing and while it does not include areas where cotton is grown (Teresa Eyre, pers. comm. 2002), the relationships between forest condition (assessed in relation to disturbances such as logging, fire and grazing) and fauna, are of interest.

Table 4.11 gives details of flora surveys in cotton growing areas. Note that in addition to these references, significant quantities of unpublished data for the BBSE are held by government departments. Refer to NSW NPWS (2002a) for details.

Table 4.11. Major vascular plant surveys and other research undertaken in cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Austin et al. (2000)	Central Lachlan Catchment, NSW	Analysis and modelling exercise predicting pre-European distribution of woodland vegetation, and assessment of priorities for remnant protection and revegetation
Beckers and Binns (2000), McCauley et al. (2002)	BBSE, NSW	Flora survey focussing on forested public land
Cannon (2002)	Part of Upper Namoi Catchment, NSW	Native vegetation map report
Centre of Environmental Management (1998)	Murray-Darling Basin	Flora survey
Dick (1993)	Narran, Culgoa and Birrie River floodplains, NSW	Flora survey
EPA QLD (2003)	Western Queensland Hardwood Region, BBE	Flora survey as part of assessment of forest condition
Eyre et al. (2001)	Forested land south central Qld	Flora survey as part of analysis of forest condition and investigation into habitat linkages
Fensham (1998), Fensham and Fairfax (1998)	Darling Downs, Qld	Flora surveys and reconstruction of pre-European vegetation
Galloway et al. (1974)	Condamine-Balonne Catchment, Qld	Description of vegetation in Condamine catchment
Goodland (2000)	Darling Downs, Qld	Flora survey of stock routes and roadsides
Gunn and Nix (1977)	Fitzroy Catchment, Qld	Description of vegetation in Fitzroy Catchment
Hunter and Earl (1999)	Moree Plains, NSW	Flora survey
Hunter and Earl (2002 unpubl.)	Culgoa National Park, NSW	Vegetation and floristics report
Lewer et al. (2002, unpubl.)	Condobolin and surrounding districts, NSW	Native vegetation map reports
Tom Lewis, PhD student, Ecosystem Management, UNE (current)	Moree Plains, NSW	Flora surveys and experiments targeting impacts of grazing, cultivation, fire and flooding on blue grass-Mitchell grass grasslands
McGann et al. (2001)	Narran Lake Nature Reserve, NSW	Flora survey and description
Miller (2001 unpubl.-a), Miller (2001 unpubl.-b)	Northern floodplains, NSW	Interpretation of floodplain vegetation
Guy Roth	Moree Plains Shire, NSW	Mapping of vegetation as part of Moree Plains Landuse Audit, details to come
Neldner (1984)	South central Qld	Investigation and mapping of flora of South Central Queensland 1:1 000 000 mapsheet, including St George and Dirranbandi districts
Sattler et al. (2002), NL&WRA (2001c)	National Land & Water Resources Audit	Assessment of status of vegetation on ecoregional basis
Sivertsen and Metcalfe (1995)	Southern wheat-belt, NSW	Flora survey
Steenbeeke (1996)	Macquarie River floodplain, NSW	Flora survey
Wilson (1992)	Macquarie Marshes, NSW	Flora survey

4.11.2 Terrestrial lower plants

Non-vascular plants include algae, lichens and bryophytes (mosses, liverworts and hornworts), and these species play many important roles in terrestrial and aquatic

ecosystems. For example, lichens stabilise the soil surface, are capable of nitrogen fixation and provide habitat for microfauna, fungi and algae (EPAQLD 1999).

New South Wales

While non-vascular plants have been the subject of investigation at many sites across NSW, they are not included in any of the major vegetation assessments and background reports recently prepared for different ecoregions (Val et al. 2001, Kearle et al. 2002, NSW NPWS 2002a). The *New South Wales State of the Environment 2000 Report* (EPANSW 2000a) stated that there is virtually no information on the status of, and threats to, terrestrial and aquatic non-vascular plants.

A current project of relevance to this report is being managed by Ian Oliver, DIPNR Armidale, in the Pilliga/Burren Junction area in the Namoi Valley. Oliver is coordinating biodiversity surveys of 43 sites in native poplar box (*E. populnea*) communities, including non-vascular plants. The sites are in remnants of varying condition and are in varying landscape contexts (e.g. adjacent to crops, adjacent to forests). Results of this work are yet to be published. Two other projects of potential interest even though they are not in cotton growing areas are a joint project between CSIRO (David Freudenberger) and DIPNR (David Eldridge) around Savernak in southern NSW, investigating the potential use of non-vascular plants as surrogates of landscape health, and an investigation by Will Cuddy of the University of New South Wales, into non-vascular plants and the health of roadside reserves at sites from Albury to Coolah, NSW (David Eldridge, pers. comm., 2003). Past work by Eldridge (1996, 1996) included landscapes in the western cotton growing areas of NSW (Condobolin, Tandou and Bourke), studying the distribution and floristics of bryophytes and terricolous lichens in soil crusts in arid and semi-arid lands.

Queensland

The biodiversity chapter in *State of the Environment Queensland 1999* (EPAQLD 1999) indicated that there is little information available on the biodiversity of non-vascular plants in Queensland. Over 1000 freshwater species of algae are known to occur in Queensland, but there is limited information on the diversity, distribution and ecological role of algae in natural ecosystems. More than 1300 species of lichen are found in Queensland, but again little is known about their ecology. Almost 1000 species of bryophytes have been recorded in Queensland, but taxonomy, biogeography and population studies have been very limited (EPAQLD 1999). The Condamine-Balonne Integrated Monitoring Pilot Project (NR&M no date) is collecting information on aquatic algae.

4.12 Native Aquatic Vegetation

In addition to microscopic and macroscopic algae and non-vascular plants (mosses and liverworts), aquatic vegetation includes large plants which may be floating (e.g. ferns such as *Azolla*), or rooted plants. Rooted plants can be classified functionally into five groups: floating (e.g. water hyacinth, *Eichhornia crassipes*), submerged (e.g. ribbon weed, *Vallisneria* spp.), emergent (e.g. reeds), amphibious (e.g. water milfoils, *Myriophyllum* spp, that can tolerate wetting and drying), and semi-terrestrial (e.g. river sheoak, *Casuarina cunninghamiana*) (Boulton and Brock 1999). Each type of plant provides habitat for different vertebrates and invertebrates, and together macrophytes affect flow patterns, bed and bank stability, water quality and nutrient cycling. In turn, the health and survival of

these plants are affected by changes to flow regimes, water quality and agricultural activities such as lake-bed cropping and grazing.

Native riverine aquatic vegetation has been sampled as part of several studies investigating water quality and stream condition, and wetlands and floodplains have sometimes been included in vegetation mapping (Table 4.12). The need for further surveys of wetland areas, particularly on private land, was noted in the NSW background report for the BBSE (NSW NPWS 2002a). It appears that information on aquatic vegetation, particularly in-stream aquatic vegetation, has similar limitations to those applying to aquatic invertebrates (e.g. lack of sampling sites over large catchments and limitations in sampling procedures making it impossible to determine accurately the causal factors behind changes to aquatic plant communities). While sampling in some streams and wetlands may have been comprehensive, understanding of the processes such as flow regimes and water quality that affect aquatic vegetation patterns, are not that well understood.

Table 4.12. Native aquatic vegetation surveys and other research undertaken in cotton growing areas of NSW and Queensland.

Reference	Location of Survey	Type of Information
Boddy and Bales (1996)	Border Rivers, Qld	Three year survey and monitoring of aquatic macrophytes and riparian vegetation
Hunter (1999 unpubl.), McGann et al. (2001), NSW NPWS (2000b)	Narran Lake Nature Reserve, NSW	Vegetation mapping, including aquatic plant communities, and management recommendations
Jarman and Montgomery (2001)	Wetlands and irrigation storages, Lower Gwydir Catchment, NSW	Seed bank of aquatic plants in mud of wetlands and storages was sampled, and related to bird survey results
Johnson (2001 unpubl.), Keyte (1994)	Lower Gwydir Wetlands, NSW	Description of aquatic vegetation of Lower Gwydir Wetlands
Kearle et al. (2002)	Darling Riverine Plains Ecoregion	Description of plant communities in major wetlands of DRPE
Marshall et al. (no date)	Condamine-Balonne Catchment, Qld	Work still in progress. Includes sampling of aquatic macrophytes at each monitored site, investigating impacts of flow modification and land use
McCosker and Duggin (1993 unpubl.)	Gingham Wetlands, Gwydir Catchment, NSW	Description of aquatic vegetation communities and analysis of changes over time
Phillips and Moller (1995)	Upper Condamine Catchment, Qld	Assessment of stream condition including aquatic vegetation
Roberts and Marston (2000)	Murray-Darling Basin	Fact sheets on water requirements of riverine and floodplain plants
Telfer (1995)	Dawson Catchment (Fitzroy Basin), Qld	Assessment of stream condition including aquatic vegetation
Wolfgang (1998)	Macquarie River Catchment, NSW	Description of aquatic vegetation of Macquarie Marshes
Phillips and Moller (1995)	Upper Condamine Catchment, Qld	Assessment of stream condition including aquatic vegetation
Roberts and Marston (2000)	Murray-Darling Basin	Fact sheets on the water requirements of riverine and floodplain plants
Telfer (1995)	Dawson Catchment (Fitzroy Basin), Qld	Assessment of stream condition including aquatic vegetation
Wolfgang (1998)	Macquarie River Catchment, NSW	Description of aquatic vegetation of the Macquarie Marshes

4.13 Exotic vegetation: terrestrial and aquatic weeds

A weed is a plant growing out of place (NR&M no date). This section focuses on plants listed as weeds under relevant state legislation. Terrestrial weeds adversely impact upon native vegetation and habitat values by inhibiting regeneration, changing microclimates (e.g. patterns of light penetration and leaf litter), affecting the structural complexity of vegetation, and altering foraging, roosting and breeding opportunities for native fauna. Aquatic weeds can have negative impacts on water quality, pumping operations, nutrient cycling and erosion and sedimentation processes. Most weed species are favoured by changes to flow regimes, water quality and physical disturbance of wetlands and riparian zones (Boulton and Brock 1999). Table 4.13 provides details of research into terrestrial and aquatic weeds in cotton growing areas.

4.13.1 New South Wales

The management of weeds in NSW is controlled under the *Noxious Weeds Act 1993*. Plants can be declared weeds under different categories of concern, and are declared noxious on a local government area basis.

Weeds recorded within the BBSE that have been declared noxious are listed in Appendix 8, Table A. In the flora surveys carried out as part of the BBSE investigations, the survey site with the highest percentage of exotic species was the Namoi Riparian Zone Survey, where almost 55% of the species recorded were exotic (NSW NPWS 2002a).

Some 229 exotic species have been recorded in the DRPE, with some of the most abundant weed species being listed in Appendix 8, Table B (Kearle et al. 2002). Kearle et al. (2002) stated that there is little information on the abundance, distribution and environmental impact of weed species found in the DRPE, and recommended research in this area be given a high priority given the widespread distribution of some species such as water hyacinth (*Eichhornia crassipes*), lippia (*Phyla canescens**) and African boxthorn (*Lycium ferocissimum*). An investigation is currently being conducted into the distribution and impacts of lippia in the Murray Darling Basin. The draft report for this project indicates lippia occurs in all of the cotton growing catchments in the Murray Darling Basin, and is generally recognised as a problem (AIMS 2003). Lippia has severely reduced native pastures and threatens biodiversity given that it has almost totally displaced native herbaceous vegetation in some areas (McCosker and Duggin 1993 unpubl.). The spread of lippia may have been aided by river regulation and abstraction affecting the vigour of native aquatic and semi-aquatic species (McCosker 1994). Water hyacinth and African boxthorn are also problem weeds on floodplains in cotton growing areas (e.g. the Gwydir Valley, McCosker and Duggin 1993 unpubl.). Invasive exotic grasses (e.g. coolatai grass, *Hyparrhenia hirta* and African lovegrass, *Eragrostis curvula*) are also a problem on the floodplains (John Hunter, pers. comm. 2003).

* Before a taxonomic revision in 1993, lippia was most commonly referred to as *Phyla nodiflora*. *Phyla nodiflora* is now thought to be common in coastal areas whereas *P. canescens* is more common on inland floodplains. Confusion remains about their location, so checking of each specimen is required for positive identification (Judi Earl, pers. comm. 2003).

4.13.2 Queensland

The *Land Protection (Pest and Stock Route) Act 2002* is the Queensland legislation governing the management of weed species. This Act replaces the *Rural Lands Protection Act 1985*. Plants that are declared pests can be listed under several classes of the Act requiring different levels of control and management. The *Draft Land Protection Regulation 2002* is currently under consideration, and will classify pest plants into designated classes. The Queensland State Government has recently prepared the *Queensland Weeds Strategy 2002-2006* (NR&M 2002b) to provide direction for weed management generally throughout the state.

In the *Condamine Catchment Strategic Plan* (CCMA 2001), high impact weeds are listed as including African boxthorn (*Lycium ferocissimum*), parthenium weed (*Parthenium hysterophorus*), honey locust (*Gleditsia triacanthos*), mother of millions (*Bryophyllum tubiflorum*, *B. daigremontianum* x *tubiflorum*; Syn. *Bryophyllum delagoense* and *B. daigremontianum* x *B. delagoense*), lantana (*Lantana camara*) and lippia (*Phyla canescens*).

In the draft document *Our Plan for the Border Rivers Catchment* (BRCMA 2001), significant weeds include parthenium weed, harissia cactus (*Eriocereus* sp.), mother of millions, African boxthorn, African lovegrass (*Eragrostis curvula*) and lippia.

Declared pest plants in the Dawson River Catchment include rubber vine (*Cryptostegia grandiflora*), parthenium weed, prickly acacia (*Acacia nilotica*), parkinsonia (*Parkinsonia aculeata*), noogoora burr (*Xanthium pungens*) and prickly pear (*Opuntia* spp). Giant rat's tail grass (*Sporobolus pyramidalis* and *S. natalensis*) is emerging as a major problem in the catchment (Anon. 2002d).

Many weed species have established self-sustaining populations (i.e. become naturalised). The Queensland Herbarium has published a list of 200 invasive naturalised plants in southeast Queensland (Queensland Herbarium 2002).

4.13.3 Cotton farms

The Australian Cotton Cooperative Research Centre has recently produced the *Weed Identification and Information Guide* (Australian Cotton CRC 2002). This Guide provides information on the identification and management of 39 weed species that commonly cause problems in cotton production. These species are listed in Appendix 8, Table C. Detailed lists of major and minor weeds in the different cotton growing catchments of NSW and Queensland are contained in *WEEDpak: A Guide for Integrated Management of Weeds in Cotton* (Anon. 2002g). When compared with the weeds listed in Section 4.13, there is some overlap between species that are of production concern and those that are a problem throughout the broader landscape, but the level of commonality is not high. Therefore cotton growers' weed prevention measures in cotton fields are unlikely to suffice in terms of their duty of care in managing weeds in other parts of the farm. This applies to weeds such as lippia which threaten both agricultural and biodiversity values.

Table 4.13. Research into terrestrial and aquatic exotic species in cotton growing areas.

Reference	Location of Survey	Type of Information
AIMS (2003) (current)	Murray Darling System	Project will report on distribution and impacts of lippia (<i>Phyla canescens</i>) in Murray Darling System
Batianoff and Butler (2002)	South-east Qld	Assessment of invasive naturalised plants in south-eastern Queensland
Boddy and Bales (1996)	Border Rivers, Qld	Three year survey and monitoring of aquatic macrophytes, including exotic species.
Franks (2002)	South-central Queensland	Effects of buffel grass (<i>Cenchrus ciliaris</i>) in poplar box (<i>E. populnea</i>) woodlands
McCosker (1994)	Lower Gwydir Valley and Murray Darling Basin	Report on distribution and ecology of lippia (<i>Phyla canescens</i>).

4.14 Threatened Communities in Cotton Growing Regions

Ecological communities can be listed as threatened under federal and state legislation. Under the Federal *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act 1999)*, three ecological communities listed as threatened are relevant to cotton growing areas:

1. Brigalow (*Acacia harpophylla* dominant and co-dominant) (Anon. 2002b). This community has been reduced to about 10% of its former distribution across NSW and Queensland. The primary threat to its existence is given as clearing for cropping (including cotton) and pasture. (Also listed under the *TSC ACT 1995*.)
2. Bluegrass (*Dichanthium* spp) dominant grasslands of the Brigalow Belt Bioregions (North and South) (Anon. 2002a). Grasslands dominated by bluegrass (*Dichanthium* spp) have declined to approximately 10% of their former range, and are threatened by conversion from native pasture to cropping. This community mainly occurs in Queensland, but it has been recorded in the Moree Plains area by Hunter and Earl (1999, NSW NPWS 2002a).
3. Grassy white box (*Eucalyptus albens*) woodlands (Anon. 2002e). This community has recently been listed due to the major reduction in its distribution and the degree of fragmentation. Clearing for cropping is again listed as a major threat.

Recovery plans can be developed and implemented for these communities, but they have not yet been completed.

In NSW, threatened ecological communities can be listed under the *Threatened Species Conservation Act 1995 (TSC Act 1995)*. Communities of interest to cotton growing include:

1. *Corymbia tessellaris* (carbeen) open forest. This community is found on the riverine plains of a number of northern rivers in NSW in the BBSE and DRPE. This community has been extensively cleared and continues to be threatened by clearing, land grooming for irrigation, weed invasion and inappropriate fire management (Kearle et al. 2002).
2. Native vegetation on cracking soils of the Liverpool Plains. This community found in the BBSE is most often dominated by grasses, but shrubs and trees can occur. Threats include weed invasion, salinity and erosion (NSW NPWS 2002a).

3. White box (*E. albens*)-yellow box (*E. melliodora*) woodland. A preliminary determination has been made to list this community found in the BBSE. Threats include clearing, degradation of remnants and loss of connectivity between remnants (NSW NPWS 2002a).

Vegetation Management Committees can list additional communities within their areas as 'Endangered', 'Vulnerable', 'Rare' or 'Of Concern', and can impose tighter restrictions on activities such as vegetation clearance within listed communities (these listings take precedence over the provisions of the *TSC Act 1995*) (John Hunter, pers. comm. 2003).

Endangered fauna populations can also be listed under the *TSC Act 1995*. None of the listed species appear to occur in cotton growing areas.

In Queensland, Regional Ecosystems can be listed as 'Endangered' or 'Of Concern' under the *Vegetation Management Regulation 2000*. As mentioned earlier, the entire BBE (north and south) has been divided into 163 regional ecosystems. Some 29 regional ecosystems have been listed as Endangered, and 51 have been listed as Of Concern (reflecting the high rates of clearance and modification in the BBE). Appendix 9 provides details of the status of Endangered and Of Concern regional ecosystems in the BBE. Regional ecosystems have been mapped by the Queensland Herbarium. Many of the listed regional ecosystems occur or once occurred in cotton growing areas. A detailed mapping project would be required to accurately correlate cotton growing areas with threatened regional ecosystems, and so provide a more relevant list than that contained in Appendix 9. Such a project should now be straightforward given the digital information held by state agencies.

Table 4.14 contains examples of recent research into threatened communities in cotton growing regions. Many of the other references cited in this report are relevant to the ecological processes affecting these communities.

Table 4.14. Examples of research into threatened communities in cotton growing areas

Reference	Threatened Community	Type of Information
Vera Banks, PhD candidate, Ecosystem Management, University of New England	Native vegetation on cracking soils of Liverpool Plains, NSW	Investigation into eucalypt dieback
Stuart Collard, PhD candidate, University of Southern Queensland	Brigalow (Toowoomba and Dalby area)	Investigation into biological services and sustainable use of remnant vegetation in BBE
Goodland (2000)	Bluegrass (<i>Dichanthium</i> spp) and brigalow, Qld	Locations of threatened species
Hunter and Earl (1999)	Bluegrass (<i>Dichanthium</i> spp), NSW	Locations in Moree area of NSW
LWA (2003)	Brigalow	Investigation into impacts of fragmentation and clearing
Perry Poulton, CSIRO, Toowoomba	Brigalow	Relationships between retaining Brigalow and cropping production
Queensland Herbarium	Threatened Regional Ecosystems in Queensland	Vegetation maps and accompanying information
Sattler et al. (2002)	Threatened ecosystems in Australian ecoregions	Assessment of status of ecoregions and nature of threats

4.15 Threatening Processes in Cotton Growing Regions

The *EPBC Act 1999* provides for the listing of Key Threatening Processes (KTPs), processes that could lead to a native species or ecological community becoming threatened under the *EPBC Act 1999*. In NSW, the *TSC Act 1995* and the *Fisheries Management Act 1994 (FMA Act 1994)* also provide for the listing of threatening processes. Some KTPs may be listed under both acts, but there are differences in definition. KTPs relevant to cotton growing areas are listed below:

1. Land clearance (listed under both the *EPBC Act 1999* and the *TSC Act 1995*). Note that in addition to native vegetation clearance, land clearance includes activities such as infilling of wetlands and drowning of vegetation through the construction of impoundments (Environment Australia 2002a). The effects of land clearing on biodiversity include (NSW NPWS 2002b):
 - destruction of habitat resulting in loss of local populations of species;
 - fragmentation;
 - expansion of dryland salinity;
 - riparian zone degradation;
 - increased greenhouse gas emissions;
 - loss of leaf litter layer;
 - loss or disruption of ecological function; and
 - changes to soil biota.

Rates of vegetation clearance across Australia are discussed in Williams et al. (2001). EPA Queensland (1999) provided information on clearing in Queensland ecoregions, and estimated an average annual rate of clearance in the BBE of 150 552 ha/yr between 1991-95. The rate of clearance of native vegetation in the BBSE and the DRPE in NSW between 1995-97 was estimated to be 1500 ha and 4400 ha respectively (EPANSW 2000a). However, the rate of clearance of native woody vegetation in the NSW wheatbelt was analysed by Bedward et al. (2001), who concluded that clearance rates were 10 times higher than previous estimates.

2. Anthropogenic climate change (listed under both the *EPBC Act 1999* and the *TSC Act 1995*). This KTP is most likely to affect species that are isolated, specialised in their habitat requirements, and have limited mobility, specific host requirements, large home ranges and long generation times (NSW NPWS 2002a). Plant species are not predicted to move with climatic zones across the landscape because of soil constraints (Hughes in press), and this will affect the habitat of dependent fauna.
3. Dieback caused by *Phytophthora cinnamomi* (cinnamon fungus) (listed under the *EPBC Act 1999*). Not recorded in cotton-growing areas, but has the potential to affect some species in the relevant ecoregions (Anon. 2003b).
4. Predation by feral cats (*Felis catus*) (under the *EPBC Act 1999* and *TSC Act 1995*). Small mammals and ground-nesting birds most likely affected (Kearle et al. 2002).
5. Predation by the European Fox (*Vulpes vulpes*) (listed under the *EPBC Act 1999* and the *TSC Act 1995*). Many bird, reptile and mammal species are likely to be affected (Dickman et al. 1993).
6. Competition and land degradation by feral goats (*Capra hircus*) (listed under the *EPBC Act 1999*). Affects flora and fauna species, particularly in semi-arid habitats.

7. Competition and land degradation by feral rabbits (*Oryctolagus cuniculus*) (listed under the *EPBC Act 1999*). Rabbits compete with native fauna for food and shelter and inhibit the regeneration of native vegetation (Kearle et al. 2002).
8. Predation, habitat degradation, competition and disease transmission by feral pigs (*Sus scrofa*) (listed under the *EPBC Act 1999*). Pigs can cause habitat changes, destroy plants, encourage weed invasion, act as possible vectors for diseases such as cinnamon fungus (*Phytophthora cinnamomi*), and prey on bird chicks, reptiles, frogs, soil organisms and invertebrates (Kearle et al. 2002).

Other KTPs relevant to cotton growing areas just listed under the *TSC Act 1995* include:

1. High frequency fire. This has the potential to disrupt the life cycle processes of flora and fauna species.
2. Predation by gambusia (plague minnow or mosquito fish) (*Gambusia holbrooki*). Mosquito fish prey on the eggs of several frog species and has been recorded in the DRPE (Kearle et al. 2002).
3. Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands. Impacts of changed flow regimes are discussed in Section 5.3.6.
4. Competition from feral honeybees (*Apis mellifera*). Honeybees compete with hollow-dependent fauna, compete with native fauna for floral resources and reduce seed set in some native plant species (Kearle et al. 2002).

A preliminary determination has been made to list the 'Invasion of native plant communities by exotic perennial grasses' as a key threatening processes under the *TSC Act 1995* (Anon. 2003c). Grasses such as coolatai grass (*Hyparrhenia hirta*), buffel grass (*Cenchrus ciliaris*) and African lovegrass (*Eragrostis curvula*), are examples of invasive exotic grasses in cotton growing areas covered by this determination.

Under the *FMA Act 1994*, listed KTPs are:

1. Removal of large woody debris. Large woody debris has many direct habitat benefits for aquatic species, and can help to prevent erosion and stabilise stream sediments.
2. Degradation of riparian vegetation along New South Wales water courses. This can have many negative impacts on riverine environments including increased sediments and nutrients, reduced inputs of large woody debris and reduced overhanging riparian vegetation affecting habitat quality (Kearle et al. 2002).
3. Introduction of fish to fresh waters within a river catchment outside their natural range. Introduced fish compete directly with native fish and degrade habitat for other species.
4. The installation and operation of in-stream structures that modify flow. Structures which modify flow include dams, weirs, floodgates, culverts, flow regulators, levee banks, erosion control structures and causeways. These structures affect fish breeding and growth, change migration patterns and lead to degradation of fish habitat (Kearle et al. 2002).

In addition to listed KTPs, there are many other threatening processes relevant to the potential impact of cotton production on flora and fauna (e.g. spray drift). See Section 5.3.8 for further discussion.

Where appropriate, threat abatement plans are prepared for KTPs. Threat abatement plans detail research needs and management actions designed to reduce the impact of threatening processes. The aim is to assist the long-term survival of listed threatened species or ecological communities.

Table 4.15 outlines several important projects relating to improving the understanding of the key threatening process of vegetation clearance, and subsequent landscape function. References relating to other key threatening processes such as river regulation and climate change are contained in Chapter 5.

Table 4.15. Key research projects into the effects of vegetation clearance and landscape change in cotton growing areas

Reference	Location of Survey	Type of Information
Bradstock and Bedward (2002)	NSW wheatbelt	Project titled 'Biodiversity dynamics, habitat loss and disturbance in the New South Wales wheatbelt'. In progress. Work involves modelling and field studies that aim to: (1) identify relationships between native vegetation and environmental variables, (2) use models to generate future possible native vegetation patterns and explore changes resulting from clearing and fragmentation, (3) undertake field studies to assess modelling, and (4) develop new approaches to vegetation management through simulation of vegetation retention targets and offset mechanisms
L&WA (2003)	Brigalow Belt South Ecoregion, southern Queensland	Assessment of ecological thresholds for native vegetation in southern Queensland. L&WA and NR&M (C. Chilcott and T. Eyre) funded project currently in progress. Using real landscapes and levels of vegetation clearance, environmental markers of ecological condition and vegetation and soil health will be used to determine status and condition of retained vegetation, measures of viability, and, where possible, threshold values for landscape function. Observations likely to be made as part of study include: ground-active invertebrates (related to vegetation cover and soil health), bird and reptile diversity, floristic composition, leaf-eating, sap-sucking and wood-boring insects and leaf pathogens, measurements of soil function, and assessments of soil cover, physical, chemical and biological properties
Pressey (2001)	Western Division, NSW (including cotton growing areas in Darling Riverine Plains Ecoregion)	Proposed approach to scheduling of conservation areas in production landscapes, to adequately protect natural features of area. Approach based on two characteristics – vulnerability to destruction or alteration of native vegetation, and irreplaceability of area (i.e. likelihood that area will be needed to achieve conservation targets)

4.16 The Biodiversity of Cotton Fields

Despite appearances, the diversity of organisms in irrigated cotton fields is much greater than at first sight. This is because the conspicuous life forms (e.g. birds, mammals and trees) represent only a tiny fraction of the total number of species in most ecosystems. Most plant diversity in terrestrial ecosystems tends to be in the understory (the herb or shrub layer), and invertebrates and microorganisms make up by far the majority of species.

There has been no systematic survey of the biodiversity of Australian cotton fields, but information from the literature coupled with expert opinion and unpublished information has allowed us to assemble the following preliminary profile of species numbers and abundance in and over irrigated cotton.

Starting with mammals, native insectivorous bats are attracted to irrigated cotton crops in inland Australia by the abundant invertebrate and moth populations. M. Dillon and L. MacKinnon (pers. comm. 2003) have recorded bats over most cotton fields they have sampled in the Namoi and Macintyre valleys, with high levels of activity (an average of one bat pass per 30 s using Anabat recorders) in some situations. Seven species of bat were recorded over cotton next to remnant native vegetation in the Lower Namoi in the 1999-2000 and 2000-01 cotton seasons, and three species over cotton isolated from native vegetation (Table 4.16). Other mammals reported from cotton fields in the Lower Namoi and Macintyre valleys include pigs (*Sus scrofa*), foxes (*Vulpes vulpes*), eastern grey kangaroos (*Macropus giganteus*) (M. Dillon, pers. comm. 2003), house mice (*Mus musculus*) and brown hares (*Lepus capensis*) (L. Wilson, pers. comm. 2003). A koala (*Phascolarctos cinereus*) was once sighted in a field of seedling cotton (M. Dillon, pers. comm. 2003).

Evan Cleland (pers. comm. 2003) has observed at least 40 species of bird in a 480-ha area of irrigated crops, including cotton and 25 ha of water surfaces, near Goondiwindi (Appendix 10). The breeding residents in or over cotton include Nankeen kestrel, Black-shouldered kite, Richard's pipit and Magpie lark and breeding residents associated with the water storages, channels, culverts and irrigation infrastructure are Australian wood duck, Pacific black duck, Grey teal, Fairy martin and Clamorous reed warbler. In Jarman and Montgomery's (2001) survey of on-farm storages in the Gwydir valley in 1999-2001, an average of 97 water birds (from a total of at least 45 species) was recorded per wetland on each visit, the most abundant being ducks and cormorants (Section 4.4.1). M. Dillon (pers. comm. 2003) has recorded Barn owls (*Tyto alba*) in cotton fields on several occasions at night.

L. Wilson (pers. comm. 2003) has seen the occasional brown snake (*Pseudonaja textilis*) and one carpet snake (*Morelia spilota*) in cotton in the Lower Namoi valley. Others have reported red-bellied black snakes (*Pseudechis porphyriacus*) and the occasional brown snake in cotton in north-west NSW (M. Dillon, pers. comm. 2003). M. Dillon (pers. comm. 2003) has seen a range of reptiles on roads and the verges of pastures and native vegetation on cotton farms, including (in order of frequency of encounter) brown snakes, red-bellied black snakes, blue-bellied black snakes (*P. guttatus*), lace goanna (*Varanus varius*), blue-tongued skinks (*Tiliqua scincoides*), bearded dragons (*Pogona barbata*), various smaller dragon lizards, eastern snake-necked turtle (*Chelodina longicollis*) and Gould's goanna (*Varanus gouldii*).

Table 4.16. Insectivorous bat species detected by Anabat ultrasound recorder around cotton fields near Narrabri in the Lower Namoi Valley in the 1999-2000 and 2000-01 cotton seasons (L. MacKinnon, pers. comm. 2003).

Bat Species	Cotton next to Remnant Native Vegetation (G. Richards, pers. comm. 2002)	Cotton isolated from Native Vegetation (L. MacKinnon, pers. comm. 2002)
Inland freetail (<i>Mormopterus planiceps</i> sp. 3)	✓	✓
Inland broadnosed (<i>Scotorepens balstoni</i>)	✓	✓
Little broadnosed (<i>S. greyii</i>)		✓
White-striped freetail (<i>Tadarida australis</i>)	✓	
Southern freetail (<i>M. planiceps</i> sp. 4)	✓	
Chocolate wattled (<i>Chalinolobus morio</i>)	✓	
Yellow-bellied sheathtail (<i>Saccolaimus flaviventris</i>)	✓	
Lesser longeared (<i>Nyctophilus geoffroyi</i>)	✓	
Total species	7	3

L. Wilson (pers. comm. 2003) reported that frogs can be locally common in cotton fields in wetter years, especially if water puddles in fields and low lying ground is nearby. At such a site at 'Doreen' in the Lower Namoi, frogs have often been caught in pitfall traps. The species present in cotton fields include burrowing frogs (*Lymnodynastes* sp.). M. Dillon (pers. comm. 2003) has occasionally found frogs (*Litoria* sp.) inside pheromone traps alongside cotton fields and once found a green tree frog (*L. caerulea*) in unsprayed cotton at 'Lowana', Pilliga, NSW.

European carp are common in irrigation channels on cotton farms in north-west NSW (M. Dillon, pers. comm. 2003).

Irrigated crops in summer in inland Australia attract a large number of invertebrates, including benign, pest and beneficial species. Fitt and Wilson (2002) recorded 450 morphospecies of invertebrate in one furrow-irrigated cotton field in the Lower Namoi valley in the 1995-96 summer. This is a conservative estimate of the species richness of invertebrates in cotton, because morphospecies can consist of swarms of morphologically similar species ('sibling species').

Cotton funded research has focused on the life cycle, ecology and management of the pest insects as well as the beneficial insects and spiders. Common pests of cotton include the native budworms (*Helicoverpa armigera* and *H. punctigera*), green mirids (*Creontiades dilutus*), cotton aphid (*Aphis gossypii*), spider mites (*Tetranychus* spp) and thrips (*Thrips tabaci* and *Frankliniella schultzei*) (Pyke and Brown 1996, Sadras and Wilson 1998, Mensah and Wilson 1999, Johnson et al. 2000). Beneficial predators in cotton include native ladybeetles (e.g. *Harmonia conformis*, *Diomus notescens* and *Stethorus* spp), red and blue beetles (*Dicranolaius bellulus*), damsel bug (*Nabis kinbergii*), big-eyed bug (*Geocoris lubra*), assassin bug (*Prithesancus* sp.), predatory shield bug (*Ochelia schellenbergii*), green and brown lacewings (*Mallada* spp and *Micromus tasmaniae*), ants (e.g. *Iridomyrmex* and *Pheidole* spp), and lynx spiders (*Oxyopes* spp). Beneficial parasitoids include minute to small wasps that attack helioverpa eggs, larvae and pupae, such as *Trichogramma* sp., *Telenomus* sp. and *Microplitis demolitor*. In their review of beneficials in cotton farming systems, Johnson et al. (2000) listed 90 species of generalist predator (Coleoptera, 25 species; Dermaptera, 2; Diptera, 3; Hemiptera, 14; Hymenoptera, 3; Mantodea, 1; Neuroptera, 2; Odonata, 2; Orthoptera, 1; Thysanoptera, 1; Acarina, 1; Araneae, 35) and 39 species of parasitoid (Diptera, 9 species; Hymenoptera, 30) from Australian cotton fields.

These are some of the more common species, and most of the invertebrate species found in cotton have yet to be identified.

Recent studies have shed light on the soil fauna found in irrigated cotton in north-west NSW. Lytton-Hitchins (1998) recorded 196 species of surface and topsoil dwelling beetle (Coleoptera), ant (Formicidae), earwig (Dermaptera) and springtail (Collembola) in irrigated cotton surveys in the Macquarie, Namoi and Gwydir valleys in the mid-1990s. About 20 species of generalist predator and litter transformer were consistently common on the soil surface in any given cotton field. The nocturnal behaviour of the predatory earwigs, beetles (carrabids and staphylinids) and wolf spiders (Araneae) may have led to their beneficial role in cotton being underrated in the past. Lytton-Hitchins (1998) found that surface-active soil fauna in furrow-irrigated cotton were strongly influenced by irrigation, cultivation, and broad-spectrum insecticide use, with ants and large predatory soil-dwelling beetles most adversely affected.

Hulugalle et al. (1997) reported a range of surface dwelling invertebrates in irrigated cotton on vertisols near Narrabri in the Lower Namoi Valley in the 1994-95 and 1995-96 seasons. Surface active invertebrates were sampled by pitfall traps and the most abundant were springtails, mites (Acarina), ants and beetles. Smaller numbers of bugs (Hemiptera), grasshoppers (Orthoptera), flies (Diptera), earwigs, wasps and bees (Hymenoptera), spiders, thrips (Thysanoptera), moths and butterflies (Lepidoptera) and book lice (Psocoptera) were also recorded. Most surface active invertebrate taxa declined between early (December) and late (March) season in both years due to insecticide spraying, with the exception of earwigs. Higher levels of soil invertebrate activity were recorded in soil cores than in pitfall traps in this study, principally mites and springtails (Hulugalle et al. 1997). Collembola averaged 2500/m² when temperatures were mild and soil moist, but were virtually absent under hot, dry conditions. Mites, on the other hand, averaged 6290/m² in the top 5 cm of soil across all sampling times and treatments, and were resilient to both cultivation and high soil temperatures.

Lytton-Hitchins (2000) quantified the impact of broad-spectrum insecticides on ground fauna in irrigated cotton experiments on two farms in the Lower Namoi Valley in 1998-99. Ground densities of ants in unsprayed furrow-irrigated cotton in mid summer reached 812 222/ha, ant densities averaging between 4 and 25 times greater than in sprayed cotton. Densities increased through the season in unsprayed cotton crops, unlike sprayed crops. Densities of predaceous beetles and wolf spiders were also significantly greater in unsprayed cotton (28 241/ha and 129 120/ha, respectively) than sprayed crops (7732/ha and 18 426/ha, respectively) on certain dates. Earwigs, on the other hand, were more abundant in sprayed cotton (10 926/ha vs 10 046/ha).

In addition to the cotton crop, there are various weeds of cotton that are part of the biodiversity of the irrigated cotton ecosystem. Up to 200 weed species of significance occur on cotton farms in eastern Australia and about 60-70 species of weed can be found in a cotton field over time (Johnson and Hazelwood 2002); G. Charles, pers. comm. 2003). In a typical furrow-irrigated cotton crop in mid-summer, at least 12-20 weed species are encountered throughout the field, contributing 100 kg/ha of above ground dry matter in a well managed (weed-free) crop (G. Charles, pers. comm. 2003). Cotton crops can attain 6 t/ha of above-ground dry matter (Hearn and Constable 1984) and 1 t/ha of below-ground dry matter prior to harvest (Oosterhuis 1990).

There is no systematic information about the diversity and abundance of most of the soil microorganisms in cotton soils, but the numbers are likely to be staggering. One teaspoon (1 g) of fertile agricultural soil contains 2500 million bacteria (Burgess 1958) comprising between 6400 and 38 000 different 'species' (Curtis et al. 2002). One gram of soil also contains an estimated 700 000 actinomycetes, 400 000 fungi, 50 000 algae and 30 000 protozoa (Burgess 1958). Many soil microorganisms cannot be identified or cultured and most are unlikely to be described for a long time to come. Populations vary considerably and rapidly under the influence of season, water, crop, cropping history, cultivation, and inputs (Allen 2002).

Although knowledge of cotton soil microorganisms in eastern Australia is very limited, the soil ecosystems are likely to be comprised of mainly native organisms because exotic species establish only infrequently (D. Nehl, pers. comm. 2003). Although some soil organisms are introduced (e.g. the fungal pathogen, *Thielaviopsis basicola*, which causes Black root rot in cotton), it is difficult to artificially establish soilborne organisms in new areas (e.g. mycorrhizal fungi, *Rhizobium*, and bacteria and fungi for biological control: (Powell 1984, van Elsas and Heinjen 1990, Kloepper and Beauchamp 1992, Smith and Read 1997) unless introductions are approached from the perspective of the organism's requirements (P. McGee, pers. comm. 2003). The native flora and microbes are better adapted to local edaphic conditions and outcompete the exotics unless there is a close relationship that fosters survival and dispersal of the exotic (such as a crop pathogen). According to D. Nehl (pers. comm. 2003), it is unlikely that even a minute fraction of the native fungi and bacteria in cotton soils has been replaced by introduced species since European settlement. Algae may be different, however. Most of the algae seen in cropping soils are wind-dispersed and therefore may be cosmopolitan (P. McGee, pers. comm. 2003).

Farming practices have probably profoundly altered the spectrum of organisms in cotton soils. Cropping would have selected for microorganisms that are better adapted to (1) oxidative conditions and disturbance caused by cultivation, (2) a reduced amount and diversity of organic carbon associated with monoculture cropping, (3) periodic anaerobiosis and flooding caused by irrigation, and (4) extreme localised changes in salinity and mineral availability associated with the use of fertilisers and pesticides (P. McGee, pers. comm. 2003; D. Nehl, pers. comm. 2003).

Populations of arbuscular mycorrhizal fungi found in cropping soils tend to be those that form large numbers of small spores, have rapid life cycles and form survival propagules rapidly, in contrast to those in undisturbed soils where the fungi sporulate infrequently and have less resilience to cultivation (McGee et al. 1997): Pattinson, Heath and McGee, unpubl.; P. McGee, pers. comm. 2003). Preliminary investigations of fungi in the Chytridiomycota indicate that cultivation reduces their diversity but not abundance (Commandeur and McGee, unpubl.). The importance of these fungi is still unclear. Research in progress indicates a high degree of specificity between substrate and fungi in the Trichocomaceae (which includes *Penicillin* and *Aspergillus*) (Markovina, Carter, Pitt and McGee, unpubl.). The consequence of specificity in the Trichocomaceae is that species loss due to reduced diversity of substrate decreases the combative fraction of native species in the soil. Thus we can speculate on the rise to prominence of some native organisms with undesirable characteristics (e.g. *Fusarium oxysporum* f.sp. *vasinfectum*, causing Fusarium wilt in cotton). We still have a patchy understanding of the diversity of microbes in cotton soils.

In recent years, V. Gupta (pers. comm. 2003) has sampled soil microbial biomass in cotton soils on 8-10 farms, finding values ranging from 270-750 kg microbial carbon/ha in the top 10 cm of soil. Comparisons with adjacent cereal and legume grain crops generally reveal higher levels of microbial biomass in the non-cotton cropping soils. This amount of microbial biomass probably corresponds to the order of 10^4 species of microbe per gram of soil (P. McGee, pers. comm. 2003). However, it is important to note that microbial communities are subject to massive changes in numbers and composition in cropping soils, for the reasons noted above.

In terms of biomass, the likely biomass profile of organisms in unsprayed furrow-irrigated cotton in eastern Australia is compared with a northern hemisphere temperate pasture in Table 4.17. As is typical of biomass pyramids (Krebs 1994), plants (in this case, the cotton crop mainly) and the soil biota dominate the biomass of the cotton ecosystem. We were unable to find any information about the biomass or number of taxa of fungi, annelids, algae or nematodes in cotton soils in Australia.

Table 4.17. Biomass of major taxa in unsprayed furrow-irrigated cotton in mid summer (various sources), compared to a temperate pasture (after Pimentel. et. al. 1992).

Organism	Cotton Crop (kg fresh weight/ha)	Temperate Pasture (kg fresh weight/ha)
Plants	13 000 ¹	20 000
Fungi	?	4000
Bacteria and Protozoans	1020 ²	3380
Arthropods	51 ³	1000
Annelids	? ⁴	1320
Algae	?	200
Nematodes	?	120
Frogs	0.42 ⁵	-
Reptiles	0.00 ⁶	-
Birds	0.02 ⁷	0.3
Mammals	0.03 ⁸	1.2

¹ Based on a cotton crop with an above-ground dry weight of 6 t/ha of cotton at harvest (Hearn and Constable 1984), a root:shoot ratio of 0.15 (Oosterhuis 1990), 100 kg/ha of weeds (dry weight), with a root:shoot ratio of 0.15 (G. Charles, pers. comm. 2003), and a dry weight percentage of fresh weight of 55% and 50% for cotton and weeds, respectively (G. Constable, pers. comm. 2003; G. Charles, pers. comm. 2003).

² Based on soil microbial carbon measurements of 250-750 kg microbial carbon/ha (G. Vadakattu, pers. comm. 2003), and assuming a fresh weight conversion from microbial carbon of x 2.

³ After Hulugalle et al. (1997), Lytton-Hitchins (2000) and Fitt and Wilson (2002), assuming an average fresh weight of 0.02 mg per collembolan and 0.01 mg per mite (K. King, pers. comm. 2003), 0.022 g per macroinvertebrate (G. Fitt, pers. comm. 2003), and a linear decline in abundance to zero at 35 cm depth for ground-dwelling taxa.

⁴ Geoff Baker (pers. comm. 2003) will have data on earthworms shortly.

⁵ Based on 1 frog per 20 samples (15 m² of soil sampled to 10 cm depth: M. Dillon, pers. comm. 2003); assumes a frog fresh weight of 5 g (Davies and C. 1993) and a linear decline in frog abundance to zero at 40 cm depth.

⁶ Based on occasional encounters of brown snakes in cotton (L. Wilson, pers. comm. 2003), assuming one snake (1 kg fresh weight, Shea et al. 1993) per 20 fields (average field size, 200 ha).

⁷ After E. Cleland (pers. comm. 2003) and assuming one pair of Richard's pipit (20 g) per 10 ha of cotton field, one pair of Magpie-larks (80 g) per 20 ha, one pair of Kestrels (175 g) per 200 ha, one pair of Black-shouldered kites (280 g) per 250 ha and one pair of Fairy martins (15 g) per 10 ha.

⁸ Based on bat encounters by L. MacKinnon and M. Dillon (pers. comm. 2003); assumes a mean density of 0.5 bat/ha, and bat fresh weight of 11 g. Also use of cotton by mice and hares (L. Wilson pers. comm., 2003) and occasional evidence of pigs and foxes in cotton fields (M. Dillon, pers. comm. 2003); assumes one pig (fresh weight, 86 kg) and one fox (6 kg) per 100 fields (average field size, 200 ha), one pair of hares (4.1 kg) and 10 house mice (17 g) per 200 ha field.

