Chapter 4

Natural resources and environment

From
Future Dilemmas: Options to 2050 for
Australia's population, technology,
resources and environment

Report to the Department of
Immigration and Multicultural
and Indigenous Affairs

By CSIRO Sustainable
Ecosystems

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October 2002

Working paper series 02/01

CSIRO Resource Futures Working Paper 02/01
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Published by
CSIRO Sustainable Ecosystems
GPO Box 284
CANBERRA ACT 2601
Phone: +61-2-6242-1600
Fax: +61-2-6242-1555
This report is available online at
http://www.cse.csiro.au/futuredilemmas

ISBN 0 95808453 X

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Disclaimer

The results presented in this report are a product of the model used and the assumptions stipulated.

Chapter 4
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ABSTRACT

The tertiary population effect dominates the analyses presented in this chapter. Production characteristics of the minerals and agriculture industries, and to a lesser extent forestry and fisheries, are driven not by domestic population levels, but by demand from global export markets. Those export markets are, in turn, driven by populations in the globalised marketplace, and their requirements for subsistence, lifestyle and affluence. Australia engages in export activities in order to pay for the goods and services that it chooses to import. Apart from oil and natural gas, Australia has few resource constraints which will prevent it meeting increased global requirements for its mineral products provided that technology and exploration develop new provinces and processes to access high quality mineral resources. Tensions between domestic requirements and domestic production of oil may be evident from 2015 and natural gas production from 2030. Because of the critical importance of oil and gas to the nation's physical metabolism, it may be necessary to develop a 50-100 year view of these resources and the possible transition pathways to other energy sources such as shale oil, biomass, methane hydrates on the seafloor and liquefaction of extensive coal resources. National and global requirements relating to greenhouse gas emissions may constrain these transitions. Given Australia's large land mass, agricultural production will meet the domestic requirements for food production out to 2050 and beyond. A large number of substitutions over relatively short timeframes, are feasible in dealing with issues such as domestic dietary change, encroachment of agricultural land by urbanisation and changes in globalised trade requirements. However, the environmental effects of agricultural production are substantial and may become further evident from 2020 onwards. Modelling indicates that more than 10 million hectares of agricultural land may be lost to dryland salinity, irrigation salinity and soil acidification by 2050. This will produce a knock-on effect in making rivers and streams more saline and more acidic, which in turn may increase the difficulty and cost of water treatment for urban and industrial use and limit the productive potential of many irrigation areas. Forestry production, mainly from managed plantations, is likely to expand several fold by 2050. This is driven by trade opportunities such as the reduction of wood and wood fibre imports, and by environmental opportunities such as carbon sequestration and dryland salinity mitigation. Domestic fisheries production and domestic dietary demand will continue to extend the physical deficit although expansion of aquaculture may moderate this outcome. There are a number of financial and trade nuances where more valuable fisheries exports (lobsters, tunas and pearls) may pay for the higher volumes of less valuable fish imports from neighbouring countries. The three main areas of resource and environmental concern are the adequacy of future oil and gas production levels, the loss of agricultural land and linked effects on water quality, and a trade imbalance in fish products for domestic dietary requirements.

INTRODUCTION

Domestic population levels have relatively minor primary or direct effects on resource and environmental issues related to mining and agriculture but more pronounced effects on forestry and fisheries. This is because production in the primary commodity sectors is geared to meeting the requirements of global trade, defined in this study as a tertiary or third order population effect. Tertiary effects occur where a nation exports goods to pay for its imports of goods and services. It is often claimed that domestic population levels have little effect on the land degradation now evident in parts of Australia's agricultural landscapes. It is also claimed that most of the land was developed, and thus damaged, in the early 1900s when there was a domestic population of about five million people (Chisholm, 1999). The argument continues that, if most of the land was degraded in a period with a population of five million, then how could a population of twenty million be blamed for the localised effects of drought, bad farming practices and inappropriate government policies.

Using the concept of the tertiary population effect, it could equally be argued that early Australian agriculture was developed to supply the food requirements and manufacturing feedstock for Great Britain which, at the time, was undergoing its own human population explosion. The industrial revolution was being constrained by lack of domestic resources — in essence, a primary effect of human population in that country. In a global and historical context, Cohen (1995) suggests four periods of evolution in human population growth, the first related to development of local agriculture (8000 BC), the second related to global agriculture (AD 1750), the third related to public health (1950) and the fourth related to fertility (1970). The tertiary population effect proposed in this report has its genesis in Cohen's second period, when new world and old world agricultural food species were exchanged (potatoes, maize and winter grains), and international trade and shipping routes were developed. This period allowed the requirements of local populations to be decoupled from the resources available within each country's borders, and saw substantial flows of bulk food and feedstock materials being transported long distances by improved modes of sea transport.

Advances in industrial and agricultural technologies introduced more complexities. The invention in the late 1800s of the Haber-Bosch process for fixing atmospheric nitrogen in the form of ammonia, allowed production of grains and other food to be decoupled from natural recycling processes based on organic wastes and animal manure (Smil, 2000). World food production now depends on the 80 million tonnes of nitrogen produced industrially in this way each year. A number of European countries, which were previously food importers, now use nitrogen and industrialised agriculture to export food and out-compete their previous suppliers in the globalised market place, a more complex example of the tertiary population effect. Concerns about oil availability may produce knock-on effects as natural gas becomes the fuel of choice for electricity generation and personal transport. One tonne of nitrogen (as urea fertiliser) requires 65 gigajoules (10^9J) of energy for both processing and as feedstock (Smil, 2000), and most of this energy is sourced from natural gas.

This tertiary population effect and its subsequent knock-on effects are pervasive in today's world of globalised trade. Australia exchanges large flows of raw commodities for a wide range of elaborately transformed goods and materials. Japan, Singapore and Korea accept our food and mineral exports while we in turn accept their electronic goods, motor cars and heavy machinery. A number of attempts have been made to reconcile the international balance sheet in terms of impacts and land area with concepts such as ecological space (IUCN, 1994), ecological rucksacks (von Weizsacker et al., 1997) and ecological footprints (Wackernagel and Rees, 1996). The tertiary effect of population is well documented in the scientific literature and increasingly being examined in terms of its specific spatial effects. The Netherlands for example (IUCN, 1994) uses six million hectares of foreign crop land to produce forage for its milk and meat cattle herds. New Zealand imports the equivalent land requirement of 3.2 million hectares in goods and services while it exports the equivalent to a land footprint of 14 million hectares, mainly in agricultural commodities (Bicknell et al., 1998). Most developed countries in the world run an ecological footprint deficit, that is, they are net importers of ecological goods and services. Canada and Australia have a footprint surplus because of their relatively low population levels and large land areas (Wackernagel and Rees, 1997).

This chapter examines the response of four resource sectors of the Australian economy to future domestic requirements (the primary population effect) and export opportunities (the tertiary population effect). The sectors are: minerals with a major focus on oil and gas, agriculture both plant and animal based, fisheries with a particular emphasis on the wild caught marine fishery and forestry with emphasis on the expected expansion of managed plantations.

KEY ASSUMPTIONS

Since most sectors dealt with in this chapter seek to supply export markets, the organising structure of the three population scenarios is not used, although those scenarios are examined in relation to oil, gas and fisheries. The mineral sector is generally expanded on the assumption that Australian commodities will maintain a trading advantage in the world marketplace and that improved exploration will continue to locate high grade ore deposits. Oil and gas stocks are quantified on the basis of 95%, 50% and 5% probability estimates of the Australian Geological Survey Organisation (1999) and are judged to be a discrete stock, rather than an unlimited flow. Agriculture is expanded in line with a market analysis undertaken for broadacre commodities several years ago (LWRRDC, 1997) but using the constraints imposed by the three landscape scenarios which attempt to deal with the problem of declining land function.

The treatment of Australian fisheries reflects recent decades where harvesting levels were not constrained, particularly in the fin fish categories. Because of the relatively speculative results of the simulation modelling, the treatment is set within a world context of wild catch fisheries and also bounded by recent State of the Environment Reports from different states on the status of individual fisheries. The treatment of forestry is derived from the expected expansion of forest plantations to deal with the nation's forest products deficit as well as prospective markets for carbon trading. Finally, since much of the chapter does not involve a primary or direct population effect, the influence of population is examined in a descriptive manner where elements of domestic demand are set within the emerging context of expected trends in the global marketplace.

ISSUES FROM THE DIMA WORKSHOP SERIES

In preparation for the design and testing of the population scenarios with ASFF, a workshop series was conducted in 1999 (Conroy et al., 2000), to critically review the structure of the analytical framework and the implementation of the scenarios. The six important issues for this chapter and the scenario implementation response are as follows:

- The treatment of resources and reserves in mining covers some important definitional issues as well as philosophical ones in relation to the decline in resource quality and availability. It is possible that within one human generation the domestic resources of gold, diamonds, copper, crude oil and natural gas may be constrained. The simulation framework uses a full stock and flow for the simulation of all important mineral resources with data sourced mainly from the Australian Geological Survey Organisation (AGSO). In implementing the scenarios, it was assumed that technological innovation leading to exploration success would ensure that most mineral stocks were not constrained in availability or quality for the duration of the simulation. Because of the importance of oil and gas to national economic function, the stock and flow approach was implemented using the 5%, 50% and 95% probability estimates from AGSO to ensure that all petroleum not yet found, was located and developed during the simulation period.

- It is uncertain whether Australia will develop value adding processes for its mining and mineral industries or whether it will continue to supply raw and partly refined commodities to lower wage countries nearby. The simulations have implemented a steady expansion of current practice and export mix in line with industry opinion sourced at the workshop and from key commodity groups. The development of newer metal types such as magnesium is covered in material and energy terms by the expansion of energy intensive commodities such as aluminium. Process efficiencies improve steadily until 2030 and then stabilise as thermodynamic and physical limits take hold.

- Australian crop and animal industries will increasingly be driven by the quality standards expected by a globalised marketplace. An opportunity exists to increase economic returns per unit of product, thereby allowing production levels to be stabilised and more attention to be given to the environmental problems facing the production system. The reality of agricultural commodity trade is that once quality standards are set (apart from highly specialised niche markets) trade in each commodity is then driven by volume. This is the driving assumption for the 'starting position' or base case scenario as well as the 'technological advance' scenario. A 'landscape integrity' scenario implements the concept of environmental care being linked to product quality and increased acceptability by the global marketplace.

- Since many modes of agricultural production are based on the use of irrigation water, the steady expansion of commodity production will increase the requirements for water in southern Australia's already stressed inland water systems. The scenarios assume both technological progress and expansion into areas that are underdeveloped in water terms. For example the expansion of dairy production takes place with a water use coefficient of 500 litres of irrigation water per litre of milk produced, a level currently attained by the top 10% of farmers. Expansion of crops such as sugar, cotton and tropical horticulture takes place in northern Australia. Chapter 6 presents the overall implications for water resources.

- Management reforms underway in the Australian fishing industry will allow the recovery of important fish stocks. As well, aquaculture has considerable potential to supply major portions of the domestic market and meet expanding global demand. The implementation of the wild caught fishing scenarios was undertaken against a considerable body of inquiry into the long-term sustainability of marine production systems and a more detailed investigation into 'national fish futures' by the CSIRO Resource Futures team. Two scenarios were implemented: an 'open slather' approach which allowed initial high production levels followed by the collapse of many fin-fish fisheries; and a 'sustainable fishing' scenario which reduced the catch but allowed it to be maintained in the long term. The opportunity for aquaculture was left as a tension in fish supply under the different population scenarios; a major expansion may occur, or alternatively, fish could be supplied from international marine resources by trade.

- Over the next human generation it is likely that environmental concerns and political forces will compound to cease most harvesting from Australian native forests. This is accepted in the implementation of the forest scenarios which assume a steady expansion of the plantation estate out to 4 million hectares by 2050 under the 'starting position' and 'technological advance' scenarios used for agriculture or an estate of 13 million hectares under the 'landscape integrity 'scenario. Over the inter-generational periods required for wood stocks in plantations to develop, there is at least a doubling of national wood and pulp production.

The following sections detail and discuss the results of the simulation analyses for natural resource issues such as minerals, oil and gas, crop and animal agriculture, wild caught marine fisheries and plantation forestry.

OIL, GAS AND MINERALS

Oil and gas

The potential domestic production of oil may peak at between 26 and 30 million tonnes per year (1,220 to 1,400 PJ) depending on success in finding new resources (Figure 4.1). The graphs need to be interpreted keeping in mind the following points. Firstly, the resource production levels simulated include those that are classed as economic and sub-economic today, as well as the resources that are still to be found. The probability curves relate to surer but smaller estimates (95%) and less sure but larger estimates (5%) with the median probability (50%) positioned in between these two. The assessment is thus reasonably optimistic encompassing the full expectations and opinions of the Australian Geological Survey Organisation (1999) within the current state of geological knowledge and with the use of advanced recovery technologies. The total resource of oil and condensate (pentane and heavier hydrocarbons), is represented by the area under the curve. The shape of the curve can be adjusted to potentially produce more now but less later, provided that the area under the curve stays the same. Generalised curves of this nature, while different for every major oil field, relate to the physical difficulty in extracting the last portion of a resource (e.g. the last 20%). The curves are well developed over long-term empirical data sets for oil and gas reserves in the USA (US Department of Energy, 2000). In general, resource extraction is physically easier for the first 70% of a resource (up to and just past the peak) and more difficult for the final 30%. This is sometimes reported as increasing economic costs of production but usually reflects the degree of physical difficulty.

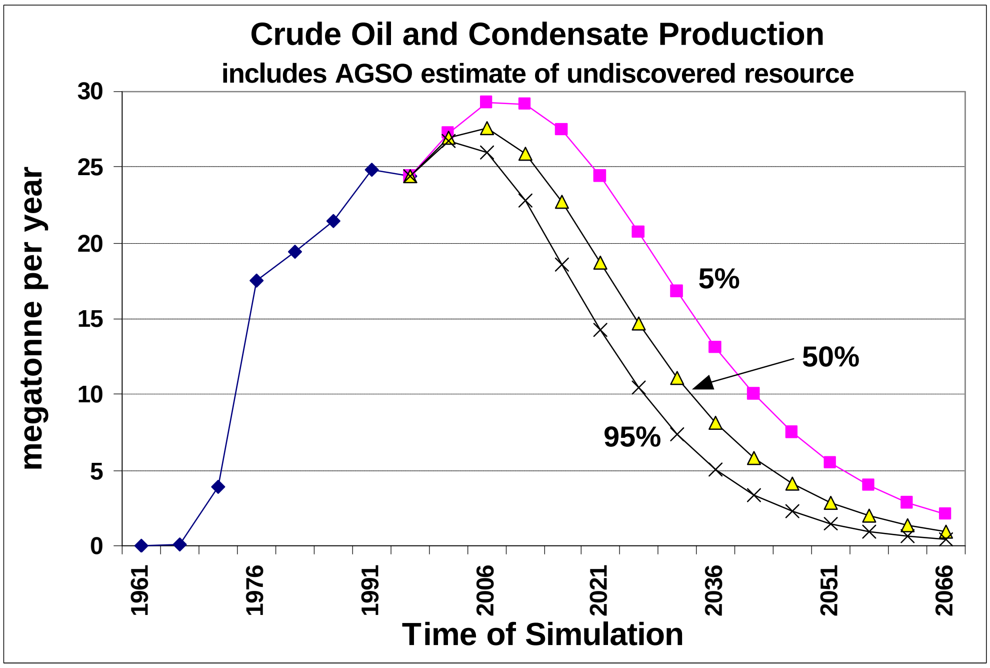

Figure 4.1. Crude oil and condensate production to 2066 based on the 95%, 50% and 5% probability estimates of the Australian Geological Survey Organisation (1999). The total area under each curve reflects the accumulation of past production, current economic and sub-economic reserves and an estimate (the probability levels) of those resources that are still to be found.

This interpretation of future production potential is based on the concept of the Hubbert Curve, which is attracting considerable debate and criticism in the resource and environmental literature (Hubbert, 1967). Laherrere (2000) notes that the method works well when it is "applied to oilfields in the natural domain which are unaffected by political and economic interference and to areas of unfettered activity". The curve also requires a time lag of 30 years post discovery before it can be fitted. The case of Australian oil provinces meets most of these analytical constraints adequately. If the scenario assumptions and analytical approach are accepted as reasonably valid, then a growing imbalance between domestic requirements and domestic production for Australia's oil resources could occur from 2010 onwards.

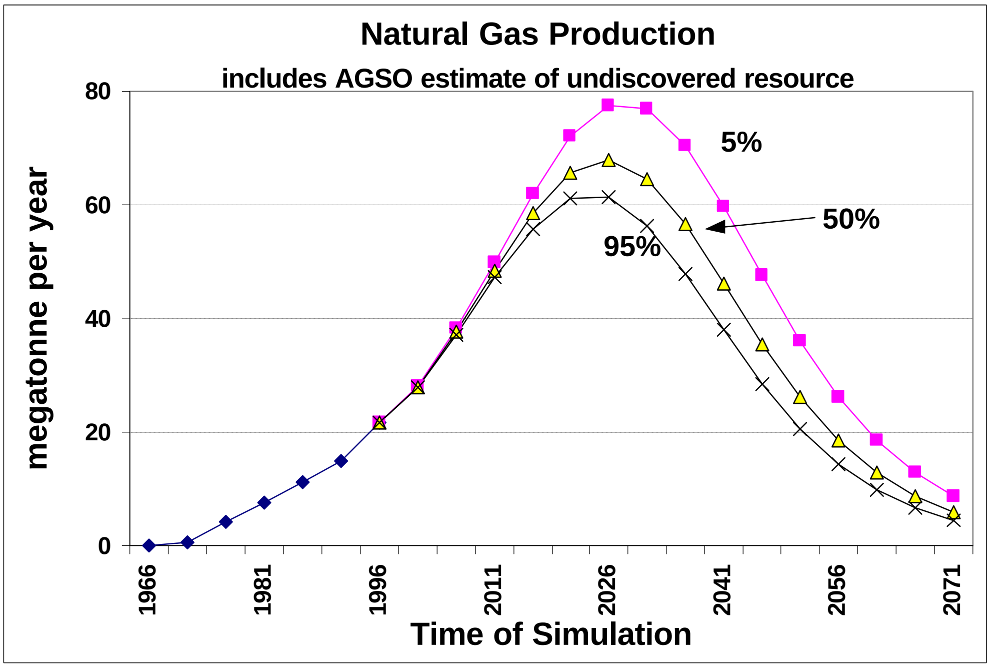

Figure 4.2. Natural gas production to 2070 based on the 95%, 50% and 5% probability estimates of the Australian Geological Survey Organisation (1999). The total area under each curve reflects the accumulation of past production, current economic and sub-economic reserves, and an estimate (the probability levels) of those resources that are still to be found.

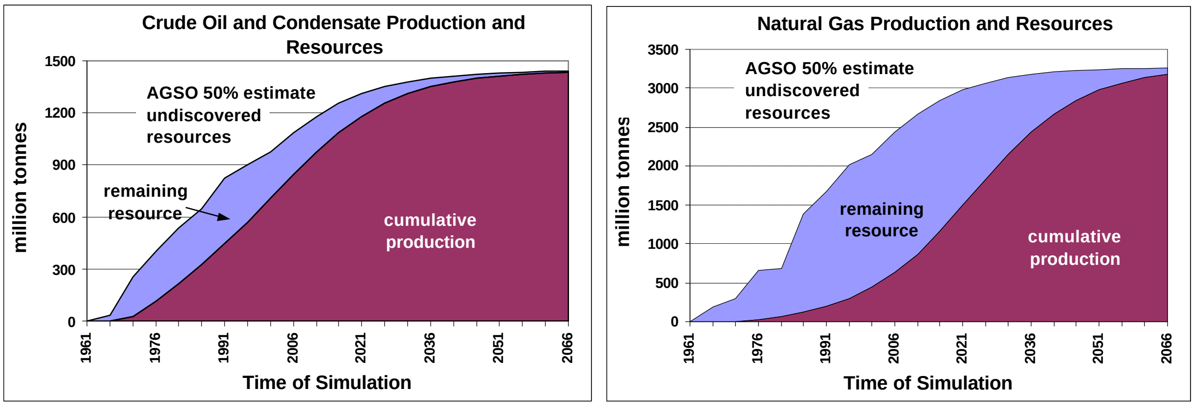

Figure 4.3. Cumulative production and remaining resource for oil and condensate (a) and natural gas (b) to 2066 based on the 50% probability estimates of the Australian Geological Survey Organisation (1999).

The same approach is used for domestic resources of natural gas (Figure 4.2). Because the resources are more plentiful, the peak production of 60 to 80 million tonnes per year (3,200 to 4,400 PJ per year) occurs in the period 2025 to 2035 and a tension between domestic and export requirements and domestic production may occur sometime after that. It is assumed that reserves of both oil and natural gas are developed and exploited as fast as is physically possible and that markets are available for any excess available after domestic requirements have been met. In the case of natural gas, world consumption in 1998 was about 90,000 PJ of which 13,200 PJ was exported by pipeline and 5,000 PJ as liquefied natural gas, giving a total world trade of about 18,000 PJ (BPAmoco, 2000). With the world market for natural gas growing at about 2% per year over the last decade, it is possible that the 1,000 to 2,000 PJ (20 to 40 million tonnes) per year that may be in excess of domestic requirements during the period 2020 to 2030, will find markets with Australia's major trading partners.

Table 4.1. Potential surplus and deficit between potential requirement and potential production for summed oil and gas in petajoules (PJ or 10^{15} J) for 2020 and 2050 using the 50% probability curve from AGSO (1999).

Population scenario	**Potential oil and gas requirement in 2020 (PJ)**	**Potential energy surplus in 2020 (PJ)**	**Potential oil and gas requirement in 2050 (PJ)**	**Potential energy deficit in 2050 (PJ)**
Zero	3,030	1,405	3,540	2,034
Base case	3,180	1,255	4,060	2,554
0.67%pa	3,410	1,025	4,880	3,374
Summed oil and gas production in 2020 and 2050 in PJ from Figures 4.1 and 4.2	4,435		1,506	

The likely time to looming constraints for domestic oil and gas reserves under the 50% probability assumption is shown in Figure 4.3. By 2030 the space between the total oil and condensate resource and the cumulative production over time has narrowed and by 2050 the 'availability' gap has closed completely. For natural gas the picture is more optimistic with the gap beginning to close in 2050 and closing completely by 2070. These outlooks depend on the 50% probability estimates used, and also on the approach which is used to infer possible rates of production and ultimately recoverable resources. It is possible that both sources of inference could attract stringent criticism from experts who expect that oil and gas production could go on forever. However major oil companies such as Shell (Skinner, 2000) note that traditional resources could be affected by both biophysical and political limitations. A report on the oil and gas industries in Texas notes that in order to maintain current natural gas production, 6,400 new wells per year need to be drilled as opposed to 4,048 wells, two years ago (Swindle, 1999). These data represent both the physical cost and the monetary cost of extracting resources from a constrained resource base. Oil output in Texas reached its peak in 1973 when 656 million barrels per year (4,000 PJ) were produced and production rates are now down to 312 million barrels (1,970 PJ) per year (The Economist, 2000). The possibility that vast reserves of shale oil could be brought into production may be limited by energy balance considerations (energy used versus energy recovered) of the process and the greenhouse gas implications (the process releases considerable quantities of greenhouse gas per unit of shale oil produced).

The prospective run down of oil and gas reserves over a 25 to 50 year period is due to a mixture of primary and tertiary population effects. Oil is mainly used domestically, although Australian light crudes are effectively bartered for heavy crudes for bunker oil and bitumen. Oil that is used to transport export goods cannot be assigned directly to domestic population size, i.e. export transport is a tertiary, not a primary population effect. Natural gas is somewhat different, being mainly used at the moment for domestic purposes but with an increasing emphasis on its export potential as a low carbon, greenhouse friendly fuel. Currently one-third of total natural gas production is exported (422 PJ exported of 1,200 PJ total production). Table 4.1 shows some possible linkages between these issues and the three population scenarios. Using the information on oil and gas production trajectories from Figures 4.1 and 4.2, there are potential energy production levels, summed across oil and gas, of 4,435 PJ and 1,506 PJ in the years 2020 and 2025. This leads to a potential surplus of (oil and gas) energy of 1,025 to 1,405 PJ in the year 2020 and a potential deficit of 2,034 to 3,374 PJ in the year 2050. The model exports any surplus, and imports to cover any deficit, with the dollar equivalents added to the merchandise trade portion of the balance of payments calculator. The reason for summing oil and gas is that there are many opportunities for substitution between them, particularly in the transportation sector where cars and buses can be converted to run on compressed natural gas. Chapter 5 explores options for dealing with the potential deficit.

Minerals

In line with industry expectations, the starting position scenario in Figure 4.4 has most key mineral commodity groups set to steadily expand production out to 2050. Production of black coal expands from about 300 million tonnes in 2000 to 1.24 billion tonnes per year by 2050. Total world production in 1998 was about 3.2 billion tonnes (BPAmoco, 2000) and the extent to which this keeps growing depends on a wide range of issues particularly the extent to which natural gas replaces coal in the generation of electricity. Royal Dutch Shell (Skinner, 2000) compares two scenarios for Asia — 'People Power' and 'The New Game'. Under 'People Power' the requirement for both oil and coal continues to expand, whereas under 'The New Game', coal is steadily replaced by natural gas from the year 2010 onwards. By comparison the Shell scenario of power sources for the OECD countries contains virtually no coal by the year 2020.

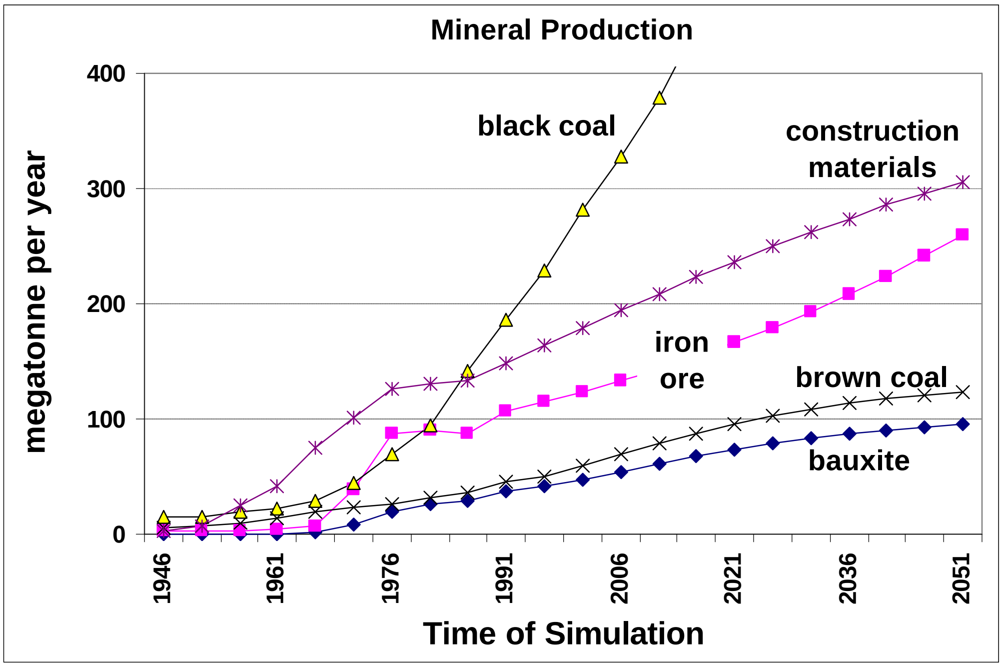

Figure 4.4. Production of major mineral commodities: black coal, brown coal, iron ore, bauxite and construction materials to 2050 for all scenarios.

The base case scenario in this analysis is guided by expert opinion from the DIMA workshop series (Conroy et al., 2000) which suggested growth in production of black coal of 3% per annum and a slower rate for brown coal which is only used in the Australian domestic market. Brown coal production in the base case scenario grows from its current level of 65 million tonnes to 120 million tonnes per year by 2050. A second consideration is the technological development underway to produce 'clean coal' thermal electricity plants. The 'Advanced Pressurised Fluid Bed Combustion' (APFBC) and Integrated Gasification Combined Cycle (IGCC) technologies could give conversion efficiency ratios of coal energy to electrical energy of 44- 47% allowing electricity production to keep growing for the equivalent use of coal and carbon emissions in evidence today. Australia's ability to compete with countries such as South Africa and the USA relies on the proximity of high-grade coal deposits close to deepwater port facilities and it is unlikely that these competitive advantages will disappear by the year 2050. Of more importance will be the global and national attitudes to the use of coal as a fuel in greenhouse gas emission terms, and the competitive advantages to the fuel source that the technological developments noted above might bring.

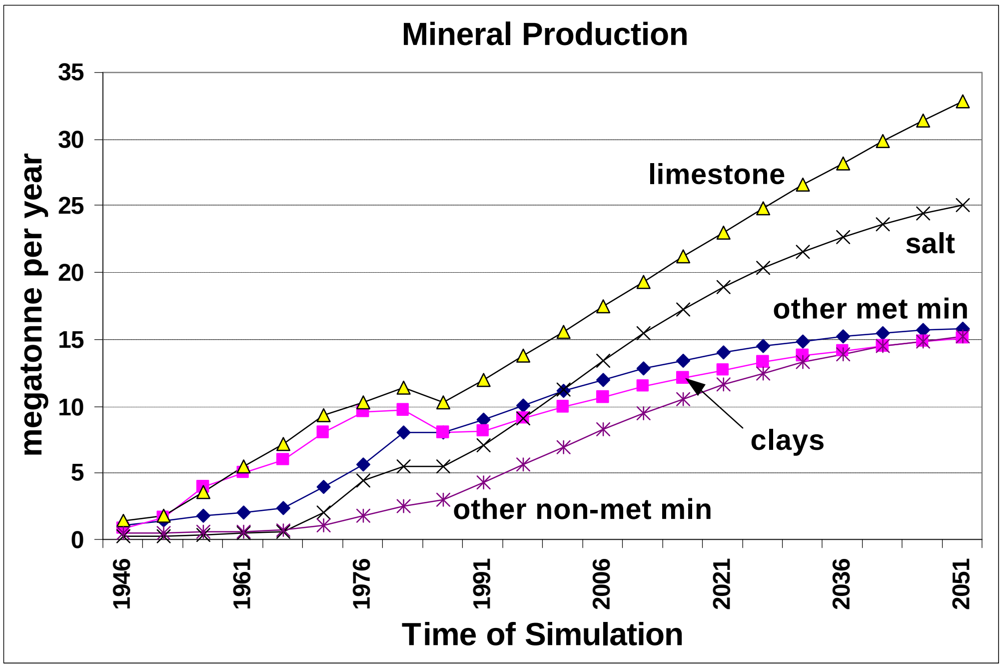

Figure 4.5. Production of major mineral commodities limestone, salt, clays, metallic minerals and non-metallic minerals to 2050 for all scenarios.

Australia's advantages in iron ore production are expected to be maintained with production expanding at the rate of 1.5% per annum from current levels of 160 million tonnes per year (ABARE, 1999) to 260 million tonnes by the year 2050. Most of this production is for export and, while facilities such as the hot iron briquette plant in Port Hedland are not modelled directly, the results can be interpreted to include a range of value adding processes that might take place in the future. The increase in production of construction materials from 180 million tonnes currently to 300 million tonnes per year in 2050 is driven primarily by the construction and maintenance of the built environment described in the previous chapter. The expansion of bauxite production from 45 million to 100 million tonnes per year by the year 2050 is derived from industry expectations of a continuing growth rate of 2 to 3% per year, which in turn is driven by the opening up of a major aluminium smelter somewhere in the world every three to four years. The world requirement for both aluminium and magnesium is expected to continue to expand (perhaps at the expense of steel) as machinery and cars become lighter and stronger in response to fossil energy and greenhouse considerations.

The next tier of mineral production in volumetric terms is shown in Figure 4.5. Limestone and salt are both relatively large items that grow from contemporary levels of about 10 million tonnes to 25-30 million tonnes by 2050. Limestone is used in cement and steel making, and while most is produced in Australia, about 10% of requirement is imported mainly from Japan. Clays are mined predominantly to produce building bricks, but specialised types such as bentonite and kaolin are exported to countries including New Zealand, Japan and the United Kingdom. Production of both metallic minerals (nickel, tin, manganese etc) and non metallic minerals (talc, silica, beach sands etc.) increases to about 15 million tonnes by 2050.

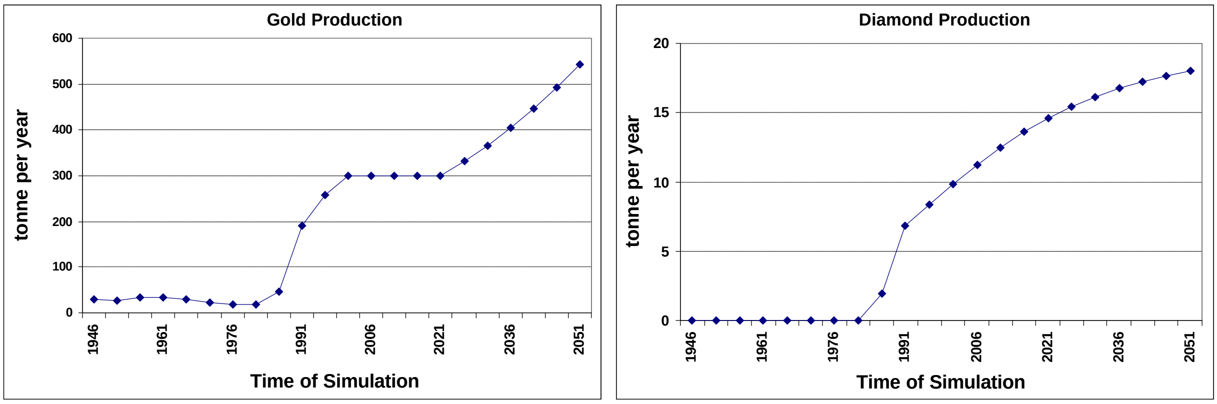

Figure 4.6. Production of precious mineral commodities: gold and diamonds, to 2050.

Gold production has increased from relatively low levels in the 1970s to about 300 tonnes per year. Production is expected to remain at about this level until 2020, influenced by a complex range of external factors (e.g. central bank sales, strength of currencies, demand for jewelry) (Figure 4.6). After 2020, the confluence of new exploration technologies which locate higher grade deposits, new treatment methods for lower grade deposits, political agreements on access to land and an increasing world requirement for gold, is expected to increase production by 2% per year. Production of diamonds is expected to grow from its current level of 41 million carats (eight tonnes) to 18 tonnes by 2050. The levels of gold and diamond production affect a number of material flow indicators that are used in the crosscutting issues in Chapter 7. Because of the low concentrations of gold and diamonds in their respective ore and earth matrices, large amounts of material must be moved and processed to obtain the forecast levels of production. These (generally) hidden material flows contribute to relatively large material flows being attributed to Australia's domestic population, in comparison to other industrial economies with which they might be compared. The high monetary value of gold and diamonds makes them important for future international trade.

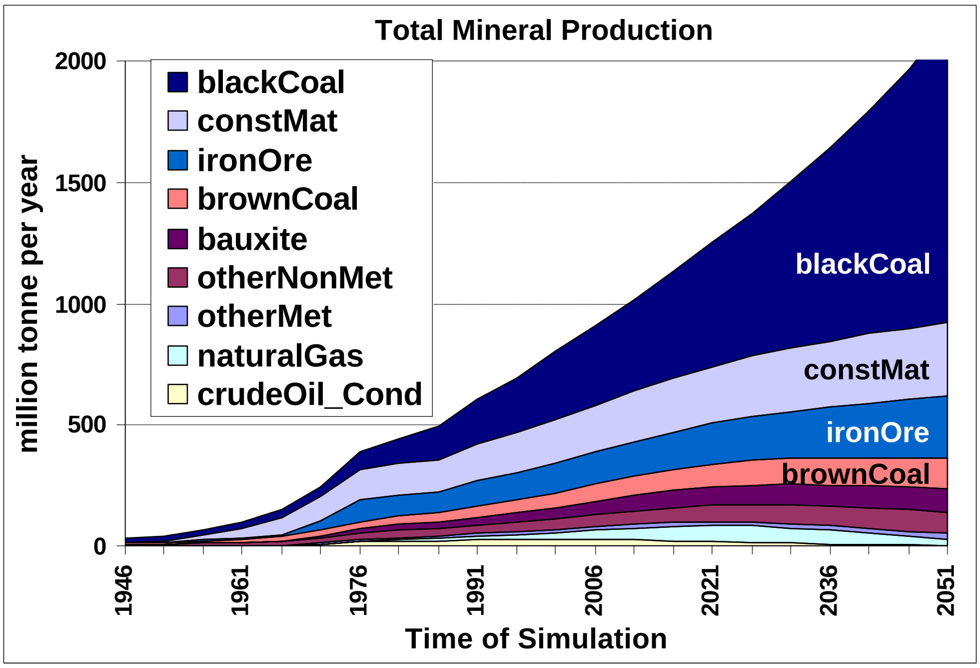

Figure 4.7. Total production of minerals, oil and gas in millions of tonnes per year to 2051.

When all the expectations for future energy and mineral commodity production are considered, total physical production of minerals, oil and gas increases from around 800 million tonnes per year currently to 2,000 million tonnes by the year 2050 (Figure 4.7). More than half of this amount is due to black coal production, most of which is exported. Whether or not this occurs, depends on decisions about the potential greenhouse and environmental consequences of the continued use of coal, mainly for electricity production. The future production of other mining commodities may shrink due to technological developments and changes in market requirements of a number of traditional trading partners. Even if the overall total were reduced by 50% from the 2050 level shown in Figure 4.7, yearly mineral production would be 50, 40 and 32 tonnes per capita per year for the zero, base case and 0.67%pa scenarios.

Apart from domestic oil and gas, this study has assumed that either mineral stocks or reserves are large enough to accommodate 50 years of expanding production, or that exploration is successful in finding appropriately concentrated deposits well ahead of production requirements. Industry expectations are that rich reserves of many minerals are waiting to be found once exploration procedures can see effectively beneath the sand layer that cloaks much of Australia's mineralised areas. It is worth noting that the DIMA workshop series (Conroy et al., 2000) reported "possible constraints on production within one human generation" of copper, diamonds, lead, gold, zinc and high quality iron ore.

AGRICULTURE

Crops

Overall production

Annual production of harvested crop and orchard commodities grows from 60 million tonnes to about 90 million tonnes by the year 2050 (Figure 4.8). The largest components are raw sugar cane and grain. Other harvested crop commodities such as hay, fruit, vegetables and cotton make up the remainder. Grazed pasture production for animals is not included in this analysis.

The problems related to agricultural production

The most important feature of current agricultural systems in Australia is not the limitation on production levels, but the looming environmental challenges posed by the problems of dryland salinity (PMSEIC, 1998; Alexander et al., 1998; Commonwealth of Australia, 2001-a), irrigation salinity (MDBMC, 1999), soil acidification and general structural and nutrient decline (PMSEIC, 1999; Gorrie and Wonder, 1999). Problems with dryland salinity affect 2.5 million hectares and potentially more than 12.5 million hectares of prime agricultural land (PMSEIC, 1999). Recent estimates from the National Land and Water Audit put the area of possible land affected by dryland salinity in 2050 at 17 million hectares (Commonwealth of Australia, 2000-a). Monetary assessments value the contemporary damage at $130 million per year in lost agricultural production, $100 million per year in damage to infrastructure and $40 million per year in loss of environmental assets. Overall, more than 24 million hectares of soil is considered acidic and, while much of this is natural, agricultural management technologies such as legume pastures without balancing lime applications, and the application of nitrogenous fertilisers, are causing the soil acidification process to accelerate. Losses due to soil acidification are estimated to exceed $134 million per year.

The problem of irrigation salinity is locally important in terms of crop production with 560,000 hectares affected by high water tables in the Murray Darling Basin. In a regional sense, irrigation salinity is also important as excess salt loads are transferred to river systems. By 2020, many of Australia's main inland river systems will exceed the 800 EC (exchangeable cations) limit, that defines water of acceptable drinking quality. In 100 years, several important rivers will have passed the 1,500 EC threshold, which then precludes the water from being used for irrigation (Commonwealth of Australia, 2001-b). The direct cost of irrigation salinity is estimated at $46 million per year in the Murray Darling Basin and is expected to continue rising as salt levels in rivers increase (MDBMC, 1999).

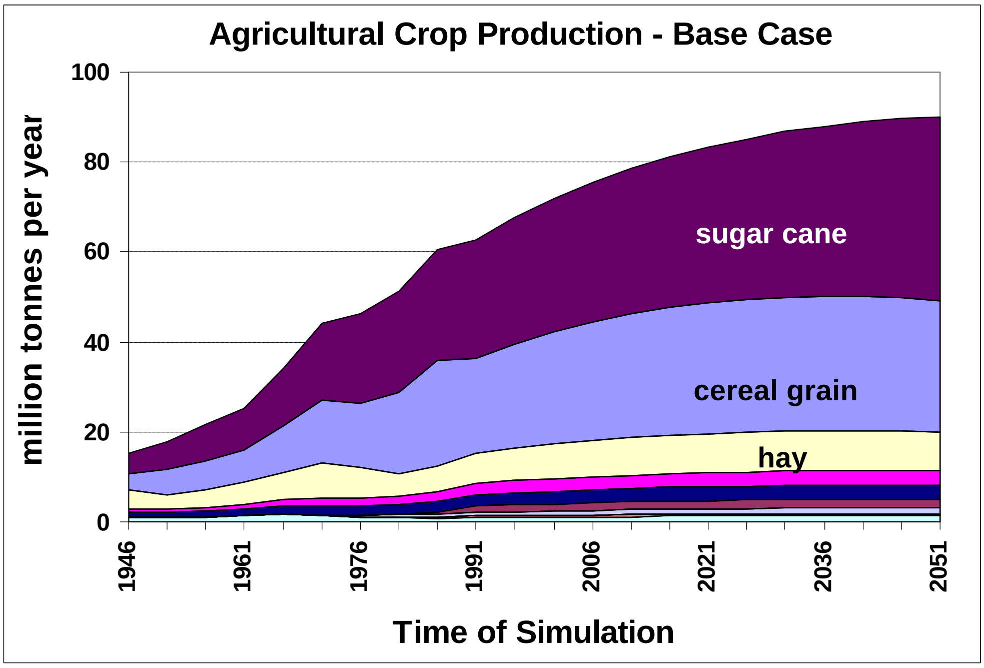

Figure 4.8. Total production of agricultural crop commodities under the starting position scenario to 2050.

As many resource management and commodity production issues are not linked directly to population size in a primary or a direct sense, the next set of analyses does not include the population scenarios as components of the agricultural sector. Production levels are several times higher than required to feed the resident population, be it 20, 25 or 32 million people by the year 2050. The base case scenario leading to 25 million people is used as the template to develop two additional approaches to dealing with the complex set of nested and linked issues described in the previous paragraphs. The key elements of the three scenarios have been developed by Dunlop et al. (2000) and are briefly described below.

The 'starting point' scenario for agricultural production

The starting point or base case scenario for agricultural production is developed from an integrated history of land development over the last 50-100 years with future development in each area reflecting past development. This has been a period of intense technological development with large increases in production. The scenario includes modest (slowing) increases in the area of cropland, representing a shift from grazing to cropping, some further clearing and more use of previously cleared land that is not currently used for agricultural production. It includes conversion of agricultural land to plantation forestry or other woody vegetation, but at a rate about half that required to meet the target contained in the 'Forests 2020 Vision' (DPIE, 1997). Some additional cropland is converted to plantation or other woody vegetation as it degrades below a threshold cropping yield. Reductions in the rates of increase of dryland salinity follow from the establishment of woody vegetation. Genetic improvements to yield, pest and disease resistance, and climatic tolerance lead to small but steady increases in crop yields. The rate of fertiliser application increases with concomitant yield benefits. The use of soil conditioner (e.g. lime and gypsum) increases, but not to the extent that it balances soil acidity and soil sodicity at a broad scale. Similarly, introductions of new crops and cropping systems (e.g. industrial quality oil-seed, agro-forestry, and alley cropping), and improvements in irrigated water use are not large enough to yield significant environmental and production gains.

The 'landscape integrity' scenario

The landscape integrity scenario aims to create agro-ecological systems that are inherently more robust and resilient by restoring hydrological and soil chemical balances that better match Australian landscapes. This approach results in lower total production and may take decades to yield significant benefits. However, it should use less energy and material inputs, reduce the on-site and off-site effects of biophysical decline, and better conserve and restore biodiversity and ecosystem services — those unpriced natural processes that contribute to overall economic value. This scenario is motivated in part by the growing interest in more biological production systems such as organic farming and consumer demand for 'clean green' food and fibre.

The scenario includes retiring at least 30% of arable cropland with matching planting of woody vegetation and no new additions to the area of cropland. More cropland is converted to woody vegetation once it becomes moderately degraded. This further concentrates production on only the best cropland and should also significantly reduce the external effects of land degradation (e.g. off-site discharge, salinisation, silting and acidification of streams and wetlands, effects on biodiversity). Conversion of cropland to woody vegetation provides direct positive hydrological outcomes which will help sustain the remaining cropland by preventing salinity. It also provides direct and indirect benefits for biodiversity. This scenario sees more legumes being incorporated into the cropping system, returning nitrogen to the landscape and also assisting with recharge control by using perennial species. Fertiliser use and its rate of application increase. More animals have been included in the farming system; in the model this is represented by increasing the proportion of cropland used to produce animal feed (hay and silage). The establishment of extensive areas of deep-rooted perennial vegetation is accompanied by significant slowing in the spread of dryland salinity. The rate of soil acidification and soil structural decline also gradually decrease when modified cropping systems are adopted over the first half of the simulation period. It is assumed the increased acidification caused by extra legumes and fertiliser use is more than balanced by better control of nitrate leaching and use of lime.

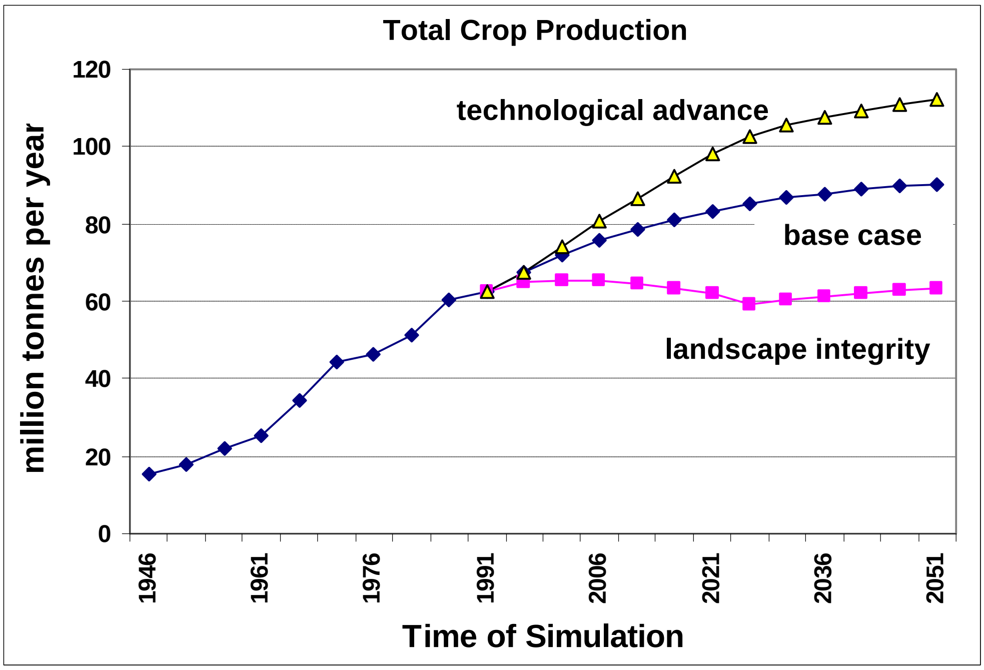

Figure 4.9. Total production of agricultural crop commodities to 2050 under three scenarios: the starting position (base case), landscape integrity and technological advance.

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The 'technological advance' scenario

The technological advance scenario uses and develops crop technology and farming systems to minimise the negative effects of the significant changes to the hydrological and soil chemical balances caused by European style agriculture in Australia. Resources are deployed with the aims of maximising yields and total production and achieving rapid reductions in the effects of landscape biophysical decline. As in the base case, this scenario includes some additions to cropland. Significant areas of agricultural land are converted to plantation forests to meet the *2020 Vision* target and the most severely degraded cropland is converted to woody vegetation. The changes in the mixtures of crops in this scenario are aimed at increasing profitability by increasing the area of high value crops e.g. vegetables, fruit and oil-seed. The use of fertiliser and irrigation is increased significantly in this scenario. As in other scenarios, the rate of increase in dryland salinity is reduced as a function of the establishment of woody vegetation. Landscape biophysical condition is also managed by more direct interventions such as deep drains and pumping to address rising water tables and increasing the application of lime and gypsum to address soil acidity and soil sodicity.

Scenario results

The technological advance scenario increases total harvested crop production to about 110 million tonnes per annum compared to the base case at 90 million and the landscape integrity scenario which maintains crop production at about the current levels of 70 million tonnes per annum (Figure 4.9). The major crops, cereal and sugar cane account for much of the difference between the scenarios (Figure 4.10). Sugar cane production increases by five million tonnes a year by 2050 under the technological advance scenario, and falls by nearly 15 million tonnes in the landscape integrity scenario, relative to the base case. For total grains, the advantage of the technology scenario is again an extra five million tonnes per annum whereas the landscape scenario reduces the base case by 12 million tonnes per annum and takes total grain production at 2050 back to levels of the late 1970s. The responses of the other crop types are similar but much smaller.

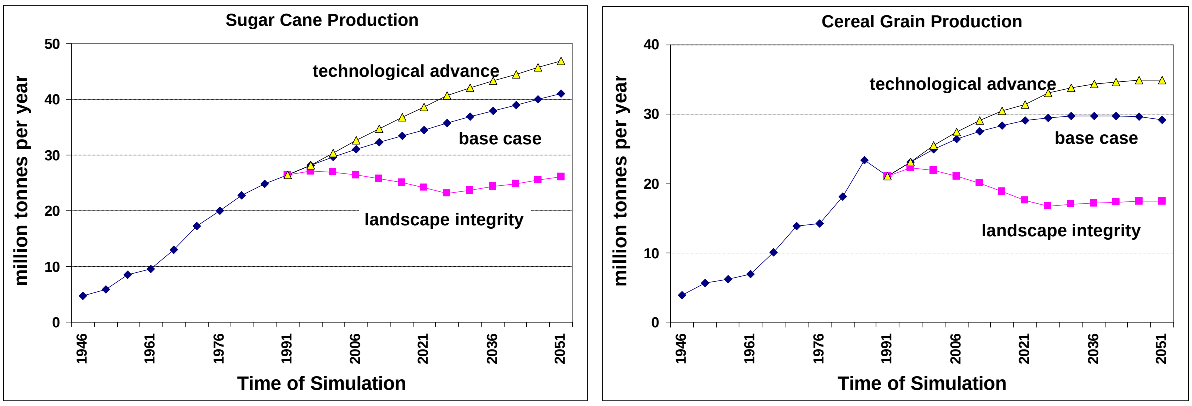

Figure 4.10. Total production of sugar cane and cereal grain to 2050 under three scenarios, the starting position (base case), landscape integrity and technological advance.

The complexity of these scenarios is based on radically changed landscapes over 60 million hectares or more in Australia. The experimental results, where catchments or sub-catchments are repaired and then refurbished as the ecosystem services are re-established, have not yet been implemented at a practical scale. At a theoretical level, research and development is accelerating along several scenario directions. Agricultural technologists are developing crop types and management systems that seek to adapt to, and live within, systems that are seemingly constrained in a bio-physical sense. Land and water scientists who study landscapes over hydrological timescales, lean towards the landscape integrity scenario and seek to re-establish across regional landscapes, the key elements of pre-European water balance and nutrient flow characteristics.

Regarding the future production context for both domestic and export agricultural products, it is possible that certain markets at a regional or product level will be regulated and that the starting position (base case) or technological advance scenarios will not be accepted because of related (real or perceived) external effects due to their production systems. Whether the amelioration and refurbishment activities included in the landscape integrity scenario are cost effective or politically acceptable is then less relevant. If the starting position scenario is precluded because of market requirements (i.e. trading partners will not accept Australian exports because of perceptions of unsustainable land management practices), then agricultural land users and the nation's citizens may be obliged to change their practices or, alternatively, accept a declining importance as an exporting sector.

Additional key biophysical issues are on the policy horizon, but are not yet being addressed. The importance of a full complement of biodiversity (or landscape process diversity) which enables ecosystems to provide the services that humans want, is now recognised commercially at a wide range of levels, e.g. the urban water catchment issues discussed in Chapter 3. A similar issue is that of carbon trading and carbon sequestration in relation to global concerns about greenhouse gas emissions. Implementation of carbon trading could see farms re-forested, arable paddocks managed specifically for carbon accumulation, and harvested products becoming a secondary consideration. Once again, the landscape integrity scenario is compatible with these views because it provides a decrease in overall production, but with assumed increases in landscape values and products that are currently not valued or rewarded in the marketplace.

Another issue is related to national or regional perceptions external to the agricultural production system but which feed back to regulate activities within that system. The concentration of salt in inland river systems and streams and how it affects urban supplies and services in cities such as Adelaide is a typical example. The issues listed above — and many others — allow the three agricultural production scenarios to be evaluated in the context of whether trade-offs can be made between more or less production for less or more delivery of ecosystem services.

Recent work at a landscape level on the macro-changes wrought by European farming methods since 1800, suggests the type of biophysical principles that help underpin scenario explorations such as this study (Gordon et al., 2000). Since 1800, 30-50% of forests and woodlands have been cleared to develop arable and pasture land. This has resulted in a general reduction in the amounts of water vapour transpired by the annual crops and pastures that have replaced the wooded vegetation types. This reduction in evapo-transpiration or water vapour flow, is in the order of 10% of the continental totals, from 3.44 billion gigalitres (10^9L) in 1780, to 3.1 billion GL per year in 1980. This reduction of 339,000 GL per year is roughly equal to 600 times the water contained in Sydney Harbour (Sydney Harbour contains approximately 540 GL). The water no longer used in plant growth has increased both river flows (enabling more irrigation than might have been possible), and the recharge of underground water, some of which elevates groundwater tables and causes dryland salinity, as previously buried salt layers are brought closer to the root zones of crops and pastures. Part of the solution is to develop new farming systems (e.g. deep-rooted perennial grain crops) which use or transpire more water, before it percolates past the root zone in the top two metres. Another approach is to replace crops and pastures with the forest and woodland types that previously covered Australia's farming zones as described in the landscape integrity scenario. The regional areas, where these landscape problems are most evident, are also those where the transpiration rates have been lowered by as much as 30% to 50% compared to pre-agricultural situations.

Land

The concept of total land stock is an important descriptor of past and present production potential. Australia has a large land area of 770 million hectares, but less than 30 million hectares of this (less than 4%) is of good or very good quality in terms of broadscale cropping potential (Dunlop et al., 1999). Compared to the more fertile soils on younger landscapes in North America and Europe, Australia is poorly endowed with good quality soils, most of them being located on narrow floodplains along rivers, or in areas with relatively recent volcanic activity.

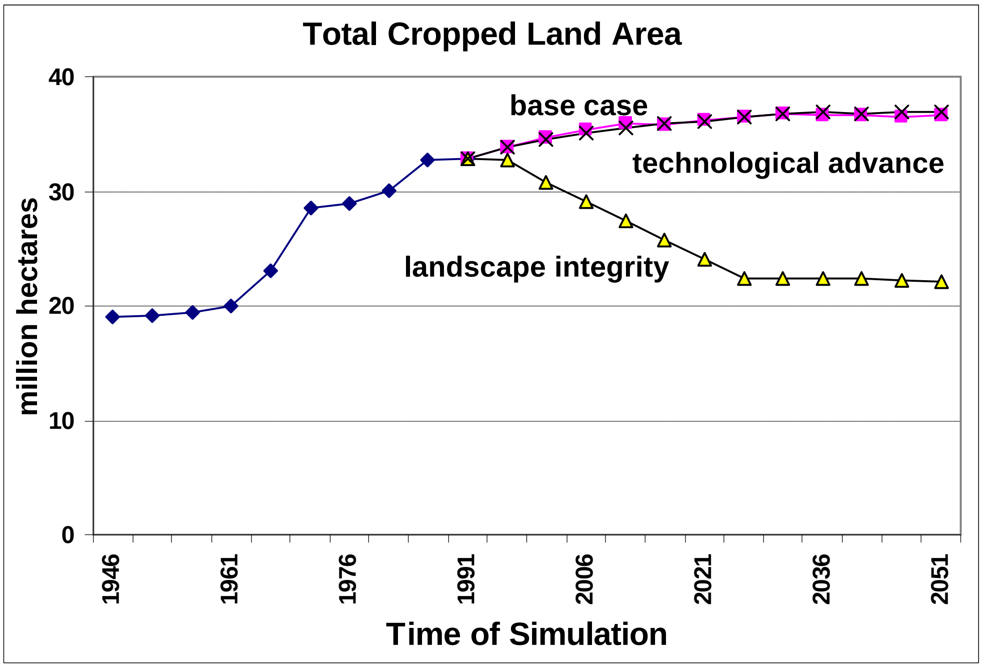

Figure 4.11. Total area of arable land to 2050 under three scenarios: the starting position (base case), landscape integrity and technological advance.

The land use implications of the three scenarios result in the stock of ploughed land increasing marginally to 37 million hectares under the starting position, and technological advance scenarios, and decreasing to 22 million hectares by the mid 2020s for the landscape integrity scenario (Figure 4.11). As noted in the scenario descriptions the changes are due to a mix of pro-active and reactive strategies. For the starting position and the technological advance scenarios, some extra areas of ploughed land are added to the stock of agricultural land. In all three scenarios, land was retired when it became degraded and could no longer maintain a sufficient level of production. The levels were set at very high thresholds of degradation and require yields to drop to 20% of that expected in the starting position and 10% of that expected in the technological advance scenarios. By comparison, in the landscape integrity scenario, land is actively retired at 30% of the expected yield and additional land is reforested. These defensive actions are assumed to reverse the degradation trends set in place by alteration to the landscape hydrology described above and other soil and biophysical processes.

The issues that relate to infrastructure size and age are portrayed for the arable land stock in Figure 4.12. All three graphs show an aggregated picture of the history of land development in the Australian farming zone over the last 50 years since the 1940s. From 1965 to 1975, about one million hectares of land were developed per year, or nearly 10 million hectares for that decade. During this period, cropping areas in Western Australia and Queensland were greatly expanded. If problems with landscape function were simply related to the length of time of arable usage, then the 'age of arable stock' factor might cause a crisis in land productivity some 100 years or more into the future as most of the arable stock loses function at the same time. However regional differences in landscapes, soils, clearance rates and farming practices mean that reductions in landscape function do not appear uniformly over time. Within the stocks and flows modelling approach used in ASFF, agricultural land use is simulated in 58 different statistical regions and the landscape function changes are tailored to current estimates of local conditions and landscape processes.

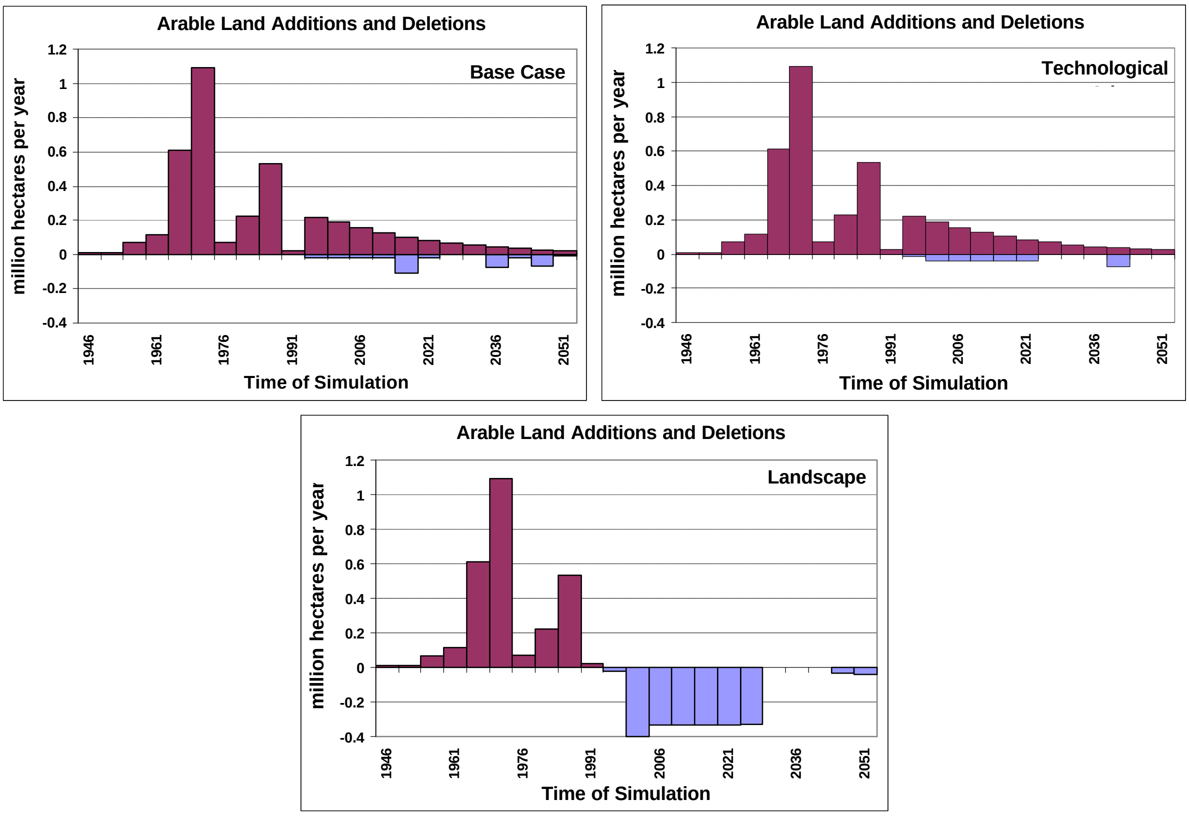

Figure 4.12. Rates of arable land development (additions) and arable land loss (deletions) under the starting position (base case), technological advance and landscape integrity scenarios. The bars represent millions of ha cleared and developed over a five-year period.

With these methodological constraints imposed, the progressive loss or alteration of the arable land stocks is shown in Figure 4.12 after 1990, for the three scenarios. Both the base case and technological advance scenarios require the further development of more than one million hectares to maintain production levels and to make up the land lost to degradation or transferred to forestry. By contrast, the landscape integrity scenario actively places 11 million hectares of land into forest or woodland vegetation, to halt and reverse the multiple causes of loss in landscape function.

The areas of land potentially prone to losing their landscape function and service are shown in Table 4.2. Three categories of threshold are presented with the 50% threshold (i.e. land where due to landscape function problems, crop production is 50% lower than expected) being the most defensible (i.e. it is unlikely that a land function effect giving a 25% reduction in yield, could be distinguished from the yearly effects of climatic variation). Using this threshold value, both the base case and technological advance scenarios could have 8-9 million hectares of arable land with low landscape function, compared to 2 million hectares in the landscape integrity scenario. In this last scenario, a large area has already moved from the cropping estate into the forest estate, and overall agricultural production has been deliberately reduced to lower absolute levels, but not necessarily a lower value of production either per unit of physical production or per farm enterprise.

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Table 4.2. Potential changes in cropping land function in millions of hectares under 75% and 50% yield thresholds for the starting position, technological advance and landscape integrity scenarios.

Yield threshold for land deletion	Starting Position	Technological advance	Landscape integrity
Voluntary or pro-active cropping land retirement by 2050 under different scenario assumptions	0.6	1.1	10.1
Cropping land with 75% of base yield by 2050	20	16	9
Cropping land with 50% of base yield by 2050	9	8	2
Degraded cropping land (zero productivity) by 2050 under different scenarios	1.3	0.4	0.7

The key point about losses in landscape function is that they occur over long time scales. If the problems keep developing past 2050 to 2100, then much of the land categorised under the 75% yield threshold may have progressed to the 50% threshold, thereby putting 16-20 million hectares, or half the arable land stock, potentially at risk of permanent decline. By contrast, moving the land back into the forested or wooded state evident a century ago, could give a landscape composition that is more resilient in an ecological sense, and one potentially with a wider array of uses. Non traditional uses for this substantial increase in stocks of forest and woodland could include a partial transition to a biomass based energy economy. Foran and Mardon (1999) compare a number of scenarios that require between 17 and 31 million hectares of forested or wooded land to power an economy which uses methanol and ethanol (from biomass) as transport fuels, and distributed electricity plants fuelled by gasified wood. The key advantages of these systems is that they are carbon neutral in greenhouse emission terms, and they stimulate employment and economic development in rural areas. Thus a biomass based fuel cycle could allow the implementation of the landscape integrity scenario for an economic rationale with shorter-term financial rewards. If landscape rehabilitation and purely biophysical returns provide the main stimulus, then it may be difficult to attract the large capital sums required for implementation of the scenario.

Animals

Animal production is simulated to expand for most commodities to meet trade expectations (sheep, beef and dairy) and domestic requirements (pig meat, chicken, eggs). Under the base case scenario sheep numbers increase from current levels of about 117 million to 170 million by 2050 (Figure 4.13). This is a rather surprising assumption, given recent constraints in the wool industry. It is based on opinion in the DIMA workshop series which saw that potential improvements in gene technology will be able to deliver a fibre grown to whatever specification is required (Coleman, 1999; Tian and Yang, 1998; Conroy et al., 2000). The fact that Australia has de-pastured flocks in excess of 150 million in the past suggests that increasing flock numbers to this level will again be physically feasible. A parallel assumption is that the effectiveness and efficiency of management must increase to best practice to deal with inevitable droughts and the many negative impacts of grazing over the past 200 years.

Under the starting position scenario, the beef cattle herd increases from about 26 million to 50 million by 2050. The peak cattle herd achieved in recent history was 34 million in 1976 (LWRRDC, 1997), a time of exceptional rainfall conditions over many parts of pastoral Australia. Some analyses suggest a systematic under-reporting of livestock numbers of more than 10%, implying that real numbers at any time are greater than national statistics might indicate (Howden, 2001).Changes in world market opportunities at that time led to restrictions in slaughterings, significant pressure being applied to the grazing land and considerable landscape degradation. Thus the physical feasibility of this component of the animal base case scenario is perhaps more contentious when run concurrently with the increasing sheep flock. The market rationale for the beef scenario is that many of Australia's trading partners will have increased their per capita wealth and their citizens will require a higher proportion of meat protein in their diets. Global food projections to 2020 suggest that beef demand will increase by 30 million tonnes, of which 15 million tonnes will be in nearby Asian countries (Rosegrant et al., 2001). While Smil (2000) proposes that world food requirements will be met in a more sustainable manner with less, rather than more animal protein, Australia has substantial capacity to produce beef from pasture provided that the country retains an adequate disease-free status. A pasture-based industry might achieve trading advantages in comparison with the more intensively managed feeding systems of other countries.

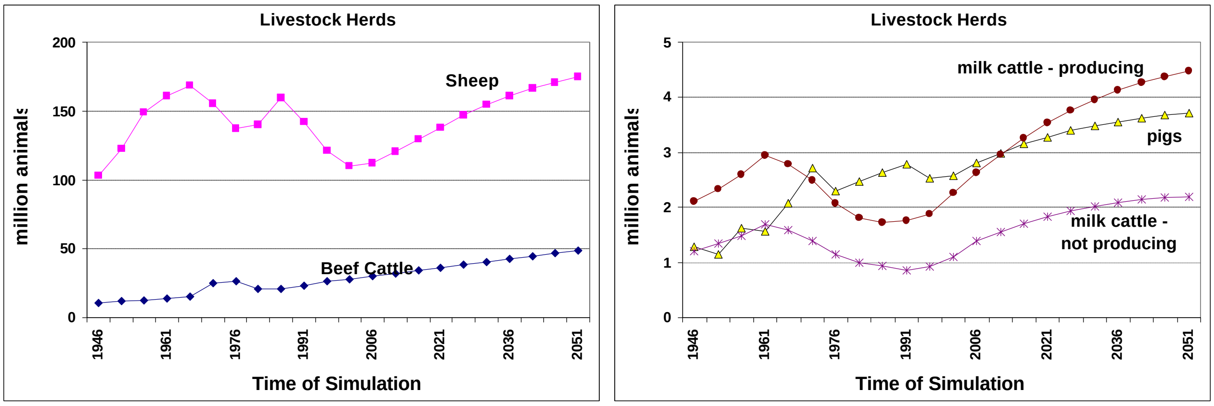

Figure 4.13. Animal numbers in millions for the starting position (base case) scenario to 2050.

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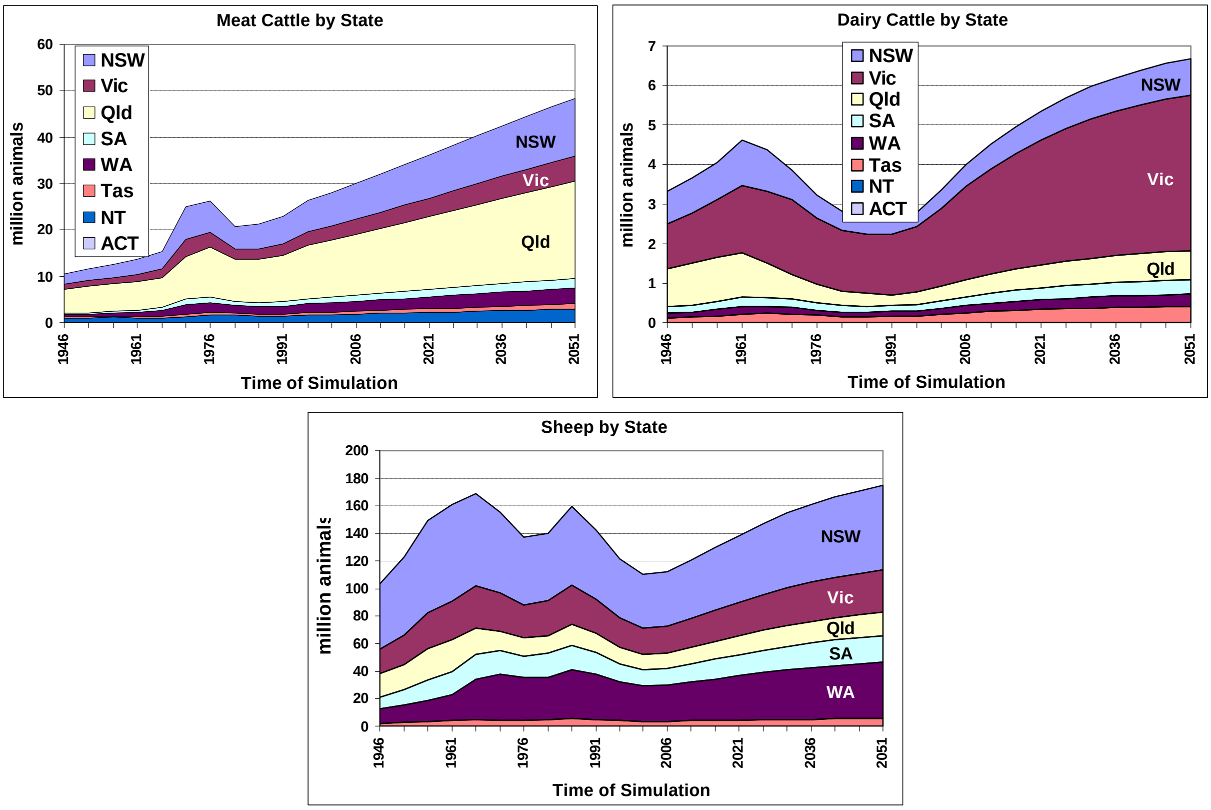

Figure 4.14. Location by state of meat cattle, dairy cattle and sheep to 2050.

Another rationale for the beef herd part of the animal scenario is based on a 2020 exploration of agricultural trade potential undertaken by the Land and Water Resources Research and Development

Corporation (1997). The continuing expansion of the beef herd continues the trend to 2020 developed in this study on the basis of population and GDP per capita growth in Australia's potential export markets. Conventional wisdom might indicate that the combined grazing pressure of the beef cattle and sheep scenarios surpasses sustainable limits. The nation's pastoral industry has not operated at this level in the past. An optimistic interpretation might assume that the next 50 years could bring substantial changes to both grazing technology and grazing management. Domestic livestock consume nearly 30% of managed yearly pasture production. Some experts argue that 60% of grown pasture could be consumed leaving enough ground cover and plant litter to ensure soil health and nutrient recycling. This may be optimistic. However by viewing these future options as scenarios, rather than as predictions, this analytical approach seeks to explore the implications of development, expansion and growth of a wide range of sectors. In general, expanding physical activity within an array of linked sectors (such as agricultural production in regional economies) stimulates the growth and development that most modern economies rely on for their continuing function and optimism.

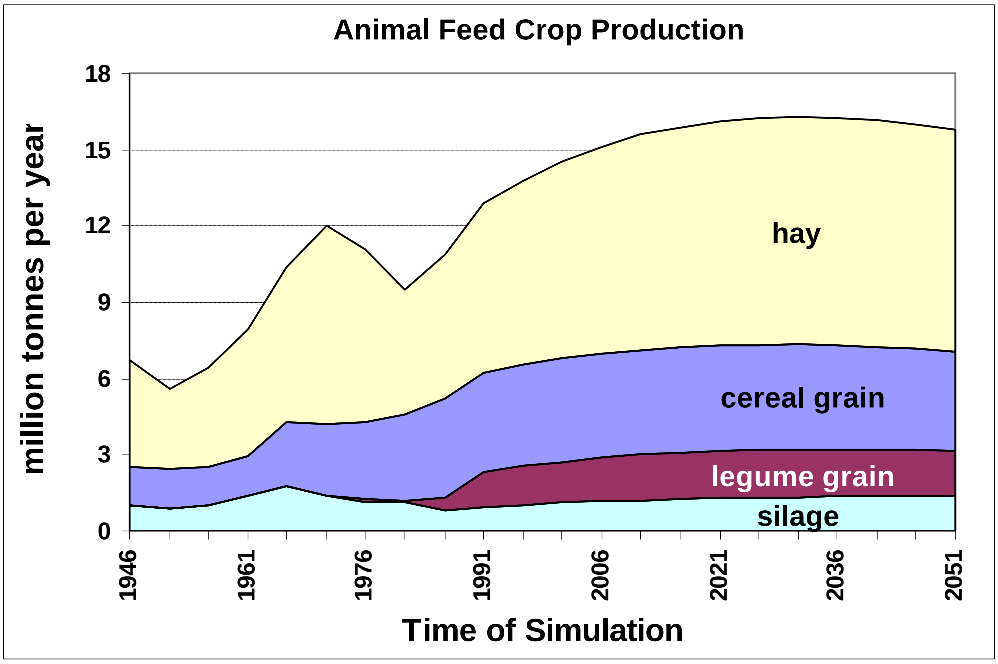

Figure 4.15. Crop production requirements for livestock feed (excluding grazed pasture) for the starting position scenario to 2050.

Under the starting position scenario, the number of dairy cattle doubles by 2050 from a contemporary level of about three million with a ratio of 2:1 for the producing versus non-producing parts of the dairy herd. The number of pigs increases from a current level of 2.6 million to nearly 4 million by 2050. The chicken flock (not shown) increases from about 90 million to 150 million by 2050. The distribution of animal numbers by state is shown in Figure 4.14. Queensland retains the greatest share of the beef cattle herd with New South Wales in second place. For dairy cattle, Victoria retains the dominant share of the industry with more than 60% of total numbers. The rest are spread around the states in proportions that reflect recent reality. The recent deregulation of the dairy industry could see Victoria gaining a greater share of the national dairy herd than assumed in this scenario. This, in turn, could affect the sectoral use of water in Victoria. Western Australia and New South Wales share most of the national sheep flock as it grows to former levels. For all animal groups, the changes in numbers and productivity shown in the historical period to 1990 are due to interacting effects of international commodity prices, domestic political decisions and climatic variability. These effects are not included in the simulations from 2000 to 2050.

The key assumption in the starting position scenario is that most of the additional forage required for livestock comes from both intensive and extensive pastures. The forage requirement produced by the arable land stock is shown in Figure 4.15 with modest increases in both hay and grain. It is assumed that the energy and environmental implications of cattle feedlots (Smil, 2000) cause a shift back to pasture feeding and that all the grain is fed to pigs and poultry. The 500,000 cattle in feedlots in 1999 (ABARE, 1999) could be assumed to gain 150 kg in liveweight over their 120-170 day stay. Assuming eight kg of grain per kg of liveweight gain, this requires approximately 600,000 tonnes of grain, or 1.2 million tonnes if there are two turnarounds of cattle per year. This is well within the grain allocation to livestock of nearly five million tonnes per year shown in Figure 4.15. The 1.2 million tonne allocation to cattle feedlots would furnish the feeding requirements (to marketable size) of two million pigs and 200 million chickens. The feed budget from the cropping sector shown above is thus within the correct order of magnitude.

Table 4.3. The feed requirements per kilogram of animal liveweight gain and edible product (after Smil, 2000). (note that low values such as 0.9 for salmon describe the wet animal weight per unit of dry feed)

	Milk	**Eggs**	**Chicken**	**Pork**	**Beef feedlot**	**Salmon**
Kilograms of dry feed per kilogram of product or liveweight gain	1	2.5	2.5	4.0	8.0	0.9
Kilograms of dry feed per kilogram of edible product	1.1	2.8	4.5	7.3	20.0	1.4

Decisions about the nature and extent of intensive livestock feeding are important ones within a future context. Authors such as Smil (2000) argue cogently that potential human hunger crises could be averted by feeding the 700 million tonnes of grain crops currently fed to animals, to people, so providing a largely vegetarian diet to more than three billion people. Australian consumers may not wish to revert to a largely vegetarian diet, but it is worth considering the amount of grain and other inputs required for intensive animal feeding to produce a kilogram of liveweight gain, or a kilogram of edible product (Table 4.3). In this context, the issue of food composition choice for a domestic population, is one area where the tertiary or trade effect of population might revert to a secondary (more directly linked) population effect. Although the use of concentrate feed to produce milk has a relatively high efficiency, in Australia there is an added dimension that each litre of milk production requires between 500 and 1,000 litres of irrigation water under many intensively managed systems (Doyle and Kelly, 1998). Salmon and many aquaculture systems achieve similar levels of feeding performance to milk, but they also have a number of environmental problems particularly their reliance on fish meal. Both chicken and pork do not perform as efficiently when the terms of conversion are changed from liveweight to edible product. Beef in feedlots gives the poorest performance under these measures of physical performance, although the resultant product might be more highly valued in financial terms, or more easily sold in export markets.

In line with assumed increases in numbers of animals in the base case scenario, the production of all levels of animal products rises steadily to 2050 (Figure 4.16). The most notable is beef and veal production which rises from two million tonnes per year (MLA, 1999) to more than four million tonnes by 2050. Mutton and lamb grow from the current 0.63 million tonnes per year (MLA, 1999) to one million tonnes by 2050 while wool production (or fibre derived from sheep) grows from 0.7 million tonnes currently to 1.8 million tonnes in 2050. There is an increase in chicken meat production grows from 0.62 million tonnes to 1.8 million tonnes over the same period. A number of other animal products, shown in Figure 4.17, double in physical production levels over the next 50 years. Milk production also doubles from a current level of 10 million tonnes of whole milk to 22 million tonnes by 2050.

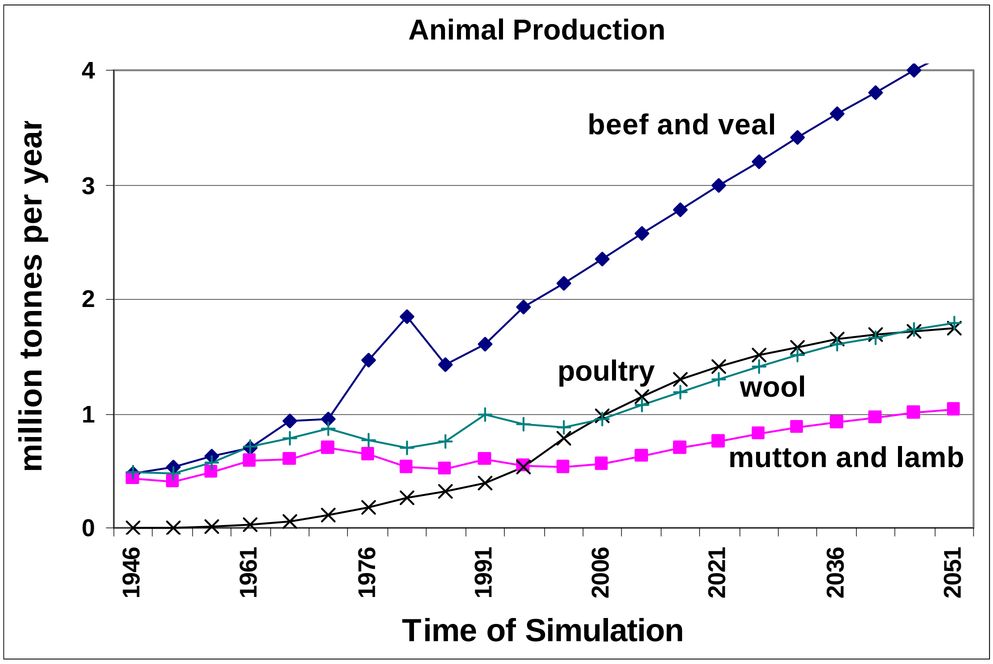

Figure 4.16. Animal production to 2050 for key commodity groups in the base case scenario.

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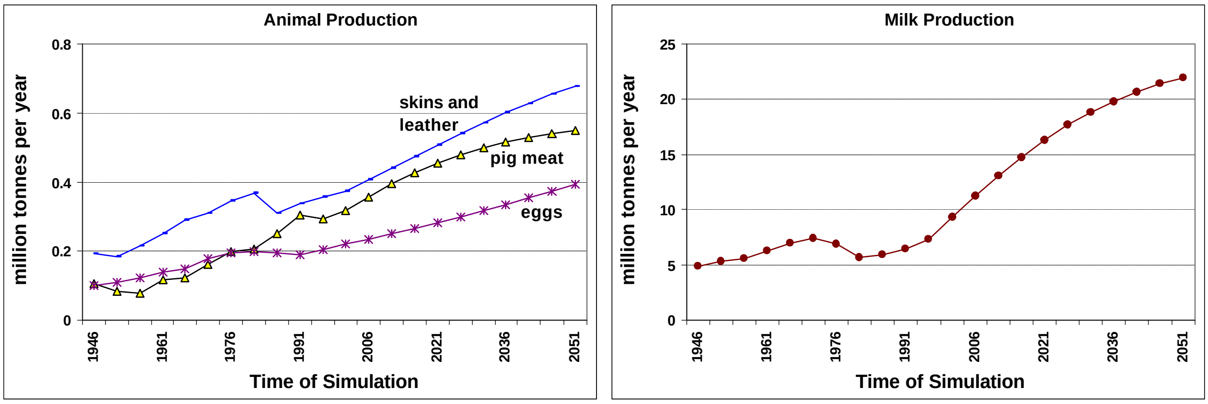

Figure 4.17. Animal production (skins and leather, pig meat, eggs) and milk production for the base case scenario to 2050.

Apart from the concurrent increase of the sheep and cattle herds already discussed, most of these increases in production appear feasible. While the full water account will be presented in Chapter 6, the implication of a doubling of milk production warrants comment here. Assuming that the entire industry moves to best practice and uses 500 litres of irrigation water for each litre of milk produced, this requires 11,000 gigalitres (10^9 L)or nearly one half of the current managed water use in Australia (ABS, 2000-b). Estimates for water usage in dairy production vary from 3,470 GL (Thomas, 1999) to 4,167 GL (Lenzen pers. comm.) per year, or approximately one sixth of the Australian total. The 2050 level of use required by dairy production would sit within a total water use of about 40,000 GL per year, or one quarter of the national total. Perhaps this is feasible, but the question of where dairy production is located in relation to requirements of other industries, the problem of salt load in rivers and high water tables in irrigation areas, and the relationship of environmental flows and overall river health, require a comprehensive and detailed study beyond the scope of this analysis.

FISHERIES

Global overview

In an effort to place Australian wild caught fisheries in a suitable context of production and management, this section opens with an expanded description of the global situation. In 1996 the production of wild caught fish was about 95 million tonnes of which 90% came from the marine areas (oceans, seas and estuaries) of the world (FAO, 1999-a). Aquaculture contributed a further 26 million tonnes of which China contributed 70%, although Chinese aquaculture now appears to have been overestimated. Seven countries (China, Peru, Chile, Japan, USA, Russian Federation and Indonesia) account for more than half of the world's wild capture. Global landings of marine fish are continuing to level off, and this is so for most of the world's major fishing areas. The main fisheries in the Atlantic Ocean and many areas in the Pacific Ocean are considered to have levelled off and substantial catch increases from these areas are therefore unlikely. Forty four percent of major world fisheries are considered fully exploited, 16% are over exploited and 10% are depleted, with expected long lead times if they are to recover former levels of production. Nearly 32 million tonnes of fish, representing nearly 30% of total world fish production, is used for high quality protein to feed other animals in the human food chain such as aquaculture fish, pigs and poultry. Environmentalists assert that fisheries decline is linked directly to human population size and will affect poor nations first, where fish protein forms a critical part of nutritional adequacy and where per capita consumption could fall by 50% by 2050 (Population Action International, 1995).

The world's fisheries literature contains considerable debate on the future untapped potential and how to manage fisheries at risk from depletion. One view (Pauly and Christensen, 1995) argues that humans are gradually eating their way down the trophic levels (the web of life) by exploiting successive layers of marine life that depend on the lower levels for their growth and reproduction. This process can lead to higher catches in the short term as top level predator species are removed, and the next layer of fish species take advantage of a wider range of ecological niches. These researchers further argue that ecosystem changes then occur because the fisheries ecosystem becomes unbalanced resulting in stagnating and/or declining catches. This leads to an overall assessment that fisheries production from wild caught world fisheries is set on unsustainable patterns of exploitation and management. There are many caveats on broad generalisations of this type and Beddington (1995) points to poor data in all national and international fisheries. By-catch production is not assessed or data is not collected and most fisheries are essentially un-managed commons where the unaccounted for, or the shadow catch, may also be substantial.

Although most informed commentators agree about the state of world's fisheries, there are many different ideas about how to move to more sustainable pathways (Caddy, 1999). In an overview of world fisheries management Mace (1996) suggests concerted action in three key areas: (i) reduce global fishing capacity by 50%; (ii) implement a workable rights system in wild fisheries; and (iii) implement a precautionary approach. The key scientific principle of the precautionary approach is that a single species 'maximum sustainable yield' represents a harvesting limit that should never be exceeded. In practice, this limit is routinely exceeded. A recent review of marine issues in New Zealand (Parliamentary Commissioner for the Environment, 1999) found that the institutional, legal and knowledge bases regarding marine and fisheries issues were fragmented and that management for sustainability was unlikely to be effective until organisational issues were reformed and integrated. The importance of incorporating up-to-date fisheries biology into fisheries management (Beverton, 1998) is an obvious, but routinely overlooked factor. Some highly productive species that are generalist feeders can recover reasonably quickly after a crash due to natural disasters or overfishing. Other long-lived and slow-growing species such as orange roughy and deepwater dories, that gather in localised areas such as sea mounts, can be quickly over-exploited when technological advances allow substantial catches to take place.

A number of more optimistic views run counter to the pervading sense of gloom on wild-caught fisheries. Nutrient enrichment of near coastal areas from agricultural and urban runoff and sewage can cause a bottom-up effect due to stimulation of algal growth and in turn the growth of a range of marine organisms which feed on the lower trophic levels (Caddy et al., 1998; Pauly et al., 1998). However the stimulation of algal growth can quickly turn to eutrophication, toxic algal blooms and 'red tides', while the entry of heavy metals into the food chain can pose problems of accumulation for human health. The importance of aquaculture and its potential for covering imbalances if wild catch fisheries decline, is also attracting attention in government policy and commercial development. Smil (2000) notes that aquaculture in China, based on plant-eating carp species, produces more than six million tonnes of fin fish yearly, with feeding efficiencies approaching those of chicken egg production. Once again, this optimism needs to be tempered by a number of developing realities.

Marine aquaculture species that are favoured in the international marketplace require an input of fish protein two to five times that of the eventual output (Smil, 2000). Further elaboration by Naylor et al. (1998, 2000) indicates that while the farming of Atlantic salmon had grown to 0.65 million tonnes per year by 1997, the industry required 1.8 million tonnes of wild fish to be added as fish meal to the diet, giving a conversion ratio of 2.8:1. The aquaculture of shrimps or prawns requires feed with 30% fish meal and fish oil. It can result in a net loss of fish protein over the whole production cycle and the system of management often produces long-term environmental damage to surrounding ecosystems. Much research is being carried out into aquaculture and breakthroughs can be expected whereby plant based proteins will eventually replace fish proteins in aquaculture diets. This will help break the trophic dependency of higher valued species such as salmon and shrimp on lower-valued species such as anchovetta, sardine, telapia and carp.

Local examples of the global situation

Australia represents a microcosm of the world situation. The simulation results reported in this study are well supported by a body of world literature. The added dimension is that Australian waters — like its arable land — are amongst the least productive in the world. This lack of productivity is exacerbated by the lack of upwelling areas, where deep cold currents rise to the surface, bringing food, nutrients and increased fish productivity, around our coasts. The Australian fishing zone is the third largest in the world, occupying 10 million square kilometres, but the tonnage caught there is 54th in the world (FRDC, 1999). The south east fishery produces 25,000 tonnes per year for all species with blue grenadier contributing 5,000 tonnes of that total. By contrast the blue grenadier (or hoki) fishery in New Zealand, produces 250,000 tonnes per year, more than the total tonnage of the entire Australian fishery. Australia produces about 220,000 tonnes valued at almost $2 billion per year. One-quarter of all fish production is exported and much of this is high value species such as lobster, tuna, abalone and pearls. Aquaculture produces about 30,000 tonnes per annum or one-eighth of the total. Australians consume more than 12 kilograms of fish per capita per year of which 70% or more is fin fish.

While the exact status or health of Australian fisheries is unknown, it generally reflects the world situation, with the proviso that many important fisheries are now under close management and monitoring and could therefore improve. Fishery status reports in 1997 and 1999 on a limited group of Commonwealth fisheries reported that four species were overfished, 10 to 12 are fully fished, 1 underfished and the status of 13 to 15 fisheries is uncertain (Caton et al., 1998; Caton and McLoughlin, 2000). The status of species such as southern school shark, orange roughy, eastern gemfish, tiger prawns and southern bluefin tuna is questionable and these species are now subject to higher scrutiny and more deliberate management actions such as changes in the levels of total allowable catch.

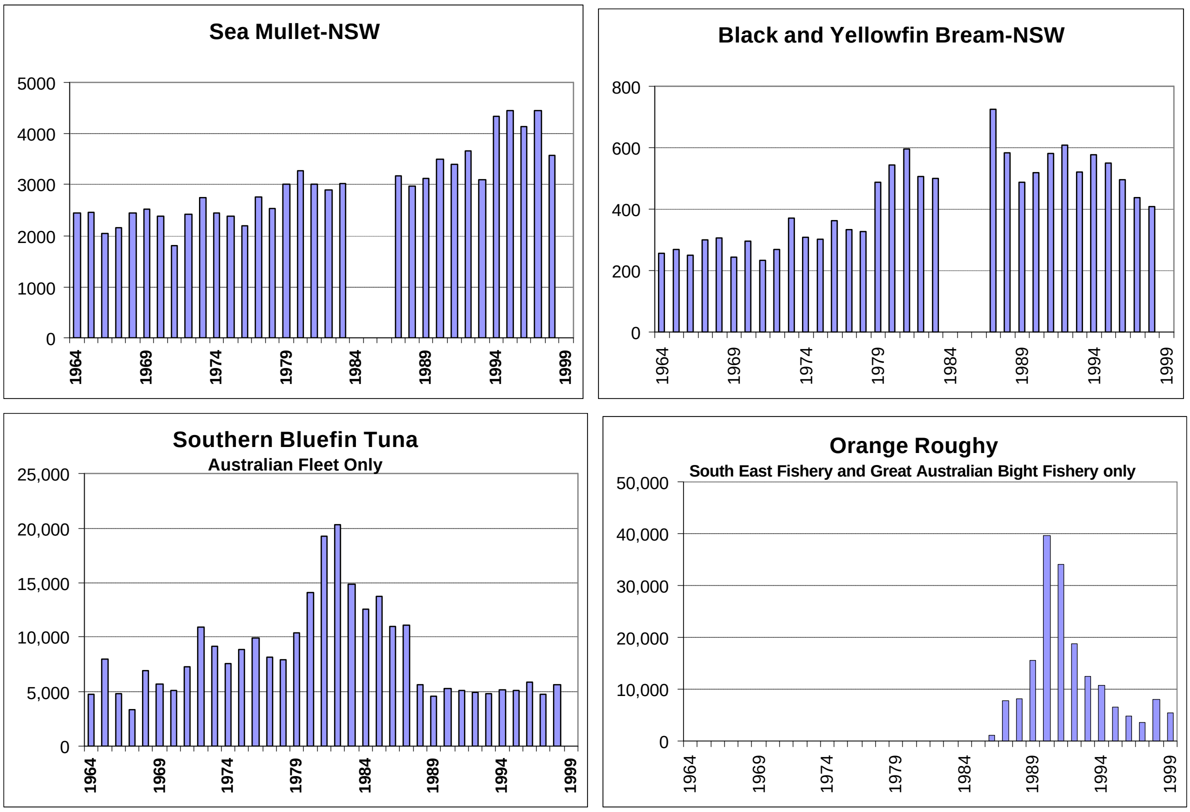

Figure 4.19. Time series of production for selected wild caught fisheries for period 1964 to 1999. Note difference in scales on y axis. (Data sources are BRS Working Paper No. WP/14/91 and ABARE Fisheries data 1990 to 1999).

The dynamics of fisheries and the management imposed on them is shown in Figure 4.19 where the actual recorded catch from four discrete species fisheries are portrayed for the last 35 years. The upper pair of graphs for sea mullet and black and yellow fin bream show moderate but increasing rates of catch for the period. Some hypotheses propose that these species are maintained by the bottom-up stimulation of algal growth due to agricultural and urban runoff. By contrast, the bottom two graphs portray data for long-lived cold-water species typical of those more prone to over fishing. Southern bluefin tuna reached a peak catch of 20,000 tonnes in the early 1980s, while orange roughy peaked at nearly 40,000 tonnes in the early 1990s. The yearly catch for both species has declined to levels much less than the peak catch and their fisheries are now subject to quotas. Studies on similar fisheries suggest that it is unlikely they will recover in the short term (Matsuda et al., 1998; Polacheck et al., 1999). In a well documented New Zealand example, more than 70% of orange roughy caught were taken from seamounts, and fish populations in those areas showed a strong decline over a ten-year fishing period (Clark, 1999; Clark et al., 2000).

The aggregated modelling approach used in ASFF uses a database from over 50 individual fisheries and a relatively simple traditional fisheries modelling approach to develop its numerical representation of past and present production. After modelling at a single fishery level, the fisheries are combined into five broad market types (freshwater, tunas, other marine fish, molluscs, crustaceans). Fishing effort is assumed to move from one fishery to another of the same type, if fish stocks in one location become exhausted. Some important biological parameters of particular fisheries, such as the time it takes to recover after a crash, are currently unknown. While this modelling presents an over-aggregated and simplified view of complex biological dynamics, the general picture is supported by more detailed work at the level of 160 different marine fisheries, under a research contract from the Fisheries Research and Development Corporation.

'Open slather' fisheries scenario to 2050

An 'open slather' management scenario is used to simulate the free market approach to marine fisheries management, overtly or covertly prevalent in many of the world's fisheries. This is followed by a 'sustainable fishing scenario'. Under an 'open slather' approach, yearly production in the 'other marine fish' category rises from 40,000 tonnes to 150,000 tonnes per year by 2010 (Figure 4.20). The production goal, implicit in the number of boats and therefore the fishing effort, is set to increase to 200,000 tonnes per year by 2040. However, simulated production from the fisheries declined to less than 50,000 tonnes per annum by 2020 and then crashed completely by 2040. The overall crash was composed of a set of sequential events that related to the dynamics under increasing fishing effort of a large number of individual fisheries (Figure 4.21).

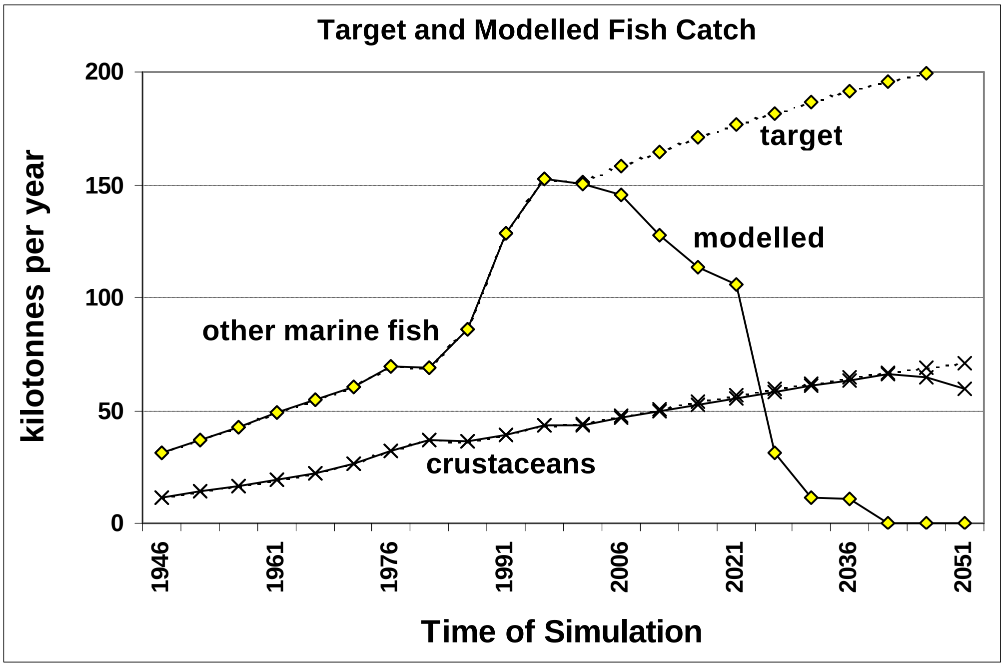

Figure 4.20. Simulated fisheries production to 2050 for an 'open slather' management scenario for fish groups 'other marine fish' and 'crustaceans' comparing the target catch and the modelled catch.

Each one of these individual; fisheries (represented by different layers in Figure 4.21) is exploited under the assumption that fishing effort moves on, if fish catch drops below a predefined level. A large proportion of total production is made up of long-lived 'orange roughy' types. It is assumed for the purposes of the simulation that further resources of this type are continually located and exploited. It could be argued that the fishing effort would not be maintained for long enough to drive the entire fishery down to virtually zero production. Long before this point of absolute crash, total allowable catch management arrangements would be implemented, or the reduction in economic return would force fishers into bankruptcy. The crustacean fishery continues a steady increase in production to about 60,000 tonnes per year by 2040 (Figure 4.20) and only in the last decade do the catch target and the actual catch start to diverge, giving early indications of a simulated decline.

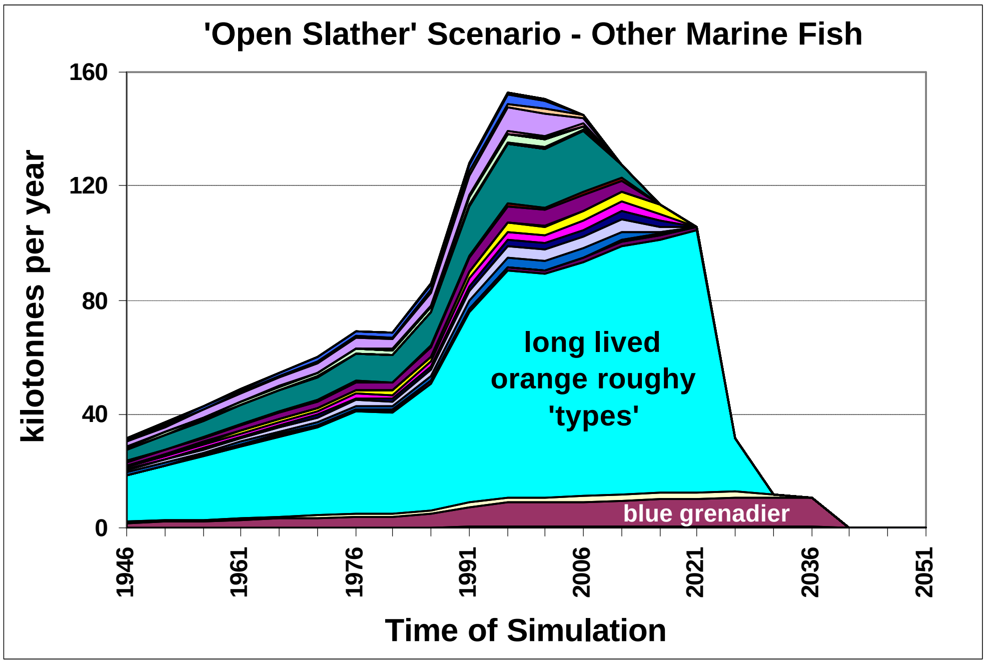

Figure 4.21. Simulated fisheries production to 2050 in the 'open slather' scenario for other marine fish showing the contribution of individual fisheries to the overall production aggregation.

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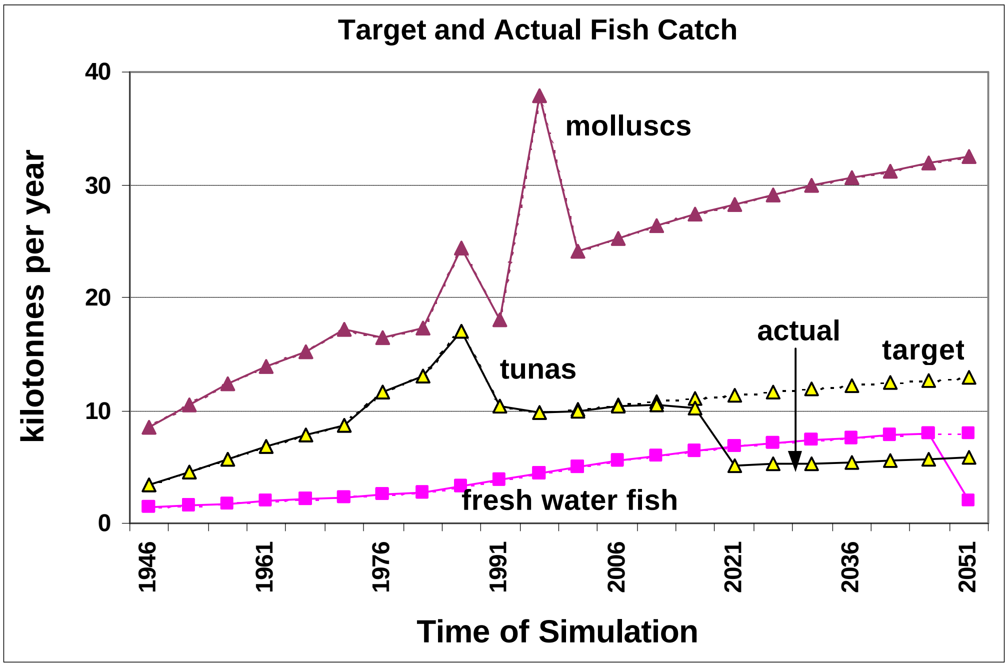

Figure 4.22. Simulated fisheries production to 2050 for the 'open slather' scenario for fish groups 'freshwater fish', 'tuna' and 'molluscs' comparing the target and actual catch. The target and actual catch are the same for molluscs and freshwater fish.

The mollusc fisheries continue a steady increase to 32,000 tonnes per year by 2050 after a range of high fluctuations in the recent historical period (Figure 4.22). The fresh-water fishery continues a steady increase to 8,000 tonnes per year by 2040 and then starts to decline. After some initial high catches in the 1980s, the combined tuna fishery fails to meet its production target of 10,000 tonnes rising to 12,000 tonnes by 2050. In the period 2015 to 2020 the simulated production declines to about 5,000 tonnes per annum which reflects the current catch by the Australian fleet for bluefin tuna only. The composition of the simulated tuna catch is shown in Figure 4.23. After an initial decline in both the southern bluefin and an aggregated class of other tuna, the fishing effort continues on the latter class until it crashes around 2020, leaving a slowly increasing southern bluefin stock to keep producing around 5000 tonnes per year.

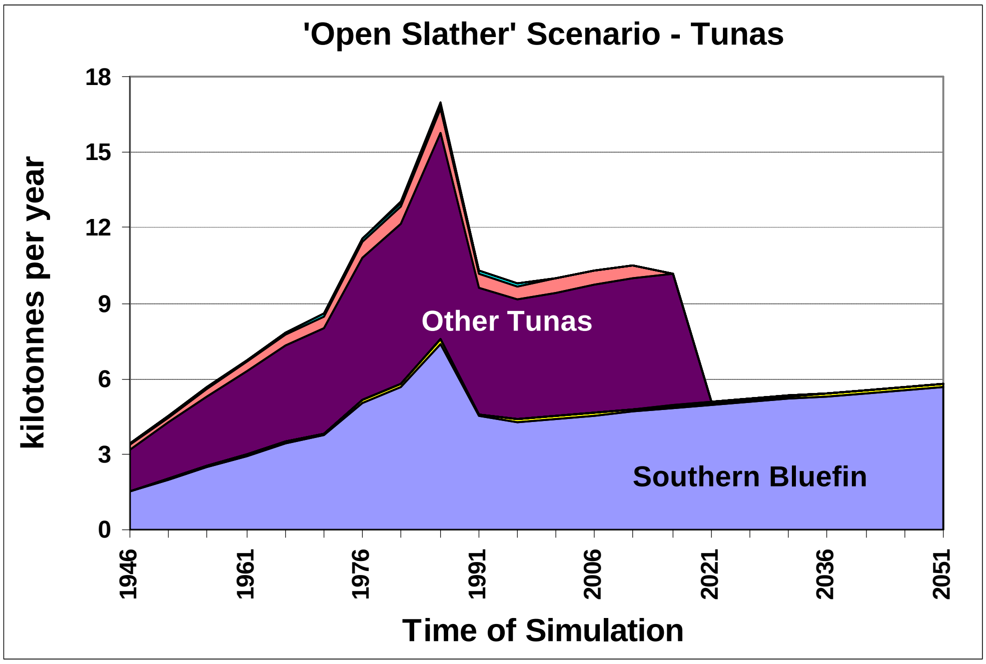

Figure 4.23. Simulated fisheries production to 2050 for tuna showing the contribution of different tuna fisheries to overall production.

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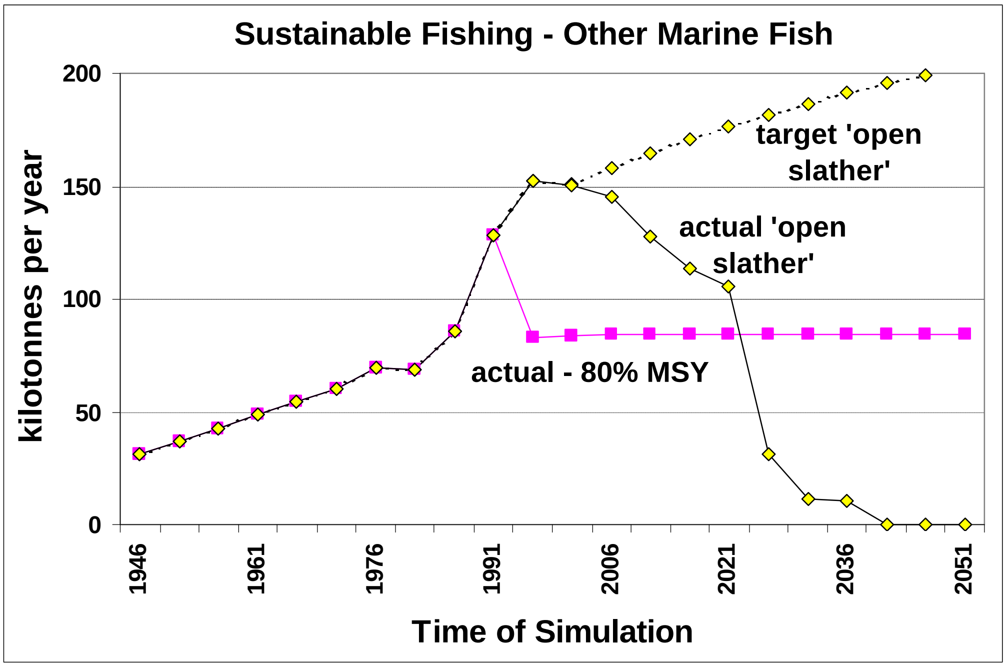

Figure 4.24. Sub-scenario of simulated fisheries production to 2050 for 'other marine fish' where production targets are reduced to 80% of the assumed maximum sustainable yield used in the 'open slather' fisheries scenario.

Sub-scenario: Sustainable Fishing to 2050

Government regulation and industry management which invoke concepts such as total allowable catch (TAC), the closure of fisheries to allow stock recovery and the buy back of fishing effort (boats) and quotas, are superseding management regimes where excess fishing effort causes a continual decline in fisheries production. The new approach is implemented in a sustainable fishing scenario for the two fin fish classes ('other marine fish' and 'tuna') which crashed in the initial 'open slather' scenario (see Figures 4.24 and 4.25). For the 'other marine fish' category, the target catch was replaced with a production goal which approximated 80% of maximum sustainable yield over all the fisheries in this category. When applied in 1996, this approach almost halved the simulated catch compared to the 'open slather' scenario, reducing it from 150,000 tonnes to 85,000 tonnes per year. The combined fishery could then operate at that production level for the rest of the simulation period. A similar result emerges for the combined tuna fishery, where relatively minor adjustments to the catch goal resulted in the fishery being maintained at round 10,000 tonnes per year for the rest of the simulation (Figure 4.25).

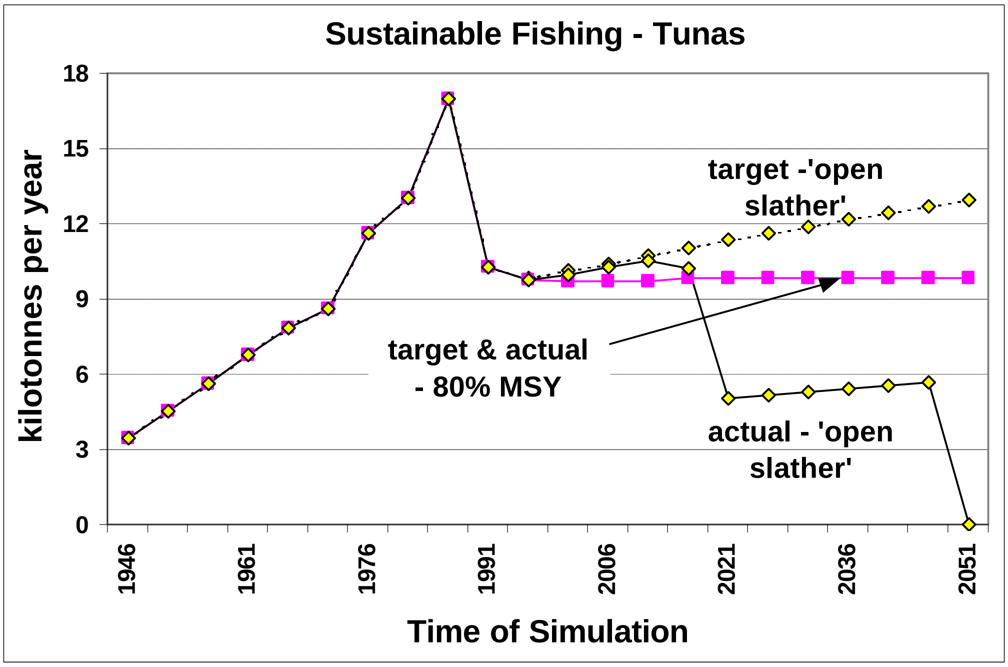

Figure 4.25. Sub-scenario of simulated fisheries production to 2050 for the tuna category where production targets are reduced to 80% of the assumed maximum sustainable yield used in the 'open slather' fisheries scenario.

Substantiating these simulated results is difficult but observations from other studies can help place them in context. There is a reasonable consensus that the production of wild fishing in marine areas is near to the maximum level, that can be sustained. Some scientific opinion argues that we have already passed the level but it is not reflected in overall production levels due to a number of lagged effects as we continue to fish down the trophic levels. At a national level, a number of economically important fisheries show evidence of being fully fished while others are overfished. At a state level, a number of State of Environment Reports suggest that difficulties in maintaining fisheries production are being experienced, or that many fisheries are near to their maximum level of exploitation (Table 4.5). The most recent SOE report from Queensland (Environmental Protection Agency, 1999) notes that six important fisheries are probably declining or declining. Almost half of the marine commercial species in South Australia are fully exploited (Department of Environment Heritage and Aboriginal Affairs, 1998). In Tasmania, 10 of the 36 species listed were overfished or fully fished. To counter this somewhat pessimistic viewpoint, institutional arrangements for many fisheries are now being changed to a total allowable catch basis. This approach promises some stability for future production levels and also suggests that fisheries production will conform more to the 'sustainable sub scenario' developed in this section, than to the 'open slather' scenario where effort was maintained until the entire complement of fin fish fisheries crashed.

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Table 4.5. Comments on the catch and productivity of individual fisheries from recent State of Environment Reports from Queensland, Tasmania and South Australia.

State of Environment Report	Resume of the status of marine fisheries
Queensland SOE Report 1999 (Environmental Protection Agency, 1999)	Commercial catch is 19,000 tonnes annually valued at $175 million and undertaken by 1,900 commercial fishing vessels. Most commercially harvested stocks appear to be fully exploited with several being over-exploited. The status of barramundi, coral trout and mud crab fisheries is listed as 'probably declining' while the king prawn, saucer scallop and Spanish mackerel fisheries are listed as 'declining'.
South Australia SOE Report 1998 (Department of Environment Heritage and Aboriginal Affairs, 1998)	Approximately 2,700 tonnes of freshwater fish is caught in inland rivers and over 19,000 tonnes per year of commercial catch from marine areas. Catches of two species (Murray cod, black bream) are declining in the inland fishery. Of the 20 species listed as key commercial species for the marine areas, 10 (black bream, cuttlefish, garfish, King George whiting, mulloway, ocean leatherjacket, pilchard, sandcrab, snapper, western king prawn) were fully exploited and 1 (mud cockle) was over exploited
Tasmania SOE Report 1996 (State of the Environment Unit, 1996)	Of the 36 major fisheries listed in the report, 4 were overfished (scallops, shark, southern bluefin tuna, orange roughy) and 6 were fully fished (jackass morwong, blue-eye trevalla, southern rock lobster, Australian salmon, abalone, warehou).

One implication of a reduced but more stable pattern of production from Australian marine fisheries is that aquaculture will play a more important role in meeting domestic and export requirements. Annual aquaculture production exceeds 30,000 tonnes, with a value of more than $500 million. The industry aims to expand this production, in terms of volume and value, to more than $2.5 billion by 2010. More than 90% of the current value of this production comes from six species: pearls, lobsters, tuna, salmon, oysters and prawns. By 2050, the domestic fish production deficit could be between 190,000 and 460,000 tonnes per year (see next section) or 6-15 times the current level of production from aquaculture. Despite a number of important environmental considerations (CSIRO, 2000), expanding aquaculture to fill this deficit could be feasible. Achieving it depends on reasonable expectations of technological progress and management improvement in the wild caught fishery (lower but more sustainable levels of production) and in the aquaculture industry (reducing the proportion of fish in aquaculture diet and minimising localised site effects).

Table 4.6. Total simulated production at 2050 in tonnes, for the 'open slather' and sustainable fisheries scenarios, and the human requirements for fish at 2050 for the zero, base case and 0.67%pa human population scenarios.

Fish type	'Open slather' fisheries production at 2050	Sustainable fisheries production at 2050	Zero scenario requirement at 2050	Base case scenario requirement at 2050	0.67%pa scenario requirement at 2050
Fresh water fish	6,840	7,754	7,640	9,211	11,767
Tuna	6,186	9,948	36,925	44,517	56,870
Other marine fish	18,765	76,946	260,730	314,334	401,556
Crustaceans	61,863	64,489	49,106	59,202	75,630
Molluscs	21,748	27,057	18,309	22,073	28,198
Total	**115,000**	**186,000**	**373,000**	**449,000**	**574,000**

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Fisheries surplus and deficit to 2050

Under the 'open slather' scenario, by 2050 the simulated total catch for all fish categories in Australia's fisheries was 115,000 tonnes per year. In contrast, the sub-scenario (80% of maximum sustainable yield) gave 186,000 tonnes per year. The human food requirements at 2050 were 373,000, 449,000 and 574,000 tonnes per year for the zero, base case and 0.67% population scenarios respectively (Table 4.6). Depending on the choice of production and population scenario the difference between catch and domestic dietary requirement could vary from 190,000 to 390,000 tonnes per year (Table 4.7).

Australia imports nearly 132,000 tonnes of fish product at an average value of $6,300 per tonne giving a total monetary value of imports in 1997/98 of $819 million. In the same year, exports of fish products (excluding pearls) reached 62,000 tonnes at a value of $24,000 per tonne, a total of $1,510 million. Thus the export balance reflects a surplus of about $700 million per year (Australian Bureau of Statistics, 2000-c; ABARE, 1999). As noted above, it may be possible to redress the physical imbalance between future food requirements and production, or it is possible to rely on imports. If, as expected, world supplies of wild-caught fish become constrained or decrease in per capita availability because of population growth, the price for imports will possibly rise. A rise in price will have a number of flow on effects within Australia possibly leading to improved management of wild caught fisheries and a stimulus to local aquaculture production. Alternatively an advantaged trade position for Australia may see domestic requirements being drawn from the fisheries of near neighbours. In many cases the imported fish might be more important to domestic dietary balances in those countries where protein is at a premium particularly for the poorer part of those populations. Thus fish trade might promote regional inequalities especially when protein sources are in abundance in Australia, and fish protein is a discretionary rather than an obligatory part of the human diet.

Table 4.7. Simulated surplus and deficit production levels in tonnes at 2050 by fish type for two fisheries scenarios ('open slather' and sustainable) and three population scenarios (zero, base case and 0.67%pa).

Fish type	**'Open slather' fishing management**			**Sustainable fishing management**		
	Zero population scenario	Base case population scenario	0.67%pa population scenario	Zero population scenario	Base case population scenario	0.67%pa population scenario
Fresh water fish	-800	-2,371	-4,927	114	-1,457	-4,013
Tunas	-30,739	-38,331	-50,684	-26,977	-34,569	-46,922
Other marine fish	-241,965	-295,569	-382,791	-183,784	-237,388	-324,610
Crustaceans	12,757	2,661	-13,767	15,383	5,287	-11,141
Molluscs	3,439	-325	-6,450	8,748	4,984	-1,141
Total	**-260,000**	**-330,000**	**-460,000**	**-190,000**	**-260,000**	**-390,000**

Two other wild cards are worth acknowledging in future options for fisheries. Fish consumption in Australia might rise as its health advantages are perceived by Australian consumers, particularly older people. With a base case population scenario of 25 million by 2050, and an increase in fish consumption of two kilograms per capita per year, this would require an extra 50,000 tonnes per year. This represents one-quarter of the current wild catch, and twice total aquaculture production. The second wild card is the impact of tourism. Many domestic and inbound tourists like to fish while on holidays and some of Australia's important commercial fisheries from Queensland to South Australia are also popular holiday destinations. Some of these fisheries are now fully-fished and others are over-fished, allowing scant return for the recreational fisher. Much anecdotal evidence points to the decline in recreational fishing experience along Australia's east coast, particularly for predators from the top of the trophic web which are some of the most sought-after recreational species. According to the 1999 Queensland State of Environment Report, "the frequency of schools of king salmon on usual fishing grounds and the number of fish in the schools have declined". Such information is part of an increasing weight of evidence that points to the state and productivity of fisheries as being key indicators of humankind's pressure on environmental processes. Similar evidence is emerging for Australia's inland fisheries (Davis et al., 2000). In the DIMA workshops, it was suggested that most commercial fisheries in coastal rivers, estuaries and near coastal areas would be closed in the next 20 years to facilitate the recreational fishing experience (Conroy et al., 2000). Monitoring and management will still be necessary and it is possible that recreational fishers could be harder to control than a limited number of professional fishers.

FORESTRY

Concern about world forests continues as demand for wood and paper continues to rise and forest land is cleared to make way for crop and animal production. Between 1980 and 1995, the area of forest cover fell by 180 million hectares; 200 million hectares were lost in developing countries while developed countries gained 20 million hectares (FAO, 1999-b). Environmental groups note that with increasing population growth, the forest to people ratio will have decreased from 1.2 hectares per capita in 1960, through 0.6 hectares per capita in 1995 to a possible 0.4 hectares per capita in 2025 (Gardner-Outlaw and Engelman, 1999). In Australian terms these ratios could change by 2050, from 2.2 hectares per capita currently (40 million ha native, 1 million ha plantation), to 1.3 hectares per capita under the 0.67%pa population scenario, 1.7 hectares under the base case and remain at 2.2 hectares for the zero scenario. The demand for industrial forest products is expected to grow at 1.7% per annum and this will continue to enhance trade flows of forest products between countries. Australian consumption of paper and packaging is expected to grow to 238 kilograms per capita per year by 2040 (Love et al., 1999) and while paper recycling is widely practiced, redressing the $2 billion deficit in total forest products presents a considerable challenge.

In the scenarios presented here, land retired from agriculture scenarios is transferred to the forest estate. Improved management and technological innovation is assumed to allow the establishment of productive forests that replicate current growth rates for particular rainfall zones (Figure 4.26). For the base case and technological advance scenarios this sees the Forests 2020 Vision (DPIE, 1997) policy implemented, with a three million hectare forest plantation stock by 2020 growing to four million hectares by 2050. For the landscape integrity scenario, large areas of land are reforested in an attempt to restore the hydrological balance and to slow the spread of dryland salinity. This gives a forest estate of 12 million hectares by 2020, increasing to 13 million hectares by 2050. The native forest estate (similar categorisation to that used in ABARE, 1999) stabilises at 41 million hectares by 2050.

The combined production of roundwood and pulpwood grows to 32 million and 41 million cubic metres for the base case and landscape integrity scenarios respectively (Figure 4.27). While the silvicultural and production technologies are currently different, in the future the confluence of a variety of production technologies will blur the distinction between wood grown for structural use and building and that grown for pulp (Conroy et al., 2000). The combined production of roundwood and pulpwood is currently about 20 million cubic metres per year (ABARE, 1999). Future scenarios of forest production (Love et al., 1999) anticipate an expansion of total wood production to 34 million cubic metres by 2040, of which 13 million will be used for saw logs and 21 million for pulp and other logs. The scenarios in this analysis are thus in accordance with industry expectations and plans. Expansion of the forest estate in line with the base case and technological advance scenarios, sees Australia developing a positive balance in most categories of wood products with the exception of paper, where one million tonnes of imports will be required in the base case population scenario if present trends in paper and packaging consumption continue.

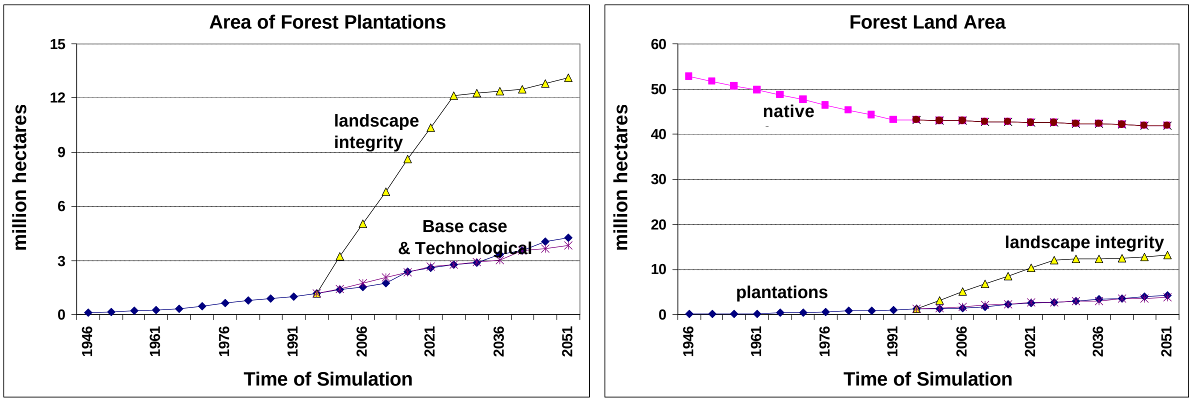

Figure 4.26. Areas of forest estate to 2050 derived from land use scenarios developed for agriculture.

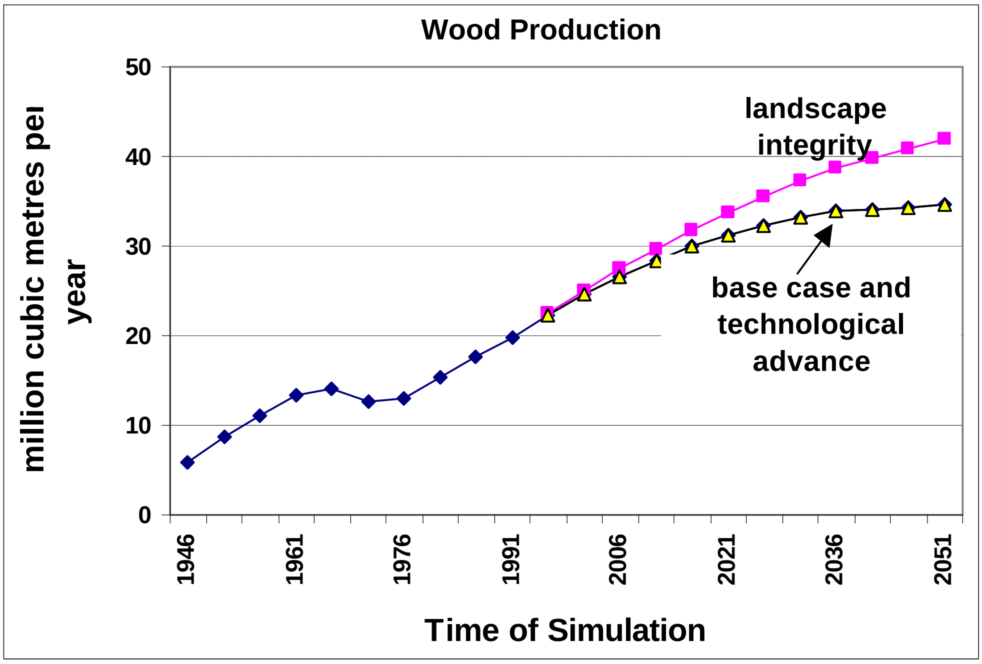

Figure 4.27. Production of roundwood and pulpwood to 2050 derived from the three land use scenarios developed for agriculture and landuse.

By 2050 the landscape integrity scenario has approximately doubled the area of plantation forest and potentially, also the volume of wood, to turn a balanced forest products account into one with a large surplus for export. In this simulation however, about half of the plantation area is left as a standing stock of forest trees for two reasons. Firstly, a key rationale of reforesting cleared land in Australia is to restore some of the hydrological balance with potential additional returns for a wide range of ecosystems services. Secondly, trees are left to act as a sink for carbon dioxide emissions from the fossil energy sector. Burns et al. (1999) in a regional analysis of farming land found that potentially 19 million hectares of cleared farming land was suitable for plantations. Much of this land could be used for either production forestry or carbon sequestration. It is possible that a range of longer lived tree species could be planted which continue growing to 60-80 years of age, about 2-3 times the length of a rotation in a normal production forest. If a market were developed for carbon sequestration at the rate of $50 per tonne of carbon ($13.50 per tonne of CO2), an actively growing forest of one hectare might sequester between 15 and 20 tonnes of CO2 per hectare per year, giving a potential monetary income of between $200 and $270 per hectare per year while the forest was actively growing. A measured 42 year old stand of *Pinus radiata* contained nearly 500 tonnes of wet biomass per hectare. This is the equivalent of 100 tonnes of carbon or a sequestration of 370 tonnes of CO2 (Australian Greenhouse Office, 1998). Given a range of management options, the implementation of the landscape integrity scenario is thus judged to be reasonably feasible.

THE EFFECT OF POPULATION ON NATURAL RESOURCES

Most of the effect of future domestic population size (apart from the effect on petroleum stocks and marine fisheries) can be interpreted through the tertiary population effect, where the arrangements and requirements of international trade drive production and the domestic population effect is less important (Table 4.8). For minerals generally, the production implemented in the base case scenario represents much higher levels than is required by the domestic population, whatever the population scenario. For oil and gas specifically, a view of a discrete, and an eventually constrained, resource has been presented. Making reasonable assumptions on the substitution options between oil and natural gas, this does not present a problem in 2020 or nearly one human generation away. However, by 2050 when the physical economy is larger in size and with more physical transactions, there could be a substantial gap in the domestic availability of easily available and easily delivered energy for the transport sector. In the case of oil and gas (but not minerals generally) population size is regarded as a primary influence on resource use, with trade in natural gas being an additional tertiary population effect which could restrict energy options over longer time scales.

Table 4.8. Description of the different levels of population effect in key natural resource areas.

Commodity	Issue	Importance of population effect
Minerals	Mineral stocks	Generally driven by the tertiary population effect due to international trading arrangements and domestic policies which form these arrangements. General assumption for most mineral stocks is that resources will not be constrained in the next 100 years as exploration and extraction technologies improve several fold in sophistication and efficiency.
	Oil and gas stocks	Domestic population drives possible constraints on traditional stocks of domestic oil in a primary sense, although there is a complex mixture containing secondary drivers of lifestyle (car technology, frequent plane trips) and tertiary drivers of international trade (inbound international tourism, transport for export goods). The importance of the tertiary population driver for future constraints on natural gas stocks will increase as liquefied natural gas exports seek to supply a rapidly expanding world market for lower carbon fuels.
Agriculture	Agricultural commodities	An export trade requirement, interpreted as a tertiary population effect, is the main driver of volume of agricultural commodities. However about 50% of many commodity food groups is for domestic consumption. Many food groups such as vegetables, fruit and whole milk products are best produced closer to major markets.

	Grain for livestock feed	A positive grain balance is maintained under all population scenarios. The use of grain for livestock feed may emerge as an ecological and energy issue within the next human generation. It may also be tied to animal welfare issues (e.g. free range versus battery hens) and to regional pollution issues (e.g. disposal of feedlot manure). Within this context, domestic population numbers will drive production of grain for chickens, pigs and aquaculture in a primary sense. Currently 25-30% of feedlot cattle are produced for domestic consumption and this proportion will be driven by domestic population levels.
	Water requirement for dairy production	Under current starting position scenario assumptions by 2050, the dairy industry produces twice the current domestic requirement for raw milk under the highest 0.67% population scenario. Thus at 2050 the domestic population effect on water requirement for dairy production could be attributed 35%, 43% and 52% to domestic population levels (a primary population effect) and the remainder to the tertiary effect of international trade. The location and availability of the required water resource could represent a water tension that may require resolution
	Land loss and river salinity	Generally driven by a tertiary (and relatively long-term) population effect due to international trading arrangements and historic land use policies, rather than a primary or direct effect of current population numbers. There will be some primary effect blending into the tertiary effect (eg grain for feed and water for dairy) as domestic population requirements become a higher proportion of total production.
Fisheries	Fish stocks and sustainability of catch levels	Both globally and at a national level, the status and productivity of wild caught fisheries are driven mostly by a primary population effect. In future the effect can be neutralised in two ways. Where fisheries are fully fished or declining, institutional arrangements can be changed and 'total allowable catch' procedures applied to each fishery. Alternatively aquaculture can be increased to make up the shortfall provided that local environmental issues and the use of fish for fish feed do not produce knock-on effects on marine situations either locally or in other countries. A 100,000 tonne per year fish products deficit is covered by imports from abroad. Additional population effects could be caused by recreational fishing pressure from domestic tourism (a secondary effect) and international tourism (a tertiary effect).
Forestry	Managed plantations	Increasing plantation areas will be driven by government and industry policy (e.g. Forests 2020 Vision) and by requirements for carbon sequestration. This transition could see relatively large increases in plantation area and an eventual neutralisation of the national forest products deficit. Thus any perceived negative effects of domestic population size on forests will become relatively neutral when the requirement for forest products starts to equalise with managed plantation production.
	Harvests from natural forests	Mainly a tertiary population effect as woodchips from native forests are exported to derive export income. The effect is more a historic one, as the reform of land use in the forestry industry will see most woodchip exports derived from managed plantations by 2020.
	Forest products in general	Currently about 70% of woodchips are derived from broadleafed species; woodchips contribute $0.6 billion of a $1.3 billion export trade in forest products. Imports of forest products are $3.3 billion per year giving a $2.0 billion forest products deficit. This deficit is mainly a primary population effect (due to the direct requirements of Australia's population). Australia's domestic requirement has a tertiary population effect on the forests of New Zealand, Indonesia, Finland, North America and many other countries.

Domestic population affects agriculture indirectly through the tertiary effect where domestic requirement by the highest population scenario (0.67%pa) does not exceed 50-60% of total production for the broadacre commodities. Another way of saying this is that any environmental effect of land use or agricultural production can be allocated at least 25-50% to the primary population effect. For some commodities, such as eggs, chicken, pork, fruit and vegetables, we assume that bulk production is geared mainly to domestic requirements as well as exports to near neighbours. However there are specific items such as wine, dried fruit, citrus and tropical fruits that form the basis of important export industries. For most items where the requirement and the production are closely matched towards the end of the simulation, production levels can be adapted relatively quickly. It is unlikely that a prolonged domestic deficit in bulk agricultural commodity items would occur for any physical reason.

A check on the food balance for each population scenario showed that no imports were required for most food commodity groups at 2050 (Table 4.9). The exceptions are fruit and vegetables, for which the scenarios have not allocated enough land, and pork for which 20% of the requirement will need to be imported by 2050. A relatively minor reallocation of irrigated land to fruit and vegetables would allow this physical tension to be resolved. Similarly an increase in pig numbers to four million by 2050 would allow domestic self sufficiency.

Table 4.9. Percentage of domestic requirement of agricultural commodity groups simulated as imported at 2050 for zero, base case and 0.67%pa population scenarios.

Agricultural commodity group	Zero population scenario	Base case population scenario	0.67%pa population scenario
Grain	0	0	0
Sugar	0	0	0
Cotton	0	0	0
Fruit	0	14	35
Vegetables	25	35	50
Beef and Veal	0	0	0
Mutton and lamb	0	0	0
Pork	0	0	20
Poultry	0	0	0
Eggs	0	0	0
Milk	0	0	0

In the fisheries sector, a primary or direct population effect was allocated. The current fish products deficit of 100,000 tonnes per year, could increase four-fold under the 0.67%pa scenario. With many wild fish stocks already fully fished, the challenge is for aquaculture to meet the requirement and allow a longer-term replenishment of fish stocks. The aquaculture option is judged to be marginally feasible, if the requirement for fish protein as a critical component of the diet can be removed. A number of location issues and environmental externalities must also be addressed. In the meantime, Australia's domestic requirements could be delivering their own tertiary population effect to wild caught fisheries or aquaculture in countries with whom we trade.

The requirement for forest products could also be considered a primary population effect. Australia maintains a sizeable forest products deficit, in that we locate part of our requirements within the forest stocks of other countries. Some of these countries are judged to have unsustainable forest production practices and Australia's domestic requirement may be directly implicated in the shrinkage of world forest resources. Within the next human generation it is probable that an expansion of domestic forest plantations and a cessation of logging in native forests will see Australia redress its forest products deficit. It is possible that if elements of the landscape integrity scenario are followed, that a substantial positive stock could be developed. This could facilitate a substantial increase in the amount and quality of ecosystem services, as well as a wide range of new products such as biomass based energy services which could be carbon neutral and help in reducing greenhouse gas emissions.

REFERENCES

ABARE (1999). 1999 Australian Commodity Statistics. Australian Bureau of Agriculture and Resource Economics, Canberra.

Alexander D Williams B and Trewin R (1998). Dryland Salinity R&D Foresighting Analysis. Land and Water Resources Research and Development Program Occasional Paper Series No 22/98

Australian Bureau of Statistics (2000-a). Australia Now, A Statistical Profile, Population, Population Size: http://www.abs.gov.au/Ausstats/ABS%40.nsf/94713ad445ff1425ca25682000192af2/66c4681ef3e774a1ca2568a900154b07!OpenDocument Accessed 10/6/2000

Australian Bureau of Statistics (2000-b). Water Account for Australia 1993-94 to 1996-97. ABS Catalogue No. 4610.0

Australian Bureau of Statistics (2000-c). Australia Now, A Statistical Profile, Forestry and Fishing, Production, processing, and exports and imports of fisheries products: http://www.abs.gov.au/Ausstats/ABS%40.nsf/94713ad445ff1425ca25682000192af2/5bd6df240ea47a5bca2568a900154b96!OpenDocument Accessed 23/10/2000

Australian Geological Survey Organisation (1999). Oil and Gas Resources of Australia 1999. Australian Geological Survey Organisation, Canberra.

Australian Greenhouse Office (1998). *Greenhouse Challenge Vegetation Sinks Workbook Version 1.0. Quantifying Carbon Sequestration in Vegetation Management Projects: A Summary*. Australian Greenhouse Office, Canberra.

Beddington J (1995). The primary requirements. Nature 374,213-214 16 March 1995.

Beverton R (1998). Fish, fact and fantasy: a long view. The Larkin Lecture. Reviews in Fish Biology and Fisheries 8,229-249.

Bicknell KB Ball RJ Cullen R and Bigsby HR (1998). New methodology for the ecological footprint with an application to the New Zealand economy. Ecological Economics 27,149-160.

Burns K Walker D and Hansard A (1999). *Forest Plantations of Cleared agricultural land in Australia; A Regional Economic Analysis.* ABARE Research Report 99.11, September 1999, Canberra.

BPAmoco (2000). Statistical Review of World Energy 1999. http://www.amoco.com/worldenergy/ accessed 22-6-2000.

Caddy JF Csirke J Carcia SM Grainer RJR (1998). How pervasive is "fishing down marine food webs"? Science 282,1383a, 20 November 1008.

Caddy JF (1999). Fisheries management In the twenty-first century: will new paradigms apply? Reviews in Fish Biology and Fisheries 9,1-43.

Caton A McLoughlin K and Staples D (1998). Fishery Status Reports 1998. Resource Assessments of Australian Commonwealth Fisheries, Bureau of Resource Sciences, Agriculture Fisheries Forestry Australia, Canberra.

Caton A and McLoughlin K (2000). Fishery Status Reports 1999. Resource Assessments of Australian Commonwealth Fisheries, Bureau of Resource Sciences, Agriculture Fisheries Forestry Australia, Canberra.

Chislolm A (1999). Land resource and the idea of carrying capacity. BCA Papers 1,2,19-26 Business Council of Australia, Melbourne.

Clark M (1999). Fisheries for orange roughy (Hoplostethus atlanticus) on seamounts in New Zealand. Oceanologica ACTA 2,6,593-602 Nov-Dec 1999.

Clark MR Anderson OF Francis RICC Tracey DM (2000). The effects of commercial exploitation on orange roughy (Hoplostethus atlanticus) from the continental slope of the Chatam Rise, New Zealand from 1979 to 1997. Fisheries Research 45,3,217-238.

Cohen JE (1995). *How Many People Can the World Support?* Norton and Company, New York.

Coleman A (1999). Dolly Polly and other "ollys": Likely impact of cloning technology on biomedical uses of livestock. Genetic Analysis-Biomolecular Engineering. 15,3-5,167-173.

Commonwealth of Australia (2001-a). *Australian Dryland Salinity Assessment 2000*. The National Land and Water Audit, January 2001, Canberra.

Commonwealth of Australia (2001-b). *Australian Water Resources Assessment 2000*. The National Land and Water Audit, January 2001, Canberra.

Conroy J Foran BD Poldy F and Quinnell T (2000). Future Options to 2050: Workshops Report. CSIRO Resource Futures Program Working Paper Series 00/03, March 2000.

CSIRO (2000) Environmental report card for Tasmania's Huon. CSIRO Media Release Friday 23 June 2000. http://www.csiro.au/page.asp?type=mediaRelease&id=Prhuon accessed 34-6-2000

Davis KM Kearney RE Beggs KE (2000). Research priorities for Australia's freshwater fisheries. Australian Journal of Environmental Management 7,28-37.

Department for Environment Heritage and Aboriginal Affairs (1998). *State of Environment Report for South Australia*. Adelaide South Australia October 1998.

Department of Primary Industries and Energy (DPIE) (1997). *Plantations for Australia: The 2020 Vision*. http://www.affa.gov.au/agfor/forests/2020/vision.html Accessed 19 May 1999.

Doyle PT and Kelly KB (1998) The Victorian dairy industry-Improving performance. In *Agronomy-Growing a Greener Future*, Proceedings of the Ninth Australian Agronomy Conference, Charles Sturt University, Wagga Wagga NSW 20-23 July 1998, page 31-36.

Dunlop M McKenzie N Jacquier D Ashton L and Foran BD (1999). Australia's Stocks of Quality Soils. CSIRO Resource Futures Program Working Paper Series 99/06, November 1999.

Dunlop M Foran BD and Poldy F (2000). Changing agricultural production and the natural resource base: Three long term scenarios for land use. CSIRO Resource Futures Program, Working Paper Series 00/05, Draft Report for the Land and Water Resources Research and Development Corporation, 26 May 2000.

Environmental Protection Agency (1999). *State of Environment Queensland 1999 Executive Summary*. Brisbane 1999.

Fisheries Research and Development Corporation (FRDC)(1999). From Antarctica to the tropics: a snapshot of the Australian fishing industry. FRDC Canberra.

Food and Agriculture Organisation (FAO)(1999-a). *The State of World Fisheries and Aquaculture 1998. Part 1: World Review of Fisheries and Aquaculture, Fisheries Resources: Trends in Production, Utilisation and Trade* http://www.fao.org/docrep/w9900e/w9900e00.htm accessed 25-6-2000.

Food and Agriculture Organisation (FAO)(1999-b). *State of the World's Forests 1999*. http://www.fao.org/forestry/FO/SOFO/SOFO99/sofo99-e.stm accessed 28-6-2000

Foran BD and Mardon C (1999). Beyond 2025: Transitions to a biomass-alcohol economy using ethanol and methanol. CSIRO Resource Futures Program, Working Paper Series 99/07. A consultancy report for the National Dryland Salinity Program of the Land and Water Resource research and Development Corporation, December 1999.

Gardner-Outlaw T and Engelman R (1999). *Forest Futures: population, Consumption and Wood Resources.* Population Action International, Washington.

Gordon L Dunlop M and Foran BD (2000). Water vapour flows from vegetation in Australia 1780-1980. CSIRO Resource Futures Program, Working Paper Series 00/0?

Gorrie G and Wonder B (1999). *Managing Natural Resources in Australia for a Sustainable Future: A Discussion Paper for Developing a National Policy*. National Natural Resource Management Task Force, Agriculture Fisheries Forestry Australia, Canberra, January 1999.

Howden SM (2001). Analysis of national livestock statistics: Assessment for systematic reporting bias. Proceedings of MODSIM 2001, Australian National University, Canberra, 10-13 December 2001. Volume 4, General Systems pp 1841-1852.

Hubbert MK (1967). Degree of Advancement of Petroleum Exploration in the United States. The American Association for Petroleum Geologists 51,11, 2207-27

IUCN (1994). *The Netherlands and World Ecology*. The Netherlands Committee for IUCN, Amsterdam, The Netherlands.

Laherrère JH (2000). The Hubbert Curve: Its Strengths and Weaknesses. (submitted to Oil and Gas Journal on 18 Feb 2000) http://dieoff.com/page191.htm accessed 24/4/2000

Land and Water Resources Research and Development Corporation (LWRRDC) (1997). Using foresighting to identify R&D priorities for LWRRDC. LWRRDC Occasional Paper Series 10/97 July 1997, Canberra.

Love G Yainshet A and Grist P (1999). *Forest products: Long term consumption projections for Australia*. ABARE Research Report 99.5 April 1999, Canberra.

Mace PM (1996). Developing and sustaining world fishery resources: The state of the science and management. Keynote paper at 2nd World Fisheries Conference 1996, page 1-20.

Matsuda H Takenaka Y Yahara T Uozumi Y (1998). Extinction risk assessment of declining wild populations: The case of southern bluefin tuna. Researches on Population Ecology 40,3,272-278.

Meat and Livestock Australia (MLA) (1999). Australian Cattle and Sheep Industry Projections 1999. Meat and Livestock Australia, North Sydney may 1999.

MDBMC (1999). *The Salinity Audit of the Murray Darling Basin: A 100-Year Perspective*. The Murray Darling Basin Ministerial Council.

Naylor RL Goldburg RJ Mooney H Beveridge M Clay J Folke C Kautsky N Lubchenco J Primavera J and Williams M (1998). Natures subsidies to shrimp and salmon farming. Science 282,883-884, 30 October 1998.

Naylor RL Goldburg RJ Primavera JH Kautsky N Beveridge MCM Clay J Folke C Lubchenco J Mooney H and Troell M (2000). Effect of aquaculture on world fish supplies. Nature 405,1017-1024, 29 June 2000.

Parliamentary Commissioner for the Environment (1999). *Setting Course for a Sustainable Future: The Management of New Zealand's Marine Environment*. Wellington, December 1999.

Pauly D and Christensen V (1995). Primary production needed to sustain global fisheries. Nature 374,255-257 16 March 1995.

Pauly D Froese R and Christensen V (1998). Response to 'How pervasive is "fishing down marine food webs"?' Science 282,1383a, 20 November 1998.

Polacheck T Klaer NL Millar C and Preece AL (1999). An initial evaluation of management strategies for the southern bluefin tuna fishery. ICES Journal of Marine Science 56,6,811-826.

Population Action International (1995). Catching the Limit: Population and the Decline of Fisheries. http://www.populationaction.org/why_pop/fish.htm accessed 23-6-2000

PMSEIC (1998). Dryland salinity and its impacts on rural industries and the landscape. The Prime Minister's Science Engineering and Innovation Council. Second Meeting Friday, 4 December 1998 Parliament House Canberra, http://www.isr.gov.au/science/pmseic/2ndmeeting.html accessed 21-6-2000

PMSEIC (1999). Moving forward in natural resource management: The contribution that science engineering and innovation can make. The Prime Minister's Science Engineering and Innovation Council. Third Meeting Friday, 25 June 1999, Parliament House Canberra. http://www.isr.gov.au/science/pmseic/3rdmeeting.html accessed 21-6-2000

Rosegrant MW Paisner MS Meijer S and Witcover J (2001). *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. International Food Policy Research Institute, Washington, August 2001.

Skinner P (2000). Asian Energy-Challenges and Opportunities. Royal Dutch Shell Group of Companies website http://www.shell.com/library/speech/1,5833,,00.html?article=50255&type=speech&siteid=1160 accessed 9-6-2000

Smil V (2000). *Feeding The World*. MIT Press Cambridge USA. http://mitpress.mit.edu/book-table-of-contents.tcl?isbn=0262194325 accessed 9-6-2000

State of Environment Unit (1996). *State of the Environment Tasmania 1996: Volume 1 Conditions and Trends*. Land Information Services, Hobart Tasmania.

Swindell GS (1999). Texas production data show rapid gas depletion. Oil and Gas Journal June 21. 1999 page 61. http://oil.server4.com/tx-depl.htm accessed 6-6-2000

The Economist (2000).Oil in Texas- A Dim Gurgle. The Economist April 15th 2000 page 31

Tian XC and Yang XJ (1998). Life on the bio-pharm: Therapeutic proteins from transgenic organisms. Molecular Medicine Today 4,10,424-425 October 1 1998.

Thomas JF (1999). Water and the Australian Economy. A joint study project of the Australian Academy of Technological Sciences and Engineering and the Institution of Engineers, Australia. April 1999 Melbourne.

US Department of Energy (2000). Long term World Oil Supply: A Resource Base/Production Path Analysis. Energy Information Administration 28/07/2000. http://www.eia.doe.gov/pub/oil_gas/petroleum/presentations/2000/long_term_supply/sld007.htm accessed 21-06-01

von Weizsacker E Lovins AB and Lovins LH (1997). *Factor 4: Doubling Wealth-Halving Resource Use*. Allen and Unwin, St. Leonards, Australia.

Wackernagel M and Rees W (1996). *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers Garbiola Island BC Canada.

Wackernagel M and Rees WE (1997). Perceptual and structural barriers to investing in natural capital: Economics from an ecological footprint perspective. Ecological Economics 20,3-24.