# Australian Fisheries Futures: 2020 and Beyond

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FISHERIES RESEARCH & DEVELOPMENT CORPORATION

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## *Prepared for*

**The Fisheries Research and Development Corporation**

## *Prepared by*


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## *September 2003*


FRDC Project 1999/160



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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a federal statutory authority jointly funded by the Australian Government and the fishing industry.

# Australian Fisheries Futures: 2020 and Beyond

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# NON-TECHNICAL SUMMARY

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## *Objectives:*

Given the world context of fisheries management, and the long-term link between population growth, economic development and fish production, this study for Australia had five goals:

1. To analyse the long-range perspective of tensions between fisheries demand and production at a national level for use in fisheries policy development.

2. To identify and quantify the linkages between the demands generated by human population growth and affluence and their effects on a range of natural resources, particularly capture fisheries and aquaculture.

3. To test a range of policy options which address demand and supply imbalances at a national level out to 2020 and beyond.

4. To strengthen future fisheries management policies by providing a comprehensive, long-term view of the dynamics of production and demand for resources.

5. To enable fisheries to be properly incorporated into an on-going national program of modelling future natural resource demand and demographic influences.

6. To provide a simplified interpretation of Australia's total long-term resource demands and likely production to enable the fishing industry to better understand their relationship with other resource users and with national development policies.

## *Outcomes achieved:*

This study provides the first nationally comprehensive physical accounting of the majority of the Australian fisheries industry. Several key implications for the management of the Australian fisheries industry have come to light by applying bio-physical constraints comprehensively across fisheries production and consumption. These implications are:

- it is physically implausible to maintain all historical trends: if this is attempted, a near-term imbalance results between the larger requirements for domestic consumption and exports and the smaller provisions through domestic production and imports;
- per capita consumption is a very significant driver in the future fisheries sector;
- commercial wild capture production cannot repeat the growth of the period 1960-1990 unless there is rapid expansion into speculative under-utilised or entirely new resources; and
- aquaculture production is likely to be a key determinant to local production and thus export capacity in the future, but relies on significant innovations and environmental control.

## *Non-technical summary:*

## *Background*

The Australian fishing industry has grown rapidly into an industry with a gross value of production of approximately $2.4billion. However, in recent years many of the resources that underpin the industry have shown the effects of excessive human impact, both targeted and accidental. As human populations grow, demand for fish increases as do the negative effects on fish populations of human impact on fish habitats and the environment in general. Clearly our limited fish resources cannot meet continuous growth in demand, and yet assessment of how we might respond to the inevitable shortfall has not previously been attempted. It is this challenge that prompted scientists from the University of Canberra and CSIRO to work with FRDC to develop a means of modelling Australia's fisheries futures to 2050.

This report represents the culmination of the first nationally comprehensive physical accounting of the majority of the Australian fisheries industry. The fisheries industry forms one sector of the whole economy represented in the Australian Stocks and Flows Framework (ASFF). A fifty-year history of the industry was recreated using ASFF and data provided by Australian fisheries agencies and the FAO. Simulating forward from the historical picture, three primary scenarios describing plausible futures were designed and examined, as a means for exploring the effects of key drivers rather than making precise predictions.

## *Global and Australian historical context*

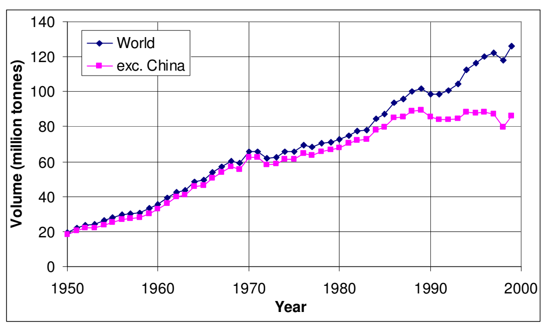
Australia is a relatively small producer of fish and seafood in terms of volume. Furthermore, it exports a significant portion of its production (especially in value terms) and imports a majority of its total domestic market (in terms of volume). As a consequence, the influence of the world market upon Australia is more significant than the reverse.

**Australian fisheries flows in 2000/01[1]**

| | Production | Exports | Imports |
|---|---|---|---|
| Vol (kt) | 230 | 59 | 220[2] |
| Value ($m) | 2428 | 2169 | 1152 |

Source: ABARE, 2000. [2] 1998/99 data

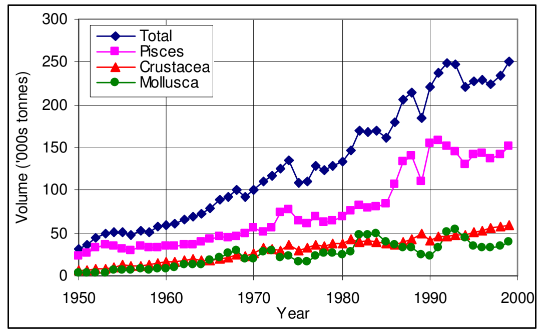
Total fisheries production (wild capture plus aquaculture) of the world, excluding uncertain Chinese production, has essentially been constant since the late 1980s, as the adjacent graph illustrates. Steadily increasing aquaculture production (dominated by China) has apparently countered a decline of more than 10% in world capture fisheries production since the late 1980s, indicating that most of the world's capture fisheries are under pressure and in many cases beyond their limits.




On the demand side, worldwide per capita apparent consumption has been declining for more then a decade. This is partly due to limits to production and partly due to changing dietary patterns as individual income increases and personal choice widens. There are some indications that for most nations, per capita apparent consumption will stabilise at about 25 to 30 kg/capita/year live-weight.

There are several implications of the global picture for Australian fisheries. Any shortfalls in constrained domestic production may not necessarily be compensated through higher imports, unless the domestic market is willing to pay higher prices. In contrast, the Australian export picture remains relatively healthy, particularly in the high value end of the market (anticipating further economic growth especially in markets that are increasingly selective, and reasonably high volume captured by other fisheries e.g., China).

Although the Australian Fishing Zone is spatially large (approximately 9 million sq km), with diverse habitats and species, it is relatively unproductive by world standards. Total seafood production (wild capture and farming) increased to around 250 thousand tonnes by 1999, although the growth appears to have slowed over the last decade (see graph opposite).




- Fish production appears to have reached a plateau at about 150 thousand tonnes;
- crustacean production has increased steadily (to about 60 thousand tonnes by 1999); and
- mollusc production has trended upwards but varied widely (ranging between 25 and 55 thousand tonnes during the 1990s).
- Aquaculture production has increased considerably since 1990, while capture production appears to have reached a plateau since the late 1980s.

Domestic supply for food has increased steadily over time, while there has been large fluctuations in the supply of seafood for use as animal and aquaculture feed. Seafood consumption per capita has increased steadily over the last 40 years. The volume of exports has steadily increased, while imports generally increased but fluctuated considerably (largely due to feed imports).

## *Future Australian fisheries scenarios*

The futures analysis reported in this document was based on a quantitative scenario approach using ASFF to examine long-term sustainability issues for Australia. A model was developed of the fisheries sector that keeps track of primary seafood production through to ultimate human consumption and utilisation. Associated labour, energy and materials with production were also calculated. A simple logistics population model for each fish unit (covering about 85% of volume and value) was adopted for the key driver of fisheries productivity. This model provides suitable utility and generality. Also included were the effects of recreational fishing and predators, such as seals.

Three primary scenarios were developed to explore the implications for the Australian fisheries industry of adopting different strategic management options. Sub-scenarios and analysis examine the influence of key uncertainties, such as domestic consumption and the virgin biomass of the fish stock.

The fisheries management scenarios are distinguished primarily by the desired catch rate:

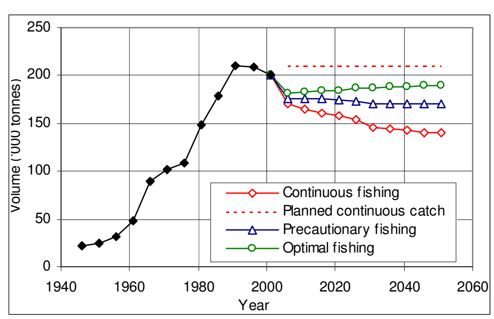
The *continuous fishing* scenario attempts to maintain the catch rate at the average of the previous decade, irrespective of the level of fish stocks. This scenario reflects a management approach where future fish stock levels are simply assumed to always be present.

In the *precautionary fishing* scenario, the same catch rate as the continuous fishing scenario is attempted unless a fishery drops to 20% of its virgin biomass, at which point the annual catch is reduced to maintain the fishery at this level. This scenario engenders a degree of ecological awareness, partly as a balance between active management and the momentum of fisheries production, and partly reflecting competing economic signals (rising catch prices and increased fishing effort).

A more proactive ecological management approach is explored in the *optimal fishing* scenario. Catch rates are adjusted to achieve 80% of the theoretical maximum sustainable yield over the long-term. Even in low stock fisheries this does not necessarily mean closing the fishery indefinitely, but adjusting a cap of the annual catch after a recovery period.

## *Implications*

All three scenarios demonstrate that the commercial wild capture production cannot achieve the peak rates of the 1990s, although on-going marginal increases are possible in the optimal fishing scenario, depicted in the graph opposite (showing average yearly production at 5-yearly intervals). By 2050 the optimal scenario is



producing about 35% more than the continuous fishing scenario, or 50,000 tonnes/year. The cumulative difference amounts to 1.7 million tonnes over the coming five decades.

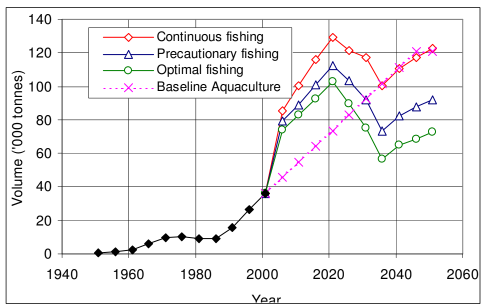
Importantly, for *each* scenario the underlying historical trends for consumption, exports, imports, and aquaculture production cannot all continue for long. For all scenarios, provision (the total of Australian production including aquaculture and imports) fails to meet the combined requirements of domestic consumption and exports. This deficit is a direct consequence of extrapolating recent linear historical trends and keeping exports constant. Such baseline assumptions primarily invoke:

- imports approximately doubling (to approx. 415 kt/yr by 2035);
- exports held immediately constant at current volume (about 100 kt/yr live-weight)
- aquaculture production more than tripling (to 120 kt/yr in 2045); and
- per capita domestic consumption saturating about 20% above current values (reaching 23 kg/yr live-weight in 2020).

By 2020 the deficit between provision and requirement peaks between 30–55,000 tonne/year depending on the scenario for managing wild capture. This range is a considerable proportion of Australia's export volume.

The analysis in this report shows that addressing the imbalance between future provision of fish and requirement for consumption/export can be achieved many ways. For instance:

- At one end of the spectrum, increasing imports by 10–15% over the assumed linear historical trend resolves the imbalance between provision and requirements. This would clearly impact financial trade figures and is contingent on gaining access to global production that is possibly constrained and at least highly competitive.
- An alternative program of dramatically increased domestic aquaculture (illustrated in the graph opposite) may take up the shortfall, but could introduce environmental impacts and relies on suitable feed inputs, technological improvements and access to water of suitable quality.
- Per capita domestic consumption could play a pivotal role: any shortfall is avoided if consumption is maintained at the present value of about 19 kg/capita/yr live-weight for several decades. Further work could explore how such a disruption of the past trend could be realised through appropriate economic signals.




## *Key issues for attention*

Two key issues stand out among the various factors underlying Australian fisheries futures:

- management of domestic wild capture; and
- rate of growth in the volume of imports.

On the issue of managing domestic wild capture, the future of Australian production could diverge substantially depending on the overall management approach adopted. The analysis points to the importance of monitoring fisheries effort and the assessment of species' available biomass. Planning for recovery periods in critical fisheries would be prudent.

Importantly, the nature of any growth in the volume of imports—whether linear or compounding annually—will influence both the future of Australian seafood consumption and trade balance figures within the sector. Attention should be given to the fundamental issue of the on-going potential for world markets to provide the volume in a possibly constrained environment.

Two other factors—domestic consumption and aquaculture production—have some potential to help alleviate any future provision-requirement deficit. The physical accounting analysis indicates that the level of change necessary for either of these factors to have a substantial impact would require substantial change from past trends.

Issues requiring further exploration or analytic development include:

- impacts of future oil production constraints and other alternative fuel supplies;
- further reality checking of modelled individual fisheries with state and federal institutions;
- exploring domestic seafood market demand;
- utilising by-catch, e.g., to augment feed from imports and domestic catch for aquaculture;
- incorporate external effects, particularly impacts of pollution and habitat degradation;
- impacts of seabirds and marine mammals other than seals;
- extension of all historical data to 1940 and resolution of discrepancies with FAO data;
- combine the bio-physical accounting with economic analysis; and
- extend the coverage into the three southern ocean FAO zones incorporating Australia.

**Keywords: Australian fisheries, stocks and flows, alternative scenarios, domestic production, aquaculture, export and import volumes**

## Roadmap for this report

This report opens with a review of world fisheries production, trade and consumption over the past 50 years in Chapter 1. Quite apart from the sheer magnitude of the current import volume to Australia, the analysis of future possible Australian fisheries scenarios (in Chapter 6) shows that imports are likely to be a key volumetric component of solutions to future challenges. A similar detailed review of the Australian fisheries sector at the national level is provided in Chapter 2. These chapters provide a quantified historical context for the physical analysis of this study. Not only do they set the historical scene but literally supply elements of the numerical constraints embedded in the stocks and flows framework.

Chapter 3 describes in some detail the physical accounting approach applied to Australian fisheries. The description works from an introduction to the philosophy of this approach to the specifics of how the bio-dynamics of the most comprehensive account of all Australian fisheries are achieved. A crucial element of the physical accounting approach—the framework calibration and reproduction of the historical data—is documented in Chapter 4. This process primes the stocks and flows framework with the starting vector for future scenarios.

Chapters 5 and 6 cover the implementation of the physical accounting approach. In Chapter 5 the first level of scenarios is developed by setting values of key factors over time, in most cases informed in the first instance by historical developments. For the wild capture sector however, three management regimes are defined. Subsequently, Chapter 6 analyses the implications of these exploratory scenarios. Various possible responses to the challenges posed by the scenarios are provided. These implications and possible responses indicate the direction, importance and priority of fisheries management options for a sustainable industry.

Naturally further questions and issues are raised by this report, and a range of these has been captured in Chapter 7.

Appendices provide further detail, and include the review of a draft of this report.

Further value and interpretation on this work is provided by an associated publication: "Modelling Australia's Fisheries to 2050: Policy and Management Implications" B Kearney, B Foran, F Poldy and D Lowe; Fisheries Research and Development Corporation, 2003.

# Chapter One - World Context

## Chapter summary

Australia is a relatively small producer of fish and seafood in terms of volume. Furthermore, it exports a significant portion of its production (especially in value terms) and imports a majority of its total domestic market (in terms of volume). As a consequence, the influence of the world market upon Australia is more significant than the reverse.

Fisheries production of the world excluding China (see Figure 1.2) has essentially been constant since the late 1980s. Although world aquaculture production (excluding China) has been increasing steadily, world capture fisheries production (excluding China, Peru and Chile) has declined significantly since the late 1980s, indicating that most of the world's capture fisheries are under pressure and in many cases, beyond their limits. There are some indications that we are fishing down the food web.

Globally, fish available for both human and non-human consumption is approaching a plateau. Worldwide per capita apparent consumption has been declining for more then a decade. This is partly due to limits to production and partly due to changing dietary patterns as individual income increases and personal choice widens. For these reasons amongst others, there are some indications that for most nations, per capita apparent consumption will stabilise at about 25 to 30 kg/capita/year.

About one-third of fishery production is traded, with 80% of this ending up in Japan, USA or the EU. A majority of Australian fisheries exports currently enter countries with relatively mature fishery markets.

## Introduction

In the context of world fisheries production, Australia is a relatively small contributor. In 1999, total Australian fisheries production was 229 thousand tonnes (ABARE, 2000), in comparison to the world fisheries production of 137 million tonnes (FAO, 2000a), or less than 0.2% of world production. This low productivity arises from our relatively nutrient-poor waters by world standards, as described in the next chapter. This production was worth AUS$2.04 billion or US$1.31 billion (ABARE, 2000) in a world total of US$125 billion (FAO, 2000c) or about 1% of global value.

There is a very significant flow of fisheries products in and out of the country (see Table 1.1). In 1998/99, at least 62kt was exported (or over 27% of Australia's fisheries production) and at least 220kt was imported (or over 57% of Australia's total fisheries consumption). This corresponds to 75% of the value of Australia's domestic production being exported (Aus$1.5 billion) and 62% of the value of Australia's domestic market being imported (Aus$0.9 billion). These flows are generally as exports of low-volume, high-value products and imports of high-volume, low-value products. Thus, the influence of the world market on Australia is very significant.

**Table 1.1** Australian fisheries flows in 2000/01[1]

| | Production | Exports | Imports |
|---|---|---|---|
| Volume (kt) | 230 | 59 | 220[2] |
| Value ($m) | 2428 | 2169 | 1152 |

Source: ABARE, 2000. [2] 1998/99 data

[1] The numbers here differ from those shown in Figure 2.13 produced by the FAO in the next Chapter. Specifically the volume of imports and exports in this table are approximately half the size of those given in Figure 2.13, while the production are in approximate agreement. This is likely due to the fact that ABARE reports imports and exports as processed/edible weights while the FAO estimate the equivalent live-weight values.

## Supply and production

### *Total Production*

Total reported world production has steadily increased since 1950, as shown in Figure 1.1. While the average rate of increase of production per annum from capture fisheries has decreased over time becoming essentially static for the past decade, production from aquaculture has been accelerating over the past fifty years to partially compensate, as shown in Figure 1.1 and Table 1.2.

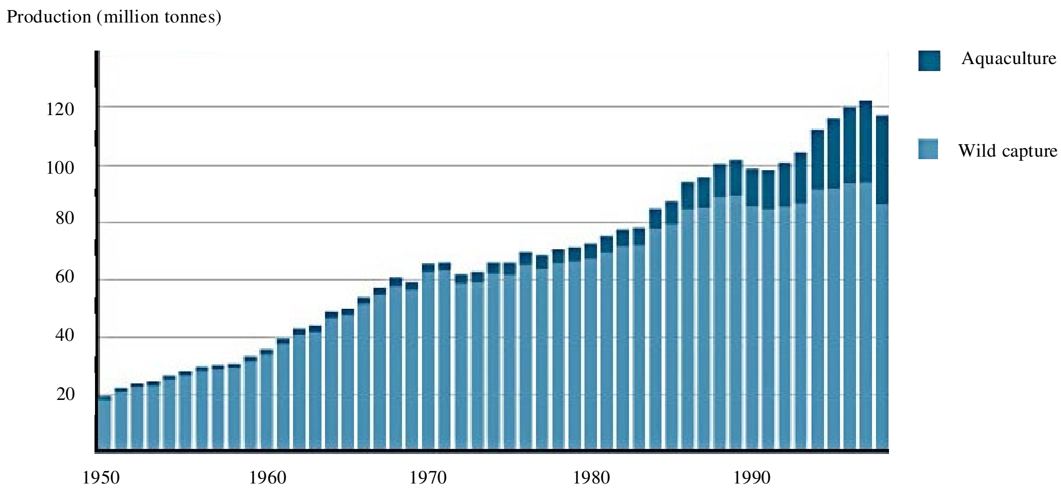



**Figure 1.1** World fisheries production by wild capture and aquaculture. Source: FAO, 2000b

**Table 1.2** Average rates of increase per annum of world production. Source: FAO, 2000b

| Period | Capture | Aquaculture |
|---|---|---|
| 1950-1970 | 6% | 5% |
| 1970-1990 | 2% | 8% |
| 1990-2000 | 0% | 10% |

The increases over the last decade owe much to the activities of China. However, the accuracy of official Chinese statistics for wild capture production has been called into question recently (FAO 2001, Watson & Pauly 2001). China is the largest single fisheries producing nation, contributing significantly to world production and thus its production figures are of critical importance.[2]

The significance of these distinctions is apparent in Figure 1.2, which show that if production from China is excluded (i.e. World* production) a much different picture emerges. Instead of a general increase, World* fish production appears to have reached a plateau. Total World* fish supply increased by 6% for 1950-1970. After a decline of 7% in the early 1970s, it increased by 2% for 1970-1990. It has essentially been constant since the late 1980s.

[2] For this reason, it is useful to distinguish between different globally significant totals, and the following definitions will apply in this text:
"World" designates all countries, including mainland China
"World*" designates all countries except mainland China

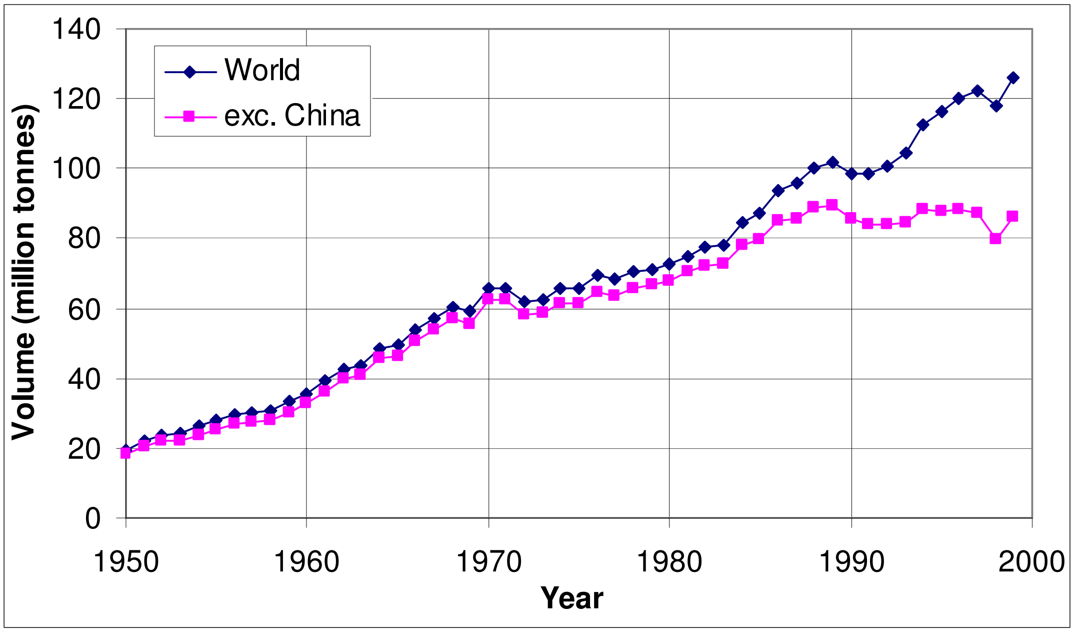



**Figure 1.2** World fisheries production. Source: FAO, 2000a

### *Capture fisheries production*

Although declining in relative importance with the rise of aquaculture, fisheries production from the marine environment still accounts for over two-thirds of the apparent world total and close to 90% of the World* total.

An initial glance at FAO statistics may suggest that world production from marine capture fisheries has basically plateaued since the late-1980s. However, as Watson and Pauly (2001) have pointed out, possible overestimates of Chinese production, combined with the large and widely fluctuating catch of species such as Peruvian anchoveta, may be causing spurious trends in global marine fisheries catch. This is illustrated in Figure 1.3, which shows that the reported total world marine fisheries catch would appear to have remained roughly constant (and perhaps even rising slightly) since the late-1980s.

Once Chinese production is removed, it would appear that remaining world production may have decreased slightly since the late-1980s. The trend is more apparent once the “noise” in the data is removed. It is easy to see that a significant contributor to this “noise” is the catch of Peruvian anchoveta once the production from the two main countries (Peru and Chile) which exploit this species is also removed. The remaining world production is observed to be much smoother, with production peaking in the late-1980s and definite trending downwards since then, with current production 10 million tonnes less than at its peak of about 71 million tonnes (a greater than 10% decline).

This decline in capture fisheries production suggests that the majority of the world fisheries have reached their limits. Other evidence comes from Pauly *et al.* (1998), who indicate that we are apparently fishing down the trophic levels. Recently, analysis of continental shelf and oceanic fish communities suggests that large predatory fish biomass is now about 10% of pre-industrial levels, with most of this decline occurring in the first 15 years of exploitation (Myers & Worm 2003).

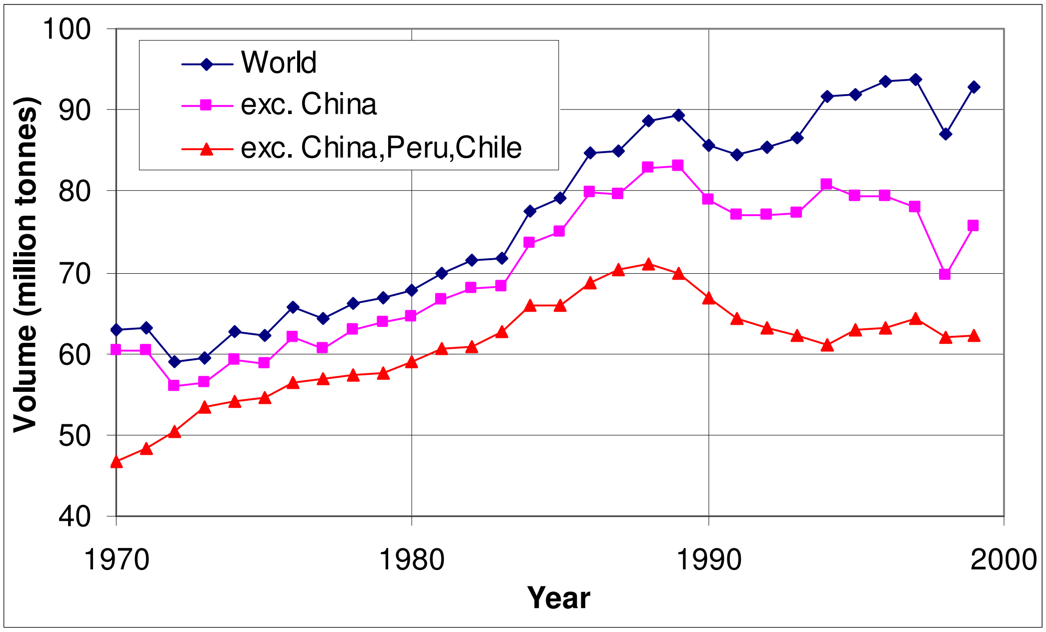



**Figure 1.3** World capture fisheries production. Source: FAO, 2000a

The process of development of a fishery as described by changes in landings with time is represented schematically in Figure 1.4. This theoretical model is essentially comprised of four phases: (I) undeveloped, (II) developing, (III) mature, and (IV) senescent. The figure shows the catch and the *rate of increase of catch* during fishery development (the units are arbitrary). This rate of increase is zero for a stable, lightly developed fishery (phase I), and then increases rapidly as the fishery is initially developed (phases I-II). However, it then decreases during the growth period of the fishery (phase III) and ultimately reaches zero as the fishery reaches maximum production. If the fishery becomes overexploited (IV), then the rate of increase becomes negative. These indicators were used to analyse the world oceans and fisheries to determine their status of development. These are shown in Figure 1.5 and reveals the ever-increasing pressure on fisheries as commented by FAO:

> “This figure strikingly illustrates the process of intensification of fisheries since 1950 and the increase in the proportion of world resources which are subject to declines in productivity ("senescent", phase IV). It also underlines the fact that the ever-growing total tonnage of world fishery production gives a misleading vision of the state of world fishery resources and a false sense of security (a comment already made by FAO). Unfortunately, a similar comment should probably be made for changes in total aggregated landings at national level, so often used as a justification for further development.” (FAO, 1997)

Applying this model to global production statistics, it implies that world* capture production is currently in the mature phase and more alarmingly, if production from China, Peru and Chile is excluded, the remaining world capture production has moved from the mature phase to senescent phase over the last decade.

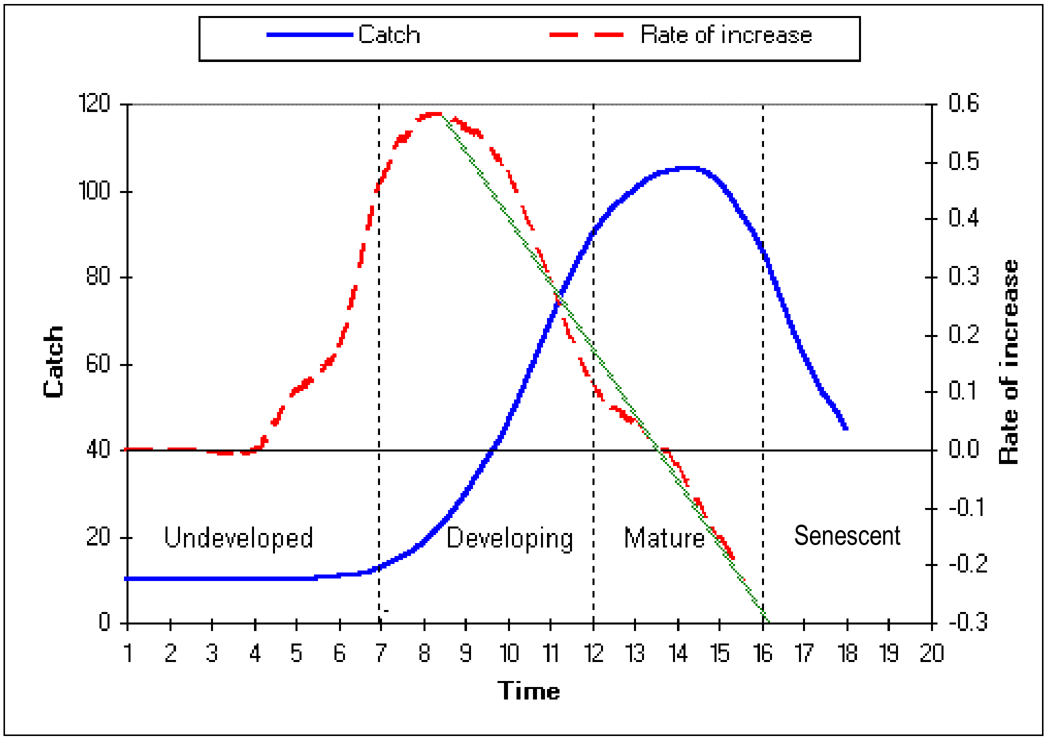



**Figure 1.4** A generalised fishery development model. Source: FAO, 1997

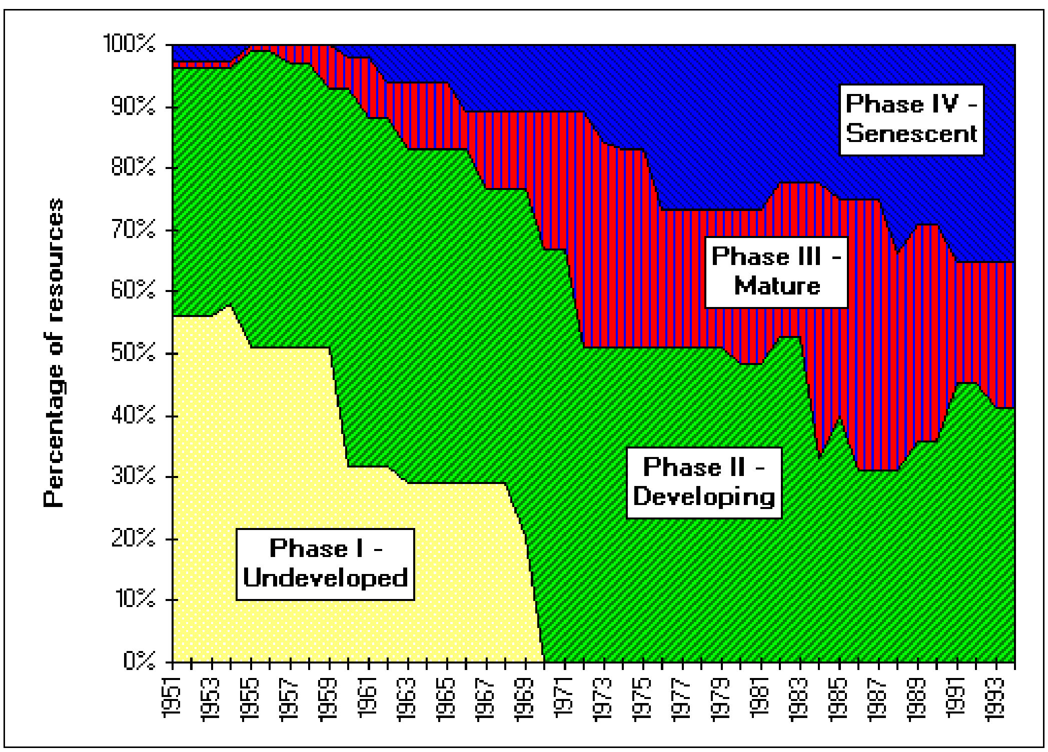



**Figure 1.5** Fraction of major marine fish resources in various phases of development. Source: FAO, 1997

### *Aquaculture production*

As shown in Table 1.3 and Figure 1.6, the *growth* of aquaculture production has apparently increased since 1970, and rapidly since 1985. However, once Chinese statistics are excluded, the growth in aquaculture production in the rest of the world is seen to have been much more moderate. The average rate of increase per annum for the last decade for the remainder of the world is less than half of that reported for the whole world.

In a similar vein, when China is included, the growth in the importance of aquaculture as a proportion of total production is quite large, reportedly increasing from 3% in 1970 to over 26% in 1999. Moreover, its importance is even greater in terms of value, with world aquaculture production comprising 38% of the total value of world production of fish, crustaceans and molluscs in 1999. However, when Chinese statistics are excluded, the proportion of World* production volume has increased from 4% to only about 12% over this time, apparently less than half for the entire world. Aquaculture production has become relatively more important as a food source, with its share of World* production increasing steadily from 5% in 1970 to 17% in 1998.

**Table 1.3** Average rates of increase per annum of world production. Source: FAO, 2000a; FAO, 2000b

| Period | World Aquaculture | Aquaculture (exc. China) |
|---|---|---|
| 1950-1970 | 5% | n/a |
| 1970-1990 | 8% | 8% |
| 1990-2000 | 10% | 4% |

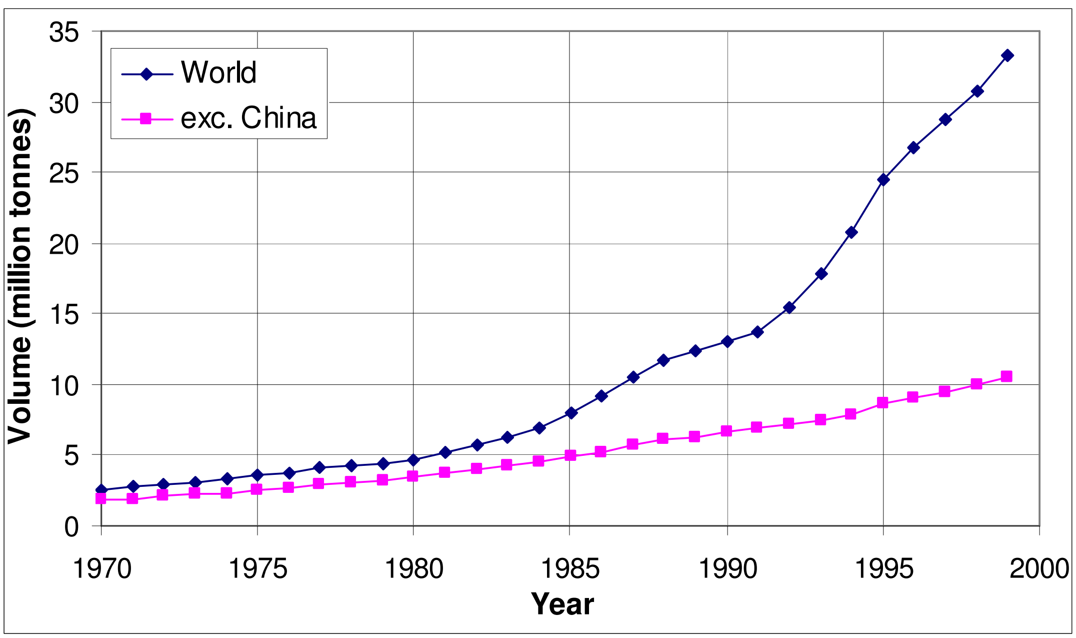



**Figure 1.6** World aquaculture fisheries production. Source: FAO, 2000a

## Demand, consumption and other utilisation

### *Fish production for both food and feed plateauing*

World* fish production for the purpose of food has increased steadily for 1950-2000, although its growth has slowed over time, levelling off over the last decade. World* fish production for feed has fluctuated widely at times in response to the changing productivity of the source reduction species such as Peruvian anchoveta. Although generally increasing for 1950-1990, it appears to also have levelled off since then and appears to have seriously declined in recent times. Since the mid-1970s and until recently, one-third of fish production has been used for feed.

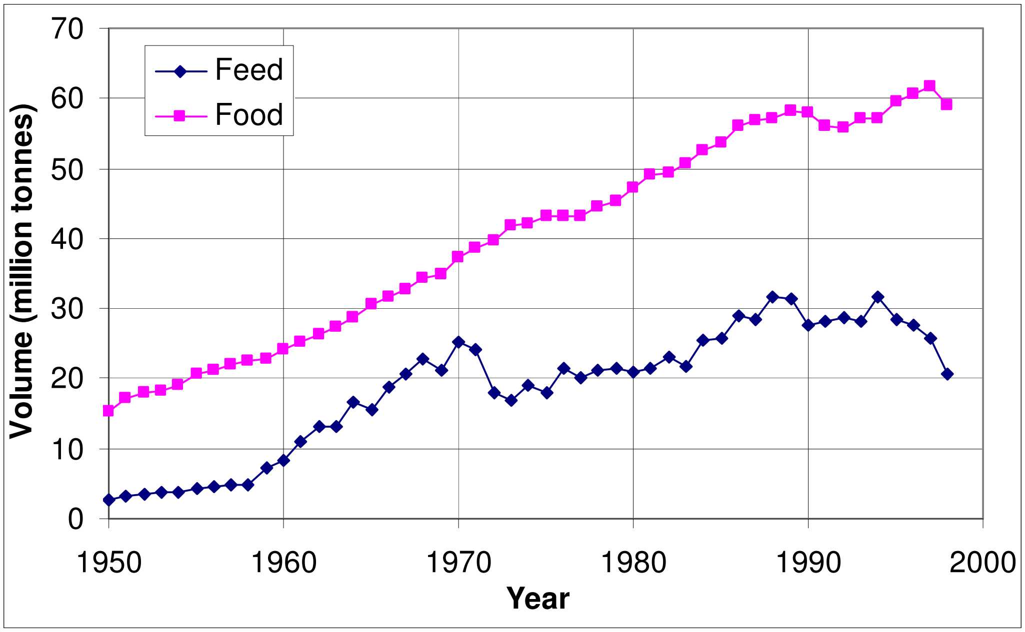



**Figure 1.7** World fisheries utilisation, excluding China. Source: After Figure 2, FAO 2000b.

### *Average per capita fish food supply in recent decline*

The average food fish supply per caput for the world, excluding China, rose from 8kg to almost 15kg in the mid-1980s. However, it has since declined from this peak to less than 13kg. The amount of consumption varies widely among countries and there is no precise way of telling the saturation level of consumption. However, it would seem reasonable to expect that for most countries it will stabilise somewhere between 20 and 40 kg/capita/year.

### *Dietary patterns are changing*

In developed countries, diets are more diversified and fish has historically contributed less than 10% of protein intake. In contrast, the contribution in Low Income Food-Deficit Countries (LIFDCs) is close to 20%. This has been gradually trending lower over the past four decades.

Dietary habits are changing, especially in developed countries. Improving incomes, developments in technology and changing social patterns are changing the type of product consumed. There is increasing desire for simple meals that are ready to eat and easy to prepare. Increasing income has allowed consumers to access a greater range of products and more eating out. There has also been more demand for fresh fish, increasing significantly since the mid-1990s, driven partly by a shift from other forms but mostly by increasing overall consumption.

As the health benefits of fish are more widely disseminated (e.g. Somerset, 2000; FRDC, 2001), markets such as USA and EU are expected to expand in the future as the perception of these benefits become increasingly important.

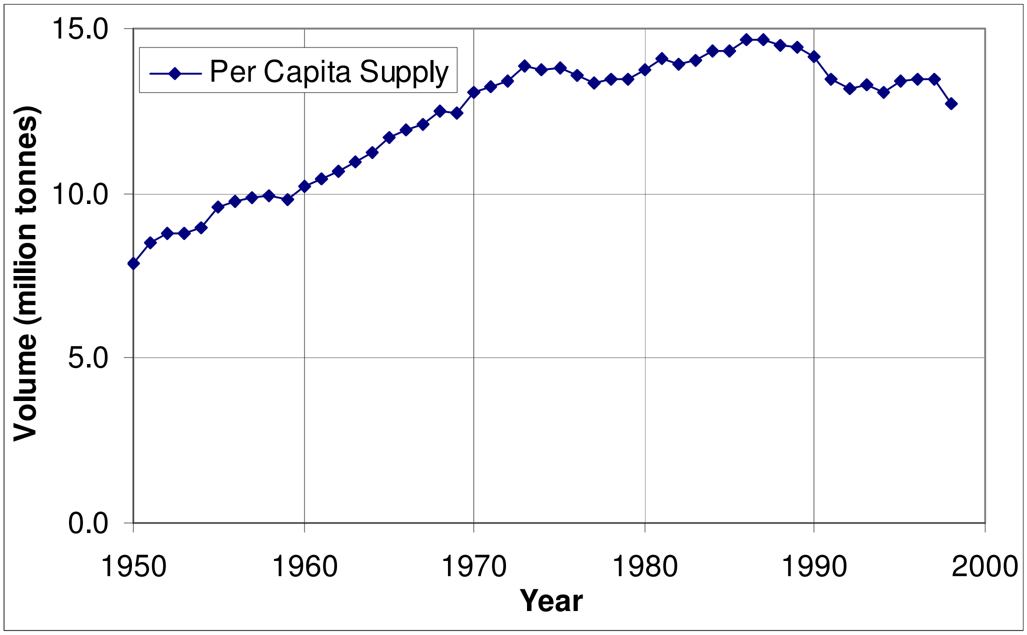



**Figure 1.8** World fisheries per capita food supply, excluding China. Source: FAO, 2000a

### *The relationship between consumption and income*

In a small study on mostly wealthy countries by FAO (2000b), it is suggested that changes in per capita consumption cannot be explained by economic growth. In this study, the correlation of income (as measured by GDP per capita) with seafood consumption per capita was calculated for selected countries for the period 1988-1997. The resulting correlation coefficients for different countries (excluding Norway and Japan) are plotted against per capita consumption in Figure 1.9. Both Norway (43.9kg) and Japan (72.1kg) have high per capita consumption levels compared to the other nations shown. They are also both traditional fishing and whaling nations. Assuming these (and perhaps other) factors make these nations atypical, the remaining data do show a great deal of variation, but some general comments can still be made:

- At low per capita consumption rates (<10kg), consumption rates strongly correlates positively with increasing income.
- As consumption rates increase, the correlation becomes weaker (and even negative)
- At 20-26kg per capita, the correlation is generally weakest.

Overall, this implies that as per capita consumption increases, there is less tendency to eat more seafood as income increases. In fact, there may be an upper limit of about 25-30kg. The most likely reason is that with increasing income, there is a larger diversity of food products consumed.

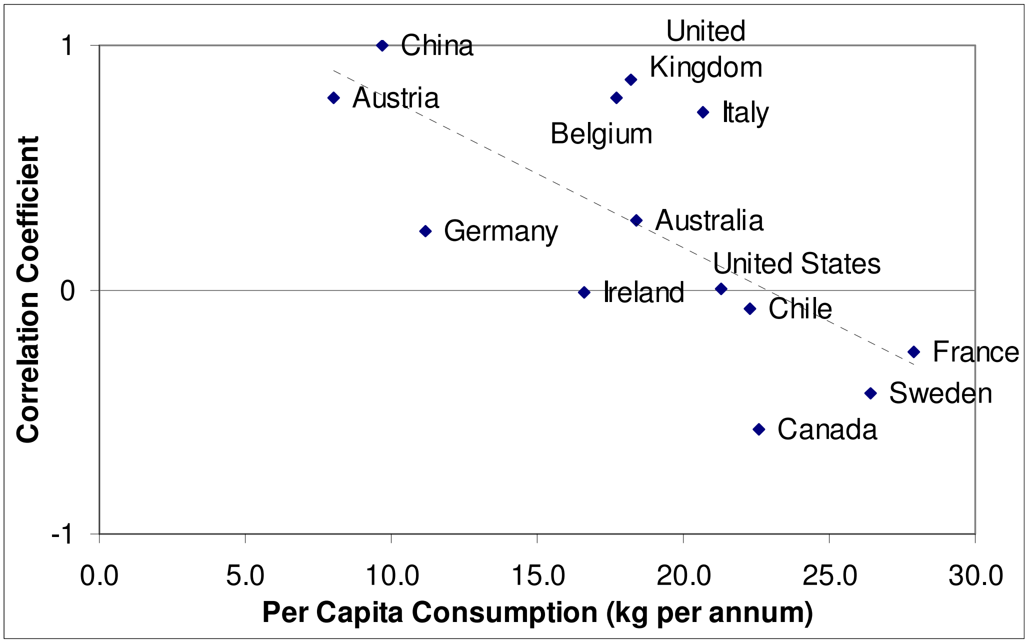



**Figure 1.9** Plot of Correlation Coefficient (of income with per capita consumption) against per capita consumption. Source: FAO, 2000b

## Global trade

Between 30 and 40 percent of all fishery production enters international trade. Some 65 percent of the volume of world fishmeal (and fishoil) production is traded internationally.

About 80 percent of the traded fish ends up in one of the three main markets: Japan, USA and the European Union. The share of these markets in the overall total remained fairly stable during the last decade. Over the last two years, the consumption of fish and fishery products has been strongly influenced by the economic crisis in Asian countries, in particular Japan. Consumption is increasing in USA and the European Union.

More than 90 percent of trade in fish and fishery products consists of processed products in one form or another (i.e. excluding live and fresh whole fish). Most is traded as a frozen food, and increasingly less as a canned or heavily dried food. Although live, fresh or chilled fish represents only a small share of world fish trade owing to its perishability, trade is growing in this high-value end of the market (e.g. live coral trout and chilled tuna), reflecting increased incomes, increased demand and improved logistics.

## Trends in important Australian markets

The main export markets in recent years are identified by ABARE as Hong Kong, Japan, Singapore, Taiwan (or Chinese Tapei), United States and China. Two potential markets for the future are Indonesia and India. The European Union, South Asia, and South-East Asia are important regional markets to keep track of. This selection is analysed below.

### *Trends of major indicators by country*

The quantity of critical importance for Australian fisheries exports is the size of the domestic supply of fish and seafood for food (which is interpreted to equate to the domestic demand) in the country in question, as shown in Table 1.4. The two most significant physical drivers of this “fish for food” demand are the population size (see Table 1.5) and the per capita consumption (see Table 1.6).

Income growth (as measured by GDP/capita/yr) is given in Table 1.7 and provides some indication of the relative wealth of individuals from different countries and consequently, the relative "purchasing power" and relative freedom of choice of goods.

**Table 1.4** Food supply

| Country | Amount (1997) | Long-term change (1970-1997) | Long-term trend (1970-1997 | Long-term growth (1970-1997) | Short-term trend (1993-1997) | Short-term growth (1993-1997 |
|---|---|---|---|---|---|---|
| | thousand tonnes/yr | thousand tonnes/yr | | % per annum | | % per annum |
| Australia | 360 | 180 | Steady rapid increase until mid-90s (doubling), becoming constant | 2.9 | Steady but fluctuating | -0.5 |
| China | 30000 | 26000 | Small increase in 70s, moderate increase in 80s, explosive increase in 90s | 8.7 | Explosive increase (but in doubt) | 15.9 |
| Hong Kong | 380 | 160 | Constant through 70s, increasing rapidly since | 2.4 | rapid steady increase | 3.2 |
| Japan | 8400 | 1800 | Steady moderate increase until late-80s becoming constant | 0.9 | small rise and fall | -0.3 |
| Singapore | 105 | 5 | Declined in 70s, rose and fell in 80s, rose in early 90s and steady since | 1.3 | Steady increase | 0.3 |
| Taiwan | 800 | 340 | Steady moderate increase until late-80s becoming constant | 2.5 | Slight decrease but fluctuating | -1.0 |
| USA | 5600 | 2500 | Steady rapid increase until early-90s (doubling), becoming constant | 2.6 | small decline | -1.6 |
| Indonesia | 3700 | 2500 | Steady rapid increase | 4.3 | Steady rapid increase | 4.6 |
| India | 4500 | 2900 | Steady rapid increase | 4.2 | Steady rapid increase | 4.7 |

**Table 1.5** Population

| Country | Amount (1999) | Long-term change (1970-1999) | Long-term trend (1970-1999) | Long-term growth (1970-1999) | Short-term change (1994-1999) |
|---|---|---|---|---|---|
| | million persons | million persons | | % per annum | % per annum |
| Australia | 20 | 6.6 | Moderate, steady increase | 1.5 | 1.3 |
| China | 1200 | 440 | Rapid, steady increase | 1.5 | 1.0 |
| Hong Kong | 7 | 2.7 | Moderate, steady increase | 1.8 | 2.3 |
| Japan | 127 | 23 | Slow, steady increase | 0.7 | 0.2 |
| Singapore | 3.2 | 1.4 | Moderate, steady increase | 1.8 | 3.1 |
| Taiwan | 22 | 7.6 | Moderate, steady increase | 1.5 | 1.0 |
| USA | 270 | 67 | Rapid, steady increase | 1.0 | 0.9 |
| Indonesia | 210 | 87 | Rapid, steady increase | 1.9 | 1.8 |
| India | 1000 | 440 | Rapid, steady increase | 2.1 | 1.8 |

**Table 1.6** Apparent consumption per capita

| Country | Amount (1997) | Long-term change (1970-1997) | Long-term trend (1970-1997 | Long-term growth (1970-1997) | Short-term trend (1993-1997) | Short-term growth (1993-1997 |
|---|---|---|---|---|---|---|
| | kg/person/yr | kg/person/yr | | % per annum | | % per annum |
| Australia | 19 | +4 | Moderate increase | 1.4 | Steady with small decline | -1.6[3] |
| China | 25 | +21 {+10 to 15} | Constant in 70s, moderate increase in 80s, rapid increase in 90s | 7.0 (8.5 for 1980-89) | Rapid increase | 14.3 |
| Hong Kong | 60 | +5 | Slow dip and rise | 0.5 | Constant | 0.4 |
| Japan | 70 | +3 (+/-5) | Steady but slowly fluctuating | 0.2 | Small rise and fall | -0.6 |
| Singapore | 36 | -15 | Declined in 70s, rose and fell in 80s, rose in early 90s and declining since | -0.5 | Steady with small decline | -2.9 |
| Taiwan | 35 | +7 | Moderate increase but fluctuating | 1.0 | Small decline but fluctuating | -1.9 |
| USA | 21 | +6 | Moderate increase | 1.5 | Small decline | -2.5 |
| Indonesia | 18 | +8 | Moderate increase | 2.4 | Moderate increase | 2.8 |
| India | 4.7 | +2 | Small increase | 2.1 | Small increase | 2.6 |

**Table 1.7** GDP per capita

| Country | Amount (1999) | Long-term change (1970-1999) | Long-term trend (1970-1999) | Long-term growth (1970-1999) | Short-term trend | Short-term change (1994-1999 |
|---|---|---|---|---|---|---|
| | $US thousand /person/yr | $US thousand /person/yr | | % per annum | | % per annum |
| Australia | 20 | 17 | Moderate, steady increase with fluctuations | 7.3 | Constant but fluctuating | 1.9 |
| China | 0.8 | 0.7 | Rapid increase | 7.9 | Rapid increase | 14.9 |
| Hong Kong | 24 | 23 | Moderate increase to mid-80s, rapid increase to mid-90s | 12.1 | Peak with recent decline | 1.7 |
| Japan | 34 | 32 | Moderate increase to mid-80s, rapid increase to mid-90s | 11.3 | Large decline with recent upturn | -1.5 |
| Singapore | 25 | 24 | Moderate increase to mid-80s, rapid increase to mid-90s | 12.7 | Peak with recent decline | 0.8 |
| Taiwan | 13 | 12 | Moderate increase to mid-80s, rapid increase to mid-90s | 12.9 | Constant but fluctuating | 2.4 |
| USA | 34 | 29 | Rapid, steady increase | 6.8 | Steady increase | 5.1 |
| Indonesia | 0.7 | 0.6 | Increase to early-80s, drop to late-80s, rise to mid-90s | 9.4 | Large drop in 1997 with partial recovery | -5.3 |
| India | 0.5 | 0.4 | Steady rise to 1990, small drop in early-90s, rise to late-90s (rapid rise since) | 5.0 | Moderate increase | 6.1 |

[3] These figures are based upon FAO apparent consumption and may differ slightly from similar ABS data.

### *Trends in major markets*

In the following section, brief descriptions of the magnitude and trends in the domestic food market, population, consumption rates and income of individual countries are given. This is not a detailed market analysis, but a summary of fundamental aspects of export markets of importance to the fishery industry in Australia. The descriptors of size used in the following text are defined in Table 1.8.

**Table 1.8** Descriptors of size for various quantities

| General descriptor | Production ('000 tonnes) | Population (millions) | Consumption (kg/person/yr) |
|---|---|---|---|
| small / low | <300 | <10m | <10 |
| small-medium | 300-1000 | 10-30m | — |
| medium / moderate | 1000-3000 | 30-100m | 10-30 |
| medium-large | 3000-10000 | 100-300m | — |
| large / high | >10000 | >300m | >30 |

### *Japan*

*Special notes*: Currently Australia's largest single export market.
*Food market*: The fish for food market is about 8400kt and not growing.
*Population*: Currently around 130 million but its growth is small and slowing.
*Consumption*: Currently about 70 kg/person/yr and constant although it has gone through slow fluctuations.
*Income*: Has had large continuous income growth to the mid-1990s, but declined and fluctuated since to be currently about US$34000 per person.
*Summary*: The medium-large population and high consumption rates both appear to be fairly constant. The market is medium-large, fairly stable and not growing. Therefore, the general need is to increase market share and/or market value of products in a medium-large, stable market.

### *Hong Kong*

*Special notes*: Second largest single export market.
*Food market*: The fish for food market is about 380kt and growing moderately.
*Population*: Currently around 7 million and growth is moderate and increasing.
*Consumption*: Currently about 60 kg/person/yr which has gone through a slow fall and rise to be constant over recent years.
*Income*: Although not as large as Japan, the growth pattern of income was similar to Japan, declining in 1997 to be currently about US$24000 per person.
*Summary:*: The small population is growing moderately while the high consumption rates are fairly constant. The market is of small-medium size and growing moderately.

### *Taiwan*

*Special notes*: A major Australian export market.
*Food market*: The fish for food market is about 800kt and not growing.
*Population*: Currently around 22 million and growth is moderate and slowing.
*Consumption*: Currently about 60 kg/person/yr and has grown moderately over the past thirty years, with a slight decline in recent years.
*Income*: Smaller again than either Japan or even Hong Kong (about US$13000 per person), the growth pattern of income was similar to both countries, but instead of declining since 1997, has remained fairly constant.
*Summary*: The small-medium population is growing moderately while the consumption, though high, seems to have plateaued. The market is of small-medium size and not growing.

### *USA*

*Special notes*: A major Australian export market.
*Food market*: The fish for food market is about 5600kt and not growing.
*Population*: Currently around 270 million and growth is moderate and fairly constant.

*Consumption*: Currently about 21 kg/person/yr that has grown moderately over the past thirty years, with a small decline in recent years.
*Income*: The USA has had moderate and sustained income growth for the whole 30 year period to currently reach about US$34000 per person.
*Summary*: The medium-large population is growing moderately while at the same time, per capita consumption is declining. The result is a medium-large market that is not growing.

### China

*Special notes*: A major Australian export market.
*Food market*: The fish for food market is probably about 20-25 Mt and growing rapidly.
*Population*: Currently around 1200 million and growth is moderately and slowing slightly.
*Consumption*: Currently probably about 20 kg/person/yr that has grown rapidly over the past thirty years (even discounting the rapid growth of the last decade).
*Income*: Personal income grew moderately until the 1990s, where it increased rapidly to be about US$800 per person
*Summary*: This large population is growing relatively moderately while consumption rates are growing rapidly. Thus, China is a large market that is growing quickly.

### Singapore

*Special notes*: A major Australian export market.
*Food market*: The fish for food market is about 120kt and growing slowly.
*Population*: Currently around 3.4 million and growth is moderate and steady.
*Consumption*: Currently about 36 kg/person/yr and after a sharp decline in the 1970s, has been fluctuating between 25 and 40 kg/person/yr for the past twenty years.
*Income*: Personal income has grown rapidly since the mid-1980s, reaching US$29000 per person in 1997 declining sharply to US$25000 per person in 1999.
*Summary*: The small population is growing moderately while the consumption rates are fairly constant but fluctuate between moderate and high levels. This market is small and growing slowly.

### Indonesia

*Special notes*: A potential export market.
*Food market*: The fish for food market is about 3700kt and growing rapidly.
*Population*: Currently around 210 million also growing steadily and rapidly.
*Consumption*: Currently about 18 kg/person/yr, it has grown moderately and steadily since the mid-1970s.
*Income*: Starting from about US$90 per person, it rose to about US$650 per person in the early-1980s and then declined to about US$470 per person in the late-1980s. It then rose rapidly to over US$1100 per person in 1996, but collapsed substantially to US$470 per person by 1998, recovering since.
*Summary*: This medium-large population is growing relatively rapidly and moderate consumption rates is growing moderately. Both have exhibited steady growth while personal income has had a more erratic rise. Thus Indonesia is a medium-large, rapidly growing market.

### India

*Special notes*: A potential export market.
*Food market*: The fish for food market is about 4500kt and experiencing relatively steady and rapid growth..
*Population*: Currently around 1000 million and also growing steadily and rapidly.
*Consumption*: Currently about 4.7 kg/person/yr, it grew slowly from about 2.9 kg/person/yr until the mid-1970s, growing more quickly since.
*Income*: Despite some small dips, it has grown moderately and relatively steadily from US$120 per person in 1970 to US$450 per person in 1999.
*Summary*: This large population is growing relatively rapidly and the low consumption rate is growing moderately. Thus India is a medium-large, rapidly growing market.

### *Overall picture*

Japan and USA are both examples of medium to large markets that are mature and not growing substantially. They also have high personal incomes. Therefore, to increase the total value of Australian exports to these countries, the general need is to increase market share and/or market value (perhaps through market differentiation) of Australian products.

Hong Kong, Taiwan and Singapore have many common characteristics. Hong Kong and Taiwan are both small-medium markets (Singapore is small). Hong Kong and Singapore both have small populations (Taiwan is small-medium), similar GDP and similar high personal incomes (Taiwan's is half the size). Taiwan and Singapore have similar consumption rates (Hong Kong's is 50% higher). The total fish for food market is growing fastest in Hong Kong, moderately in Singapore and not at all in Taiwan. Generally speaking, Hong Kong and Singapore have the most potential in the short term. However, Taiwan (with relative large population and relatively low personal incomes) may be of long-term potential if their economy grows steadily.

China is a huge emerging market, driven both by population growth and increasing consumption rates, that is growing rapidly. Indonesia is potentially another large market with population growth and already significant and growing consumption rates. India could be a large market if consumption rates increase from current low levels. Although this is of importance to Australian exporters, it may have just as great impact on Australian importers as Australia competes with these countries for international fish supplies.

## Important producers for the Australian domestic market

Australia imports fisheries products from a large number of nations. In 1999, the most significant of these by a considerable margin were Thailand and New Zealand. These two countries alone contributed 49% of the volume and 43% of the value of total Australian fisheries imports. In the same year, the next eight countries (in alphabetical order: Canada, Chile, Taiwan, Japan, Malaysia, South Africa, USA, Vietnam) contributed a combined total of 32% of the volume and 28% of the value of total Australian fisheries imports.

### *Thailand*

The main export markets of Thailand are Japan, USA and the EU. In 1998/99, Thailand exported 1860 thousand tonnes worth about US$4100 million. According to ABARE (2000) Australia imported 34 thousand tonnes of edible weight (or 3.6% of total volume) worth US$147 million (3.6% of total value), making it a significant but relatively small export market for Thailand.

### *New Zealand*

In 1995, the main export markets for New Zealand were Japan, USA and Australia, although they were expanding further into Asian and European markets at the time. In 1996/97, New Zealand exported 641 thousand tonnes worth about US$830 million. ABARE reported that Australia imported 27 thousand tonnes of this (or 8.6% of total volume) worth US$87 million (11% of total value), making it an important export market for New Zealand.

The key issues for Australia in the future are the increasing competition for supplies of fisheries products with other nations as seafood consumption rises throughout the world and the capacity of producers to supply the global market.

## Future projections

Among the factors that could influence future demand for seafood products are population growth; changes in economic and social conditions (such as lifestyle and family structure); developments in fish production, processing, distribution and marketing strategies; and the prices of fish compared with those of competing foodstuffs.

Asia is the centre of world fish consumption (accounting for some two-thirds of the total at the end of the 1990s), what happens there will determine global developments.

Livestock production is expected to continue to increase rapidly over the period to 2030, and with it demand for animal feeds, hence also for fish meal and fish oil. To this should be added a growing demand for both fish meal and oil in feeds for aquatic animals produced in intensive aquaculture systems.

FAO (2000c, 2000d) have made projections of the possible range of production in 2010 based on pessimistic and optimistic scenarios (Table 1.9). In the pessimistic scenario, overfishing leads to declining capture production while in the optimistic scenario, it is believed that there is potential for improved management to increase production. Similarly, aquaculture production may move in either direction, presumably depending on management and environmental constraints.

**Table 1.9** Current Production and projections for 2010. Source: FAO, 2000c; FAO 2000e

| | 1999 | 2010 Pessimistic Scenario | 2010 Optimistic Scenario |
|---|---|---|---|
| Capture fisheries | 93 | 80 | 105 |
| Aquaculture | 33 | 27 | 39 |
| Total production | 126 | 107 | 144 |

## References


ABARE (2000) Australian Bureau of Agricultural and Resource Economics, Australian Fisheries Statistics 1999.

FAO (1997) FAO, Review of the state of world fishery resources: marine fisheries. FAO Fisheries Circular. No. 920. Rome.

FAO (2000a) FAO Fisheries Department, Fishery Information, Data and Statistics Unit, FISHSTAT Plus. Universal software for fishery statistical time series. Version 2.3.

FAO (2000b) FAO Fisheries Department, The state of world fisheries and aquaculture 2000.

FAO (2000c) FAO Fisheries Department, Trends in global aquaculture production, Accessible on webpage http://www.fao.org/fi/trends/worldprod99e.asp.

FAO (2000d) FAO Fisheries Department, Projection of World Fishery Production in 2010. Accessible on webpage http://www.fao.org/fi/Prodn.asp.

FAO (2001) FAO Information Division, The State of Food and Agriculture 2001.

FRDC (2001) Fisheries Research and Development Corporation, What's so healthy about seafood?, FRDC Final Report 1996/340.

Goldsworthy S.D., C. Bulman, X. He, J. Larcombe and C. Littnan (2002) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach.

Myers R.A. and B. Worm (2003) Rapid worldwide depletion of predatory fish communities, Nature, 423, pp.280-283.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese and F.C. Torres (1998) Fishing down marine food webs, Science, Vol 279, p860-863.

Somerset, S. (2000) Enhanced usage of contemporary scientific findings on health benefits of seafood to promote fresh seafood consumption.

Watson, R. and D. Pauly (2001) Systematic distortions in world fisheries catch trends, (2001). Nature, Vol 414, p534-536.

# Chapter Two - Australian Context

## Chapter summary

Although the Australian Fishing Zone is spatially large, with diverse habitats and species, it is relatively unproductive by world standards. This is mostly due to nutrient-poor waters caused by a combination of geological and hydrological factors including low levels of runoff from the dry continent and no permanent major up-welling.

According to FAO, total seafood production increased steadily to 250 thousand tonnes including about 50,000 tonnes of aquaculture by 1999, although the growth appears to have slowed over the last decade. Fish production appears to have reached a plateau at about 150 thousand tonnes, crustacean production has increased steadily (to about 60 thousand tonnes by 1999) and mollusc production has trended upwards but varied widely (ranging between 25 and 55 thousand tonnes during the 1990s). Aquaculture production has increased considerably since 1990 while capture production appears to have reached a plateau since the late 1980s.

Domestic supply for food has increased steadily over time, while there have been large fluctuations in the supply of seafood for use as animal and aquaculture feed. Seafood consumption per capita has increased steadily over the last 40 years. The volume of exports has steadily increased, while imports generally increased but fluctuated considerably (largely due to feed imports).

## Introduction

Many excellent introductions to fisheries resources in the Australian context exist including the following:

- Australian Fisheries Resources (1993)
- BRS Fishery Status Report 1999 (2000)
- FRDC Fishery Snapshot (1999)
- ABS Australia Now (2001)

Much of the material in this section draws heavily from these sources.

### *The Australian Fishing Zone is large*

The Australian Fishing Zone (AFZ) extends up to 200 nautical miles (370.4 km) from the shoreline. It covers an area of approximately 9 million square kilometres making it the third largest fishing zone in the world after France and USA.

### *The coastline, habitats and fauna are diverse*

Australia's coastline is one of the longest in the world at about 36,000km. Australia's waters extend over a broad range of latitudes (sub-tropical to sub-Antarctic regions) and over a broad range of depths (over 5km below sea level in places). These factors result in many major habitat types being represented. Over 3600 species of fish, over 2000 species of the crustacean order Decapoda (prawns, lobsters, crabs etc) and tens of thousands of species of aquatic molluscs are found around Australia. Of these, we commercially exploit about 200 species of fish, 60 species of crustaceans and 30 species of molluscs.

### *However, the productivity is low by world standards*

Despite a large zone and diverse environments, Australia's waters are relatively unproductive by world standards (with wild capture production ranked about 50$^{th}$ globally at around 220,000 tonnes in 1999. This is largely due to the generally low nutrient levels of Australian waters caused by a combination of factors including:

- low levels of runoff from the dry, well-weathered (and thus) nutrient–poor continent

- a narrow continental shelf that limits photosynthetic production
- the predominantly southwards, warm to cold, flow of the main Australian coastal currents
- no major permanent upwellings[4]

For this reason, Australia imports a significant proportion of its domestic market (mostly relatively low-value product such as hoki fillets from New Zealand and hake from South Africa) and concentrates on exporting relatively low volumes of high-value fish and fish products (such as rock lobster).

### *The management jurisdictions*

Management of fisheries is shared between the Commonwealth, the States (New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia) and Territories (Northern Territory). In most cases fisheries are solely the responsibility of one management authority but there is also often co-management between the Commonwealth and one or more states/territories for fisheries that extend over large areas, reflecting the extent of the target species and the fishing operations that hunt them.

## *A brief history of fishing in Australia*

### *Wild capture*

It is likely that fishing was a normal aspect of life of people near bodies of water, as much as hunting land animals and gathering of edible plants. Archaeological evidence suggests that humans have fished for tens of thousands of years[5]. Australian aborigines are known to have fished from at least 25000 BC[6]. These behaviours were probably similar to modern-day artisanal, sustenance or subsistence fisherman. They may derive pleasure from fishing, but the prime purpose for fishing is to obtain food (Iversen, 1996). This activity is widespread in underdeveloped countries and probably undertaken by some low income families in developed countries (Pitcher, 2002; Kearney, 2002). Before British colonisation, Aboriginal people fished a wide range of marine and freshwater resources, fish being a major dietary item for coastal Aboriginal people and Torres Strait Islanders. A wide range of techniques were used including hand-gathering, spearing, trapping and hook-and-line (Kailola et al., 1993).

### *Wild capture commercial*

After settlement, exploitation of whales and seals became one of the first major industries. Exploitation of these marine animals, pearl oysters and inshore oysters, prawns, crabs, rock lobster and fish dominated until the 1920s. Until the late-1940s, sea mullet and barracouta were the most common commercial fish species caught.

The catching of additional species and use of new fishing methods began in the early part of the 20$^{th}$ century. Exploitation of more distant and deeper waters began with trawling, Danish seining and long-lining during the 1920s and 1930s. Larger scale commercial operations began in the 1950s increasing and further diversifying during the 1960s and 1970s. Apart from the pearl fishery, commercial fisheries in northern Australia began developing during the 1960s. During the 1980s, exploitation of deep water fisheries such as orange roughy, blue grenadier, oreos, scampi and carid prawns commenced. By the early 1990s, most of Australia's inshore and coastal fisheries were fully developed and fisheries were developing in the most remote regions of the Australian Fishing Zone (AFZ).

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[4] Minor upwellings around Australia include (Kailola, 1993):

1. Some in the western Tasman sea off eastern Tasmania at various times of the year
2. A seasonal one, off south-eastern South Australia

[5] For example, http://www.handprint.com/LS/ANC/stones.html (retrieved 1/3/02)

[6] Evidence of net fishing at Willandra Lakes region (http://www.glenn.morton.btinternet.co.uk/chron.htm) (retrieved 1/3/02)

### *Wild capture recreational*

The history of true recreational fishing (as opposed to commercial or subsistence) is harder to discern, but it is logical to believe that it only occurred when there was both (1) no immediate necessity to fish for food and (2) there was sufficient leisure time to allow for such non-essential activities. Thus it was most likely the province of the very wealthy in any community or society. As agriculture and labour-saving technology has improved more individuals have gained the opportunity to take part in true recreational fishing.

As fish have long been considered common property and belonging to no-one, fishing of all types has been considered a right rather than a privilege. As commented by Pepperell, this attitude is common in most western nations, including Australia (Hancock, 1994). Probably due to the relatively large volumes involved, licensing of commercial fishing operations came first. Licensing of recreational fishing has come later, with some states such as Queensland still allowing unlicensed fishing. However, as resources have come under increasing pressure, resource sustainability and resource allocation have become issues.

### *Aquaculture*

Since development commenced in 1870, Sydney rock oyster was the most important aquaculture species for most of the 20th century. Pearl culturing began in the 1950s, becoming one of the most valuable aspects of present-day aquaculture. Aquaculture diversified during the 1970s and 1980s, when different species were experimented with and developed such as brown and rainbow trout, atlantic salmon, blue mussel, yabbies and prawns. During the 1980s and 1990s, production increased overall, but most rapidly in atlantic salmon, southern bluefin tuna, giant tiger prawn and pacific oyster.

## Supply and production

### *FAO data*

The FAO data are aggregated to relatively high level, particularly in terms of spatial extent, with only three FAO statistical regions covering all the waters that surround Australia.[7] Although much of the data is specified at the level of species, there can still be significant volumes which remain unidentified below a certain level of disaggregation. Despite these limitations, they still offer a reasonable and convenient time series of data on commercial fisheries production that can be analysed for overall patterns and trends for Australia. For this reason, much of the material in this section draws heavily on FAO statistical databases.

### *FAO statistical regions adjacent to Australia*

The adjacent FAO regions to Australia are generally considered not to be over-utilised. According to the FAO report, *The State of World Fisheries and Aquaculture 2000* (FAO, 2000b), these regions were all generating their maximum production in current years. Additionally, FAO estimated that only 15% of Eastern Indian Ocean fisheries stocks, 8% of Western Central Pacific fisheries stocks and 0% of South-west Pacific fisheries stocks were exploited beyond Maximum Sustainable Yield (MSY) levels in 1999. This is in contrast with most other FAO statistical regions, which achieved their peak production in previous decades (and have been in general decline since), and which had an estimated 30% or greater of their fisheries stocks exploited beyond MSY levels in 1999.

### *Total production by major groups*

According to FAO, since 1950 there has been a generally steady rise in fisheries production over the last fifty years, with significant drops in the mid-1970s, 1989 and more recently, in the mid-1990s (Figure 2.1). The majority of the production is in fish (about 150 thousand tonnes in 1999) with the

[7] The three FAO regions are

1. Indian Ocean, Eastern (IE)
2. Pacific, South-west (PSW)
3. Pacific, Western Central (PWC)

contributions from crustaceans and molluscs being approximately equal (about 50 thousand tonnes each in 1999).

### *Total fish production appears to have plateaued*

Since 1950, fish production exhibited a gradual increase until the mid-1980s, followed by a rapid rise until the early-1990s and an apparent stabilisation since that time (Figure 2.1). During this period, fish production has been comprised almost entirely of marine species (about 140 thousand tonnes in 1999), with much smaller contributions from diadromous[8] and freshwater species (a combined total of 17 thousand tonnes in 1999), as seen in Figure 2.2. Production of diadromous species has increased eight-fold since the mid-1980s (from 2 to 16 thousand tonnes) while freshwater production collapsed in the mid-1990s (from 3 thousand tonnes to virtually zero, recovering somewhat since).

### *Total mollusc and crustacean production have increased steadily*

Crustacean production has risen very steadily over the whole historical period shown to reach 60 thousand tonnes in 1999 (Figure 2.1). Molluscs have also risen steadily but also shown a cyclical decadal pattern since the early-1970s ranging from 25 to 55 thousand tonnes during the 1990s. This is reflective of the underlying variation in scallop wild capture production.

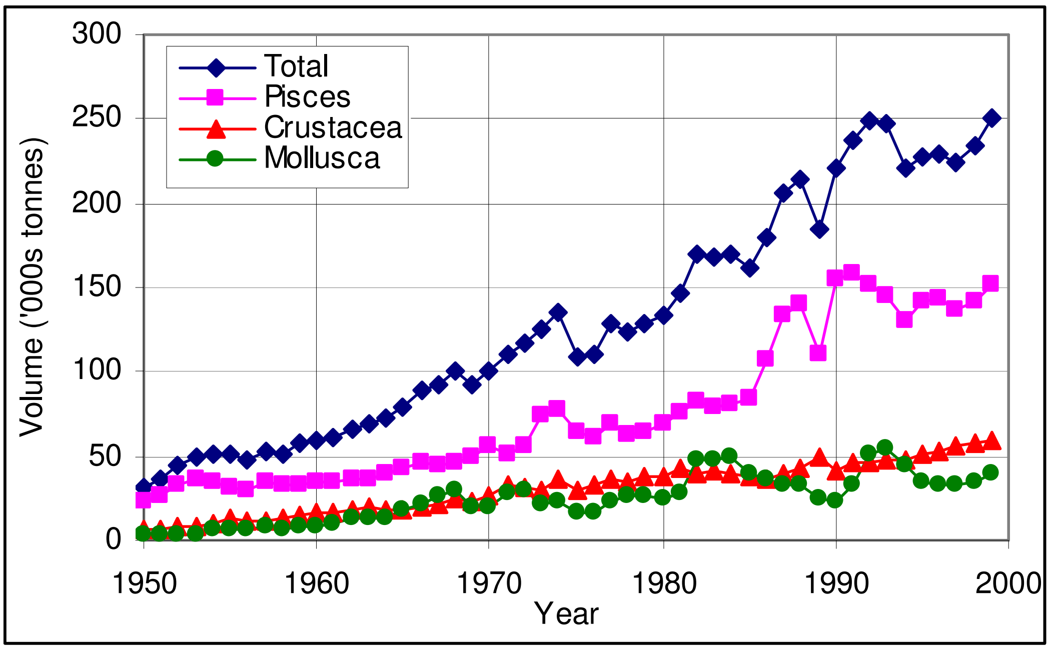


**Figure 2.1** Australian production by major groups. Source: FAO, 2000a

[8] 'Diadromous' species are those spend time in both freshwater and marine environments for parts of their lifecycles.

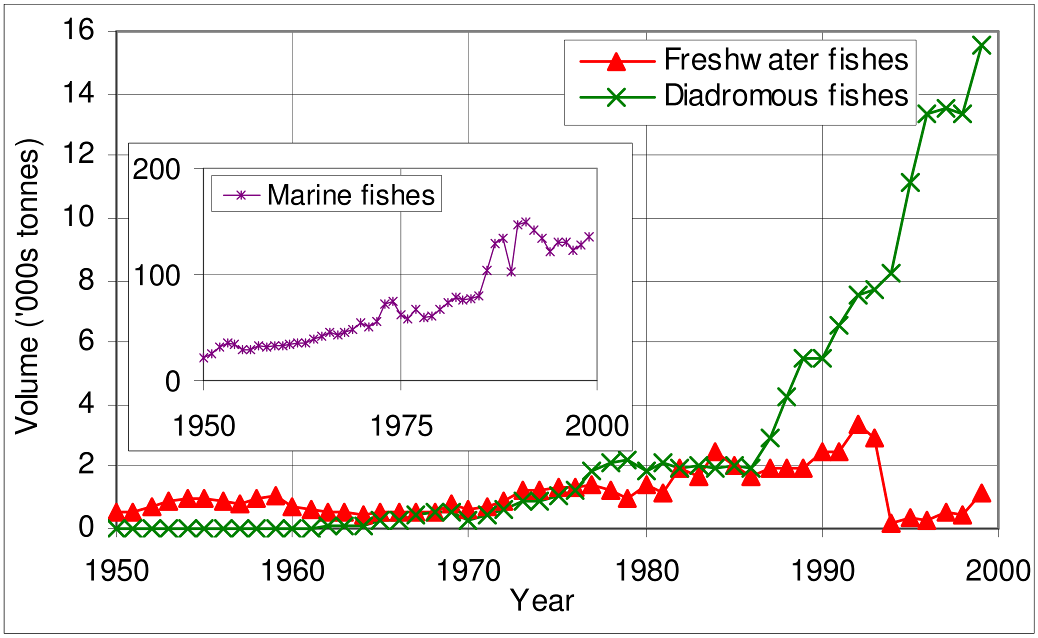


**Figure 2.2** Australian fish production. Source: FAO, 2000a

### *Total production by sector*

When analysed by sector, it is clear that the majority of production (by volume) has come from wild capture fisheries (Figure 2.3). Production from capture fisheries generally increased steadily until the early-1990s where it has since apparently plateaued (at about 200 thousand tonnes per year) despite recent increases. On the other hand, aquaculture production was quite stable until the mid-1980s, at which time it rose dramatically, tripling production (from 10 to 30 thousand tonnes) by the end of the century[9].

### *Production of major groups by sector*

As the major contributor to total fisheries production, it is unsurprising that capture production displays the same patterns exhibited at a total aggregate level (Figure 2.3). Disaggregating by major seafood groups, there has been an apparent decline and stabilisation of capture production of fish during the 1990s at about 130 thousand tonnes (Figure 2.4). It is clear that much of the recent increase in total fish production (Figure 2.1) arose from the apparently rapid increase in aquaculture production of fish during the last decade (Figure 2.5). Crustacean production from both sectors has increased steadily since 1970 (Figure 2.4 and Figure 2.5). Capture production of molluscs has risen steadily, but fluctuated considerably (Figure 2.4), whereas the aquaculture production of molluscs has been relatively constant, increasing slightly during the late 1990s (Figure 2.5).

[9] Some care must be taken in interpreting this apparently dramatic rise in aquaculture production. As is stated later, the aquaculture production of marine fish during the 1990s is almost entirely southern bluefin tuna (SBT), rising from zero in 1991 to 6 thousand tonnes in 1999. This species is caught wild, ranched and on-grown, rather than produced in a complete lifecycle process, and therefore only the weight gained should be considered as aquaculture production (about 1400 tonnes in 1998/99). FAO statistics do not reflect this distinction so that some double counting occurs.

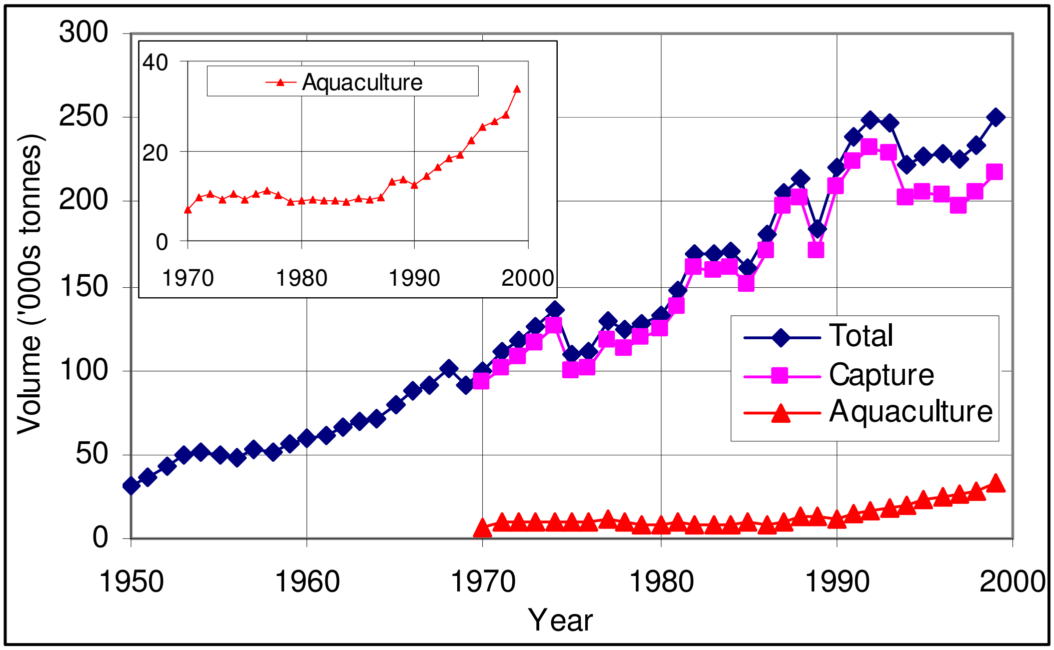


**Figure 2.3** Australian production by sector. Source: FAO, 2000a

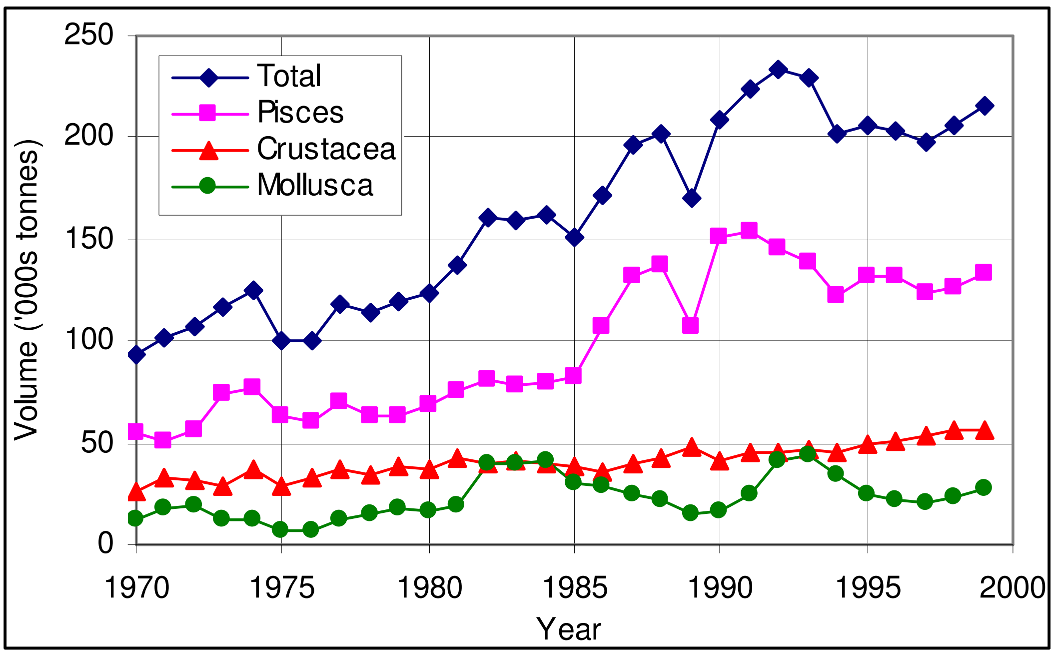


**Figure 2.4** Australian capture production by major groups. Source: FAO, 2000a

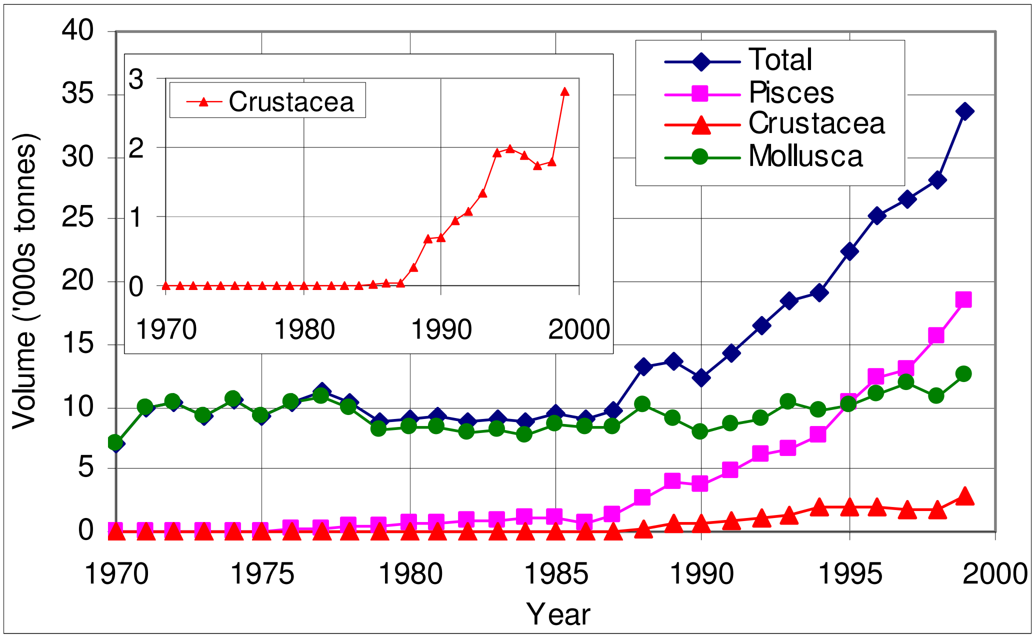


**Figure 2.5** Australian aquaculture production by major groups. Source: FAO, 2000a

### *Australian crustacean production*

Crustacean **capture production** has increased steadily over the last thirty years doubling from 25 to 55 thousand tonnes per annum between 1970 and 1999. Using the ISSCAAP groupings of species[10] developed by the FAO, the majority of this production are '*Shrimps, prawns*' (various species including banana, endeavour, tiger prawns) and '*Lobsters, spiny-rock lobsters*' (mostly western and eastern rock lobsters[11]). Starting from virtually zero in 1985, crustacean **aquaculture production** has increased to 3kt/yr in 1999. Most of this production consists of prawn (mostly giant tiger prawn and Kuruma prawn) and freshwater crayfish (mostly yabbies).

### *Australian mollusc production*

Mollusc **capture production** has fluctuated considerably but with otherwise increasing overall production. The fluctuations appear to occur over an approximate decade cycle. Again using ISSCAAP groups, the production consists mostly of (in order of volume) '*Scallops, pectens*' (mostly southern scallop), '*Abalone, winkles, conchs*' (mostly blacklip abalone), '*Squids, cuttlefishes, octopuses*' (various) and '*Mussels*' (entirely blue mussel). The apparent decadal cycle is a reflection of the underlying fluctuations in scallop production. **Aquaculture production** has long been a significant contributor to total mollusc production and remained steady for 1970-1990. However, there appears to be a general increase over the last decade. Early on, Australia's aquaculture production of molluscs was entirely Sydney Rock Oyster. However, this has slowly declined while Pacific Oyster production increased, in part to fill the market niche, with production of both of similar magnitudes in recent years. At the same time, the production of blue mussel has steadily been increasing.

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[10] ISSCAAP is a coding system developed by FAO (www.fao.org), with the acronym standing for 'International Standard Statistical Classification of Aquatic Animals and Plants'. They codes are designed specifically for data entered into the FAO databases plus about four hundred other species specifically requested for inclusion.

[11] Curiously, the FAO database did not record southern rock lobsters as a significant component of this group, whereas ABARE data would suggest it should be so. We are currently unsure of the reason for this discrepancy.

## *Australian fish production*

Capture marine fishes are still the main component of fish production, but appears to have stabilised since rising rapidly during the late 1980s (see insert of Figure 2.6). Although both are rising, aquaculture rather than wild capture, produces the majority of diadromous fish (Figure 2.6 and Figure 2.7). Farmed production of marine fishes has increased rapidly recently, although this is mainly southern bluefin tuna which is currently on-growing and not closed life-cycle and so only the weight increase should be counted as aquaculture production (which is currently not the case with FAO statistics). Freshwater fish capture production collapsed dramatically in the early 1990s (Figure 2.6), and will not recover as most inland commercial fisheries have now been closed. Aquaculture production of fish is still in its infancy in Australia.

### *Australian fish capture production*

The breakdown of fish capture production is shown in Figure 2.6. The FAO data are not detailed enough to specify the makeup of freshwater species caught. The diadromous production is composed mostly of barramundi, with a smaller contribution of eel.

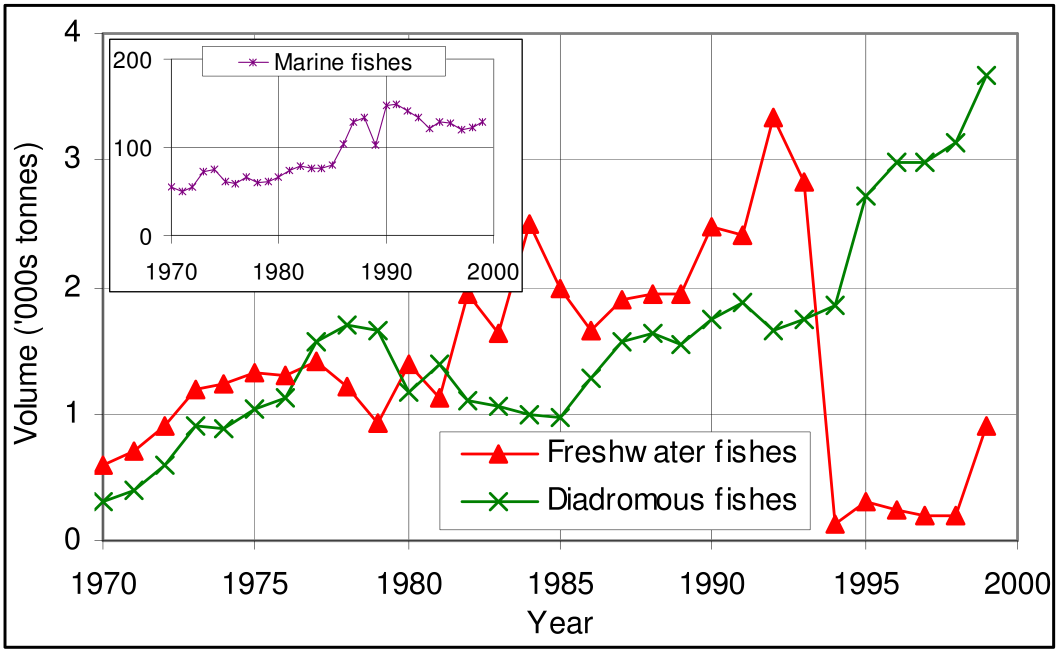



**Figure 2.6** Australian fish capture production. Source: FAO, 2000a

Marine fishes consist of a number of species groups. According to ISSCAAP groups, the largest single component is the group '*Redfishes, basses and congers*', most of which being a large peak of Orange Roughy production around 1990. Other major species and species groups are Australian salmon, whitings, flatheads, warehou, snapper, morwongs, Australian herring and Patagonian toothfish). The total (excluding Orange Roughy), show a gradual rise until the late 1980s after which, it has been fairly constant.

The next largest identifiable grouping is '*Tunas, bonitos, billfishes*' which peaked in the 1980s and appears to be rising again. The peak in the 1980s is almost wholly due to southern bluefin tuna but which has since declined and become stable. The recent increase is mostly due to catches of skipjack, yellowfin and bigeye tuna and broadbill swordfish.

The next largest identifiable groups are (1) '*Jacks, mullets, sauries*', (2) '*Herrings, sardines, anchovies*' and (3) '*Sharks, rays, chimaeras*'. These divisions all show generally rising catches during the 1970s, peaking in the late 1980s. '*Jacks, mullets, sauries*' and '*Herrings, sardines, anchovies*' appear to have generally declined since while '*Sharks, rays, chimaeras*' have generally stabilised since. '*Mackerels, snoeks, cutlassfishes*' (mostly gemfish) show quite variable production while

'*Cods, hakes, haddocks*' (mostly blue grenadier) have been increasing from low values since the late 1980s.

The unidentified division, '*Miscellaneous marine fishes*', is a large component of the total and must be taken into account. After a peak in the early-1970s, production gradually fell and rose through the 1980s peaking again in the early-1990s. After a sharp drop in 1994, production increased rapidly.

### *Australian fish aquaculture production*

The main components of diadromous fish aquaculture shown in Figure 2.7 has been Atlantic salmon (increasing rapidly to 9kt/yr since the mid 1980s), rainbow trout (relatively constant at ~2kt/yr since the late-1980s) and barramundi (currently only 1kt/yr but rising). The production of marine fish has been almost entirely southern bluefin tuna, which is caught wild, ranched and on-grown rather than produced in a complete life-cycle process, and therefore only the weight gained should be considered as aquaculture production (about 1400 tonnes in 1998/99). FAO statistics currently do not reflect this distinction so that some double counting occurs.

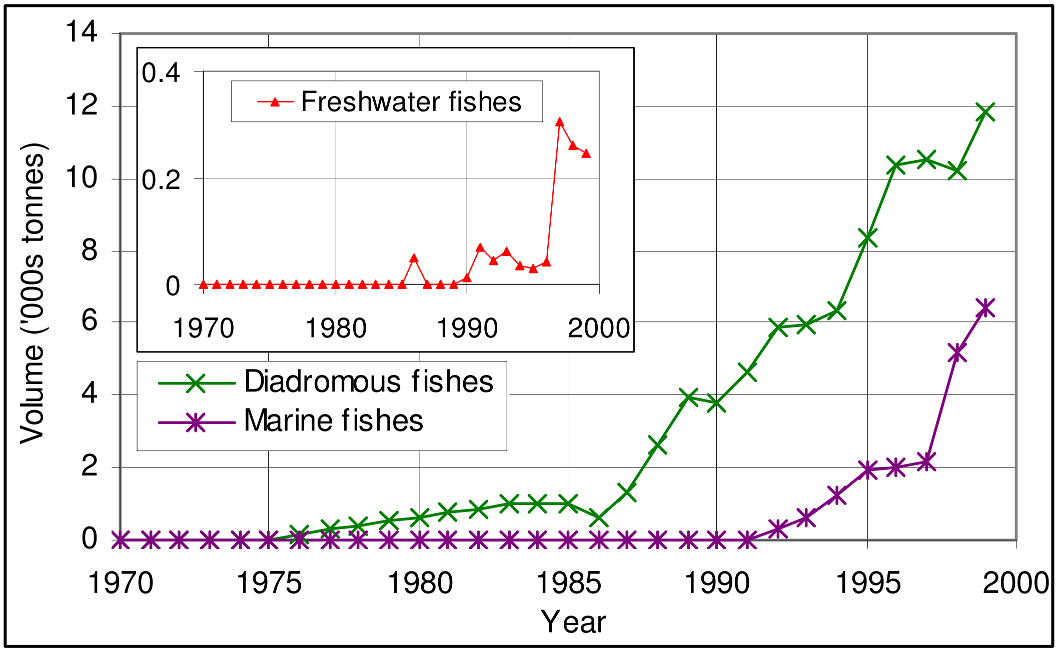



**Figure 2.7** Australian fish aquaculture production. Source: FAO, 2000a

## Demand, consumption and other utilisation

### *Australian fish and fish products utilisation*

The total domestic supply of fisheries products (equivalent live weight) has been trending upwards since 1960 (Figure 2.8). The large fluctuations have been entirely due to large variations in the supply of fish for feed. In contrast, the supply of fish production used for human consumption has steadily increased over time, with only small fluctuation.

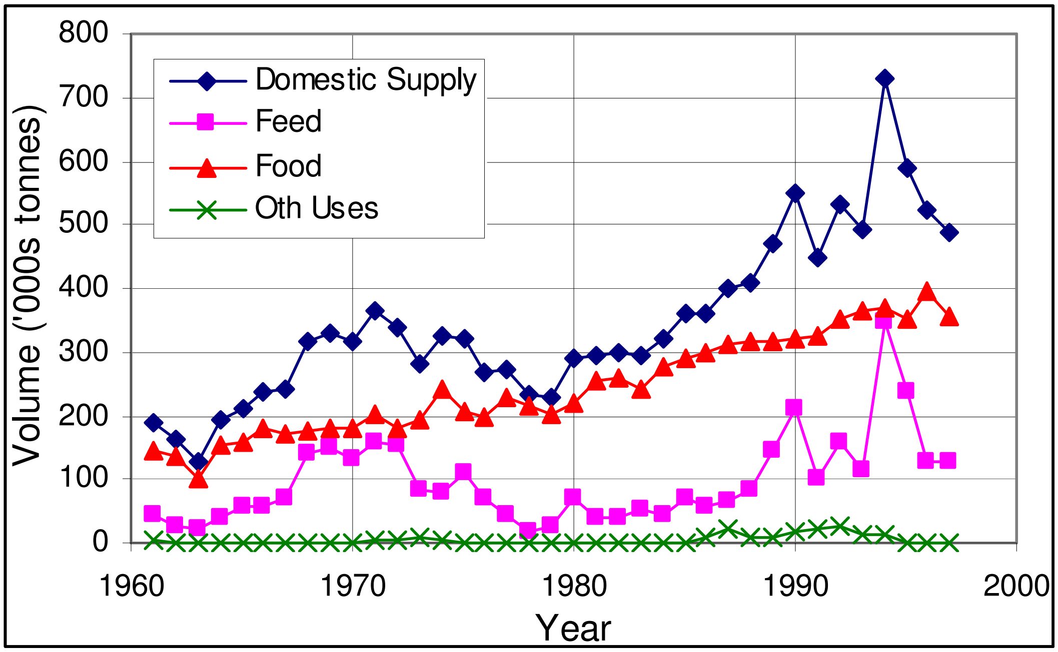



**Figure 2.8** Australian fisheries utilisation. Source: FAO, 2002

### *Australian fish and fish products utilisation by major groups*

The Australian use of fish for feed peaked strongly around 1970 and in the mid-1990s (Figure 2.9). In contrast, fish used for human consumption has increased steadily since 1960. Nearly all of the supply of crustaceans and molluscs has been used as food (Figure 2.10 and Figure 2.11). Crustacean supply has fluctuated considerably but trended upwards until 1990, whereupon it appears to have decreased slightly. Mollusc supply decreased during the 1970s but then increased rapidly until the early-1990s, apparently stabilising.

### *Australian per capita food supply*

The total fish supply apparently consumed as food has generally increased from about 12kg/capita in 1960 to about 21 kg/capita in the late 1990s (see Figure 2.12). Apparent per capita consumption of crustaceans increased through the 1960s, 1970s and 1980s but appear to have decreased slightly during the 1990s. In contrast, apparent per capita consumption of molluscs decreased during the 1970s but subsequently increased to the same level of crustacean consumption by the early-1990s.

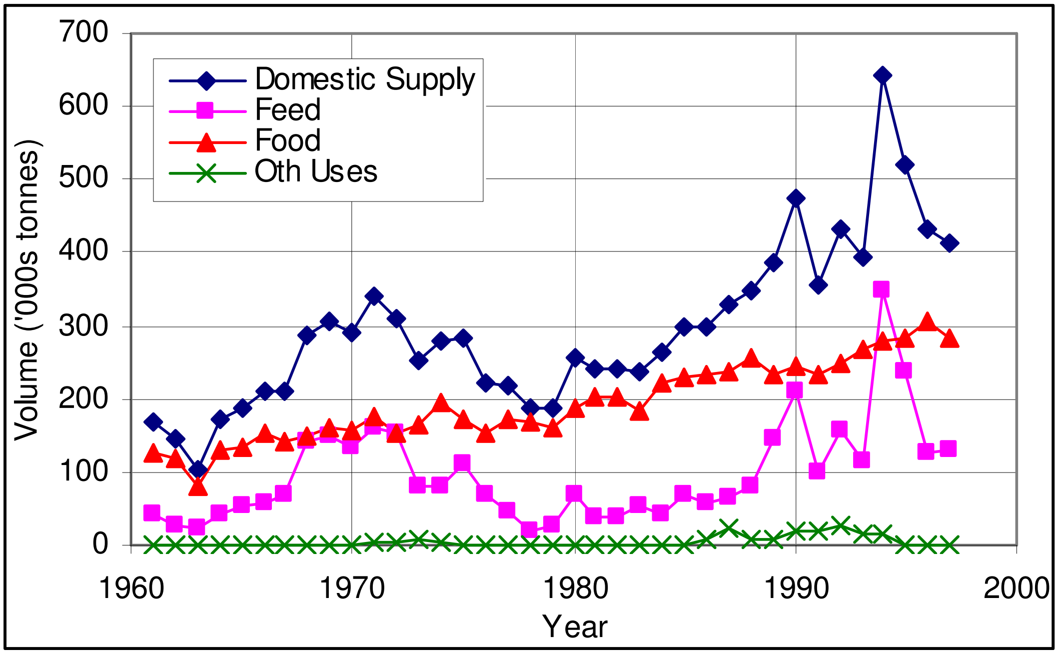



**Figure 2.9** Australian fish utilisation. Source: FAO, 2002

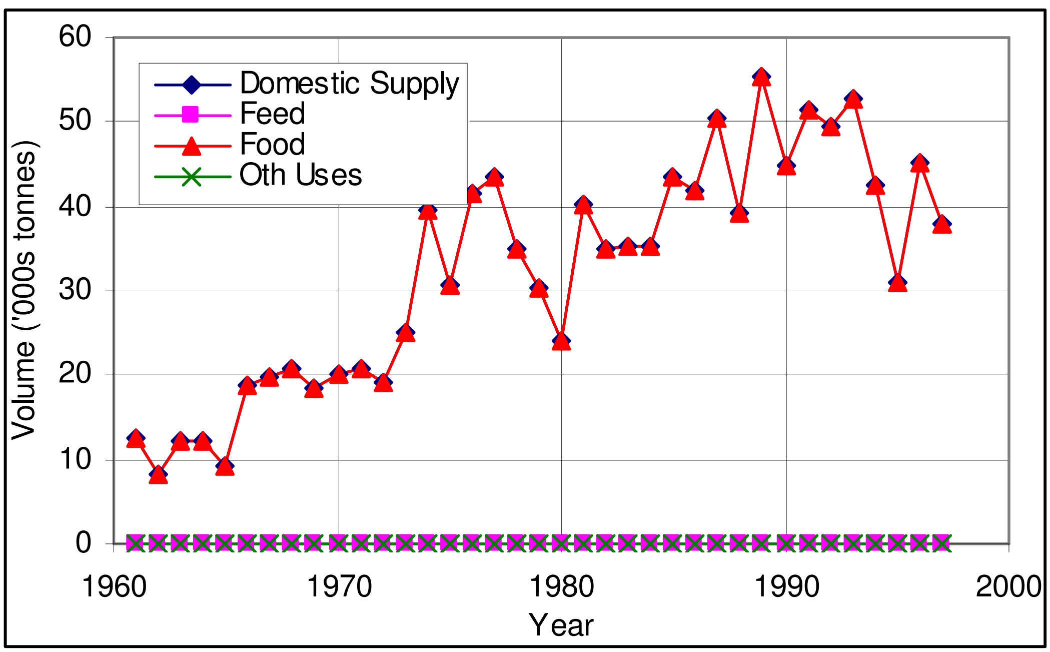



**Figure 2.10** Australian crustacean utilisation. Source: FAO, 2002

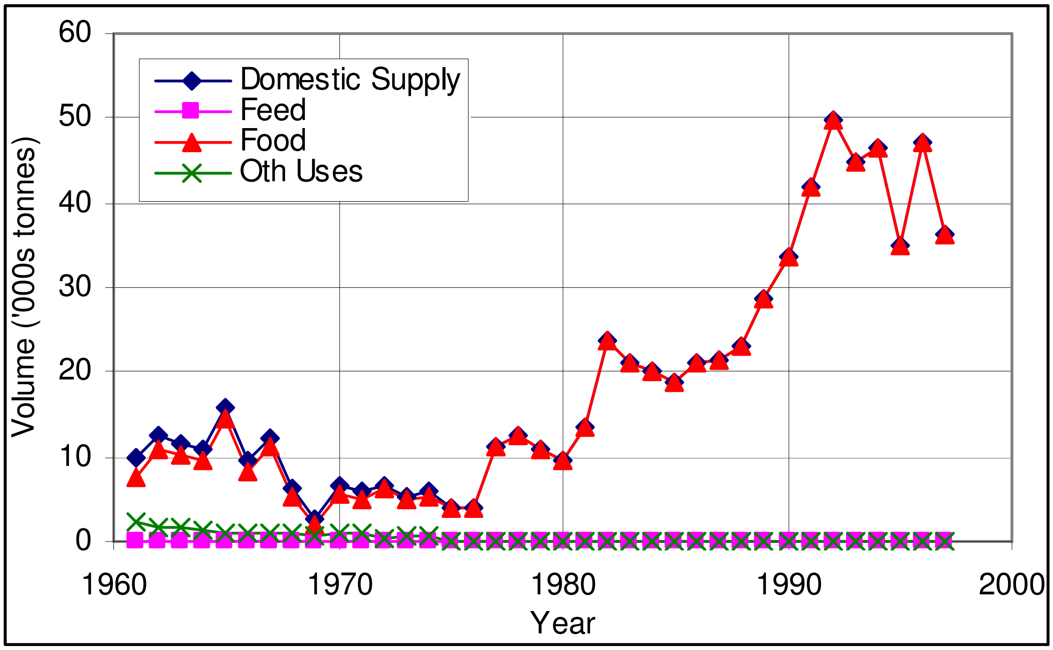



**Figure 2.11** Australian mollusc utilisation. Source: FAO, 2002

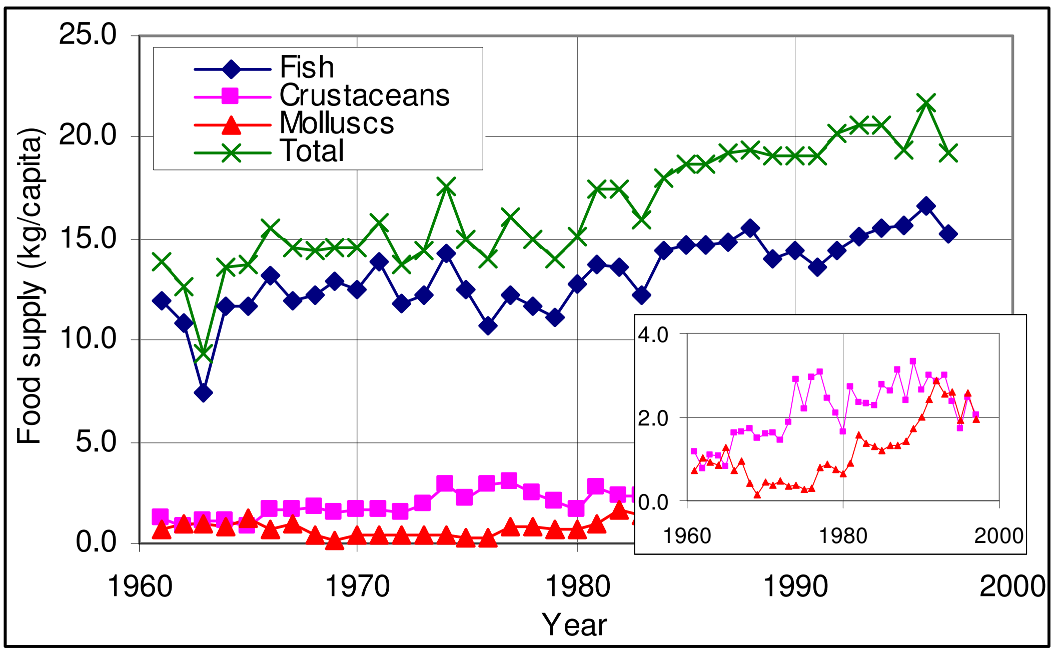



**Figure 2.12** Australian fish per capita food supply. Source: FAO, 2002

## Trade

### *Australian total trade flows*

The breakdown of fishery production and flows is shown below (Figure 2.13). Domestic production steadily increased until the 1990s, after which it plateaued and even decreased slightly. Since the early 1970s, more than 40% of this production was exported. The volume of imports has long exceeded local production, supplying the majority of total domestic supply.

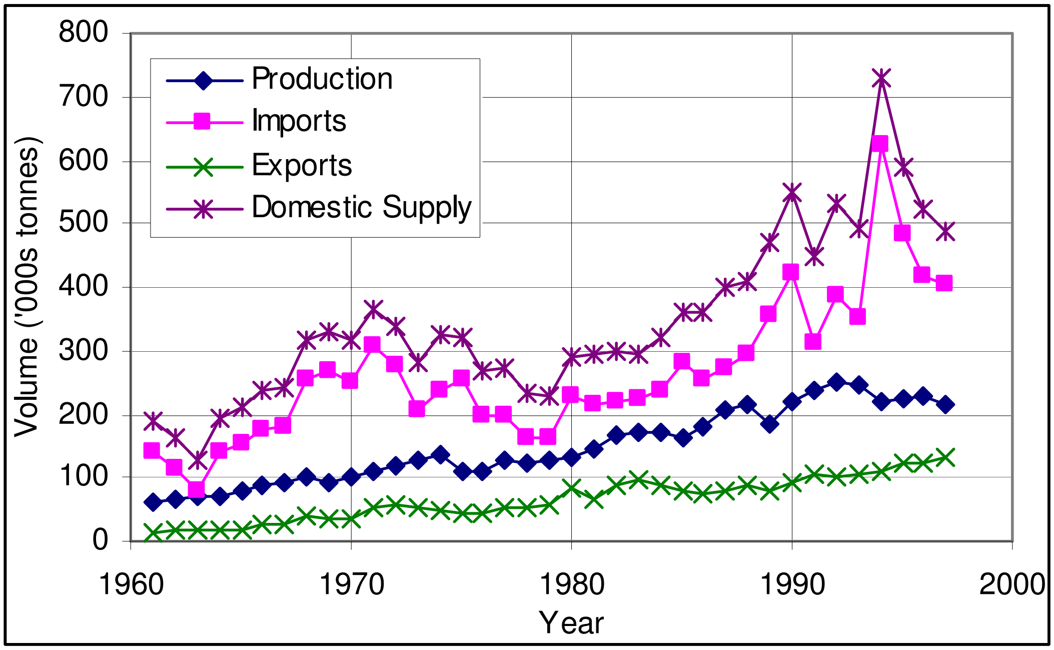



**Figure 2.13** Australian imports and exports of total fish and fish products. Source: FAO, 2002

### *Australian trade flows by major groups*

It is clearly apparent that fish production dominates total production and the patterns exhibited in total production are mostly due to the fish production component (Figure 2.14). The volumes of production and trade flows in and out of the country of crustaceans have historically all been similar, leaving a domestic supply of similar magnitude (Figure 2.15). Mollusc production has been increasing generally but quite variable (Figure 2.16). Exports have long been a significant component of this production. Imports have steadily grown to become comparable to the domestic production.

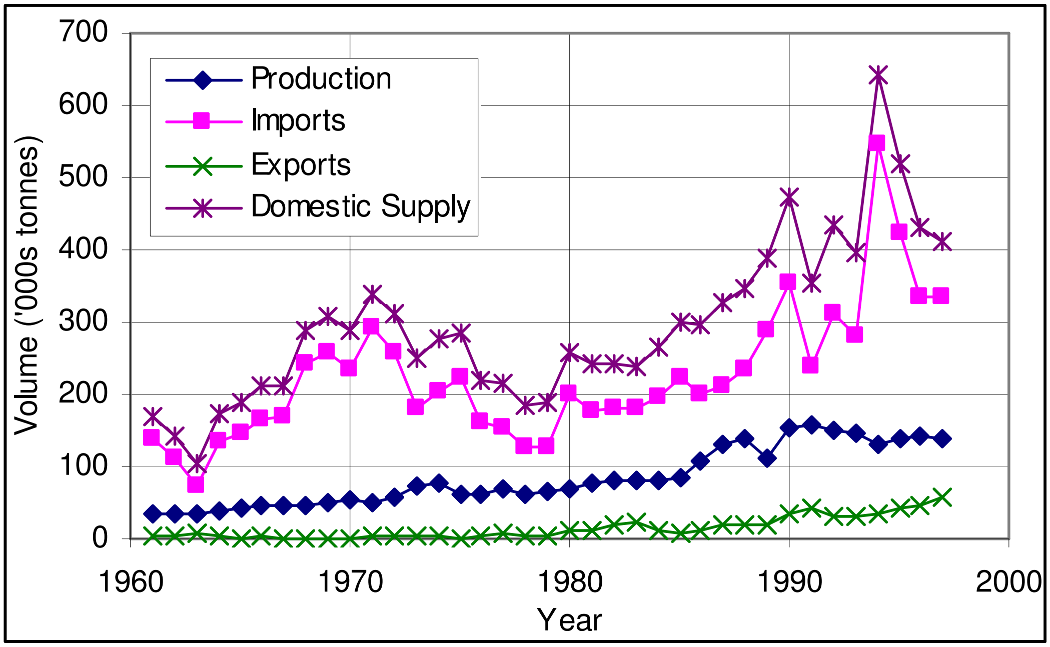



**Figure 2.14** Australian fish imports and exports. Source: FAO, 2002

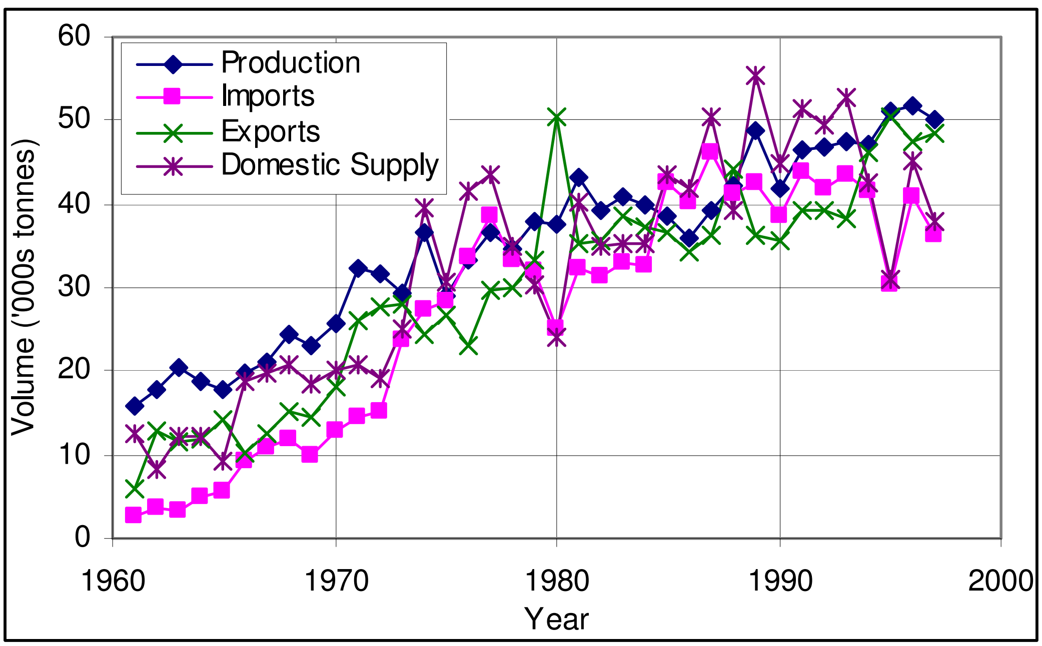



**Figure 2.15** Australian crustacean imports and exports. Source: FAO, 2002

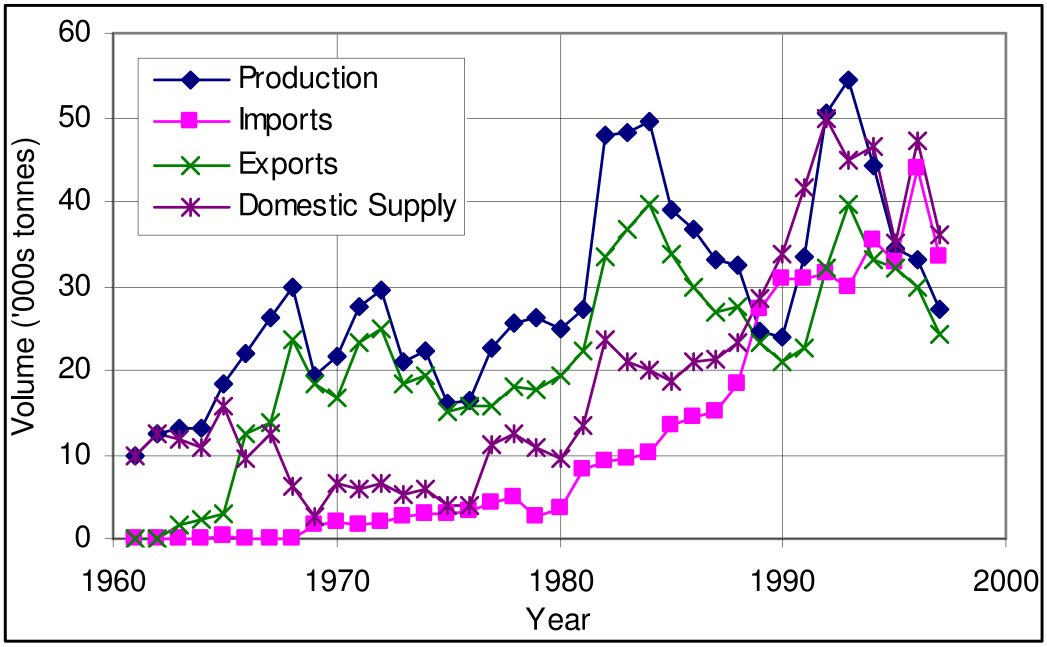



**Figure 2.16** Australian mollusc imports and exports. Source: FAO, 2002

## References


ABS (2001) Australian Bureau of Statistics, Australia Now.

BRS (2000) Bureau of Rural Sciences, Fishery Status Reports 1999.

FAO (2000a) FAO Fisheries Department, Fishery Information, Data and Statistics Unit, FISHSTAT Plus. Universal software for fishery statistical time series. Version 2.3.

FAO (2000b) FAO Fisheries Department, The state of world fisheries and aquaculture 2000.

FAO (2002) FAOSTAT: FAO online Statistical Databases. Accessed at webpage www.fao.org.

FRDC (1999) Fisheries Research and Development Corporation, Fishery Snapshot.

Hancock, D. A. (1995). Recreational fishing: What's the catch? Australian Society for Fish Biology Workshop Proceedings., Canberra, Australian Society for Fish Biology, Canberra.

Iversen, E.S. (1996) Living Marine Resources: Their Utilization and Management.

Kailola P.J., M.J. Williams, P.C. Stewart, R.E. Reichelt, A. McNee and C. Grieve (1993) , Australian Fisheries Resources.

Kearney, R. E. (2002). Recreational Fishing: value is in the eye of the beholder. Recreational Fisheries: Ecological, Economic and Social Evaluation. T. J. Pitcher and C. E. Hollingworth. Oxford, UK, Blackwell Science**:** 17-33.

Pitcher, T. J. and C. E. Hollingworth (2002). Fishing for Fun: Where's the Catch? Recreational Fisheries: Ecological, Economic and Social Evaluation. T. J. Pitcher and C. E. Hollingworth. Oxford, UK, Blackwell Science**:** 1-16.

# Chapter Three - Physical Accounting–the Stocks and Flows Approach

## Chapter summary

The modelling approach adopted can be succinctly described as quantitative scenario analysis. The main purpose is to explore alternative futures of Australia with the aid of an underlying analytical and numerical framework. Fundamentally, the approach is based upon keeping account of the material and energy flows as they move through the Australian socio-economy, and how these physical quantities underpin the economy, environmental sustainability and the path to the future. Since 1996, this computer model, known as the *Australian Stocks and Flows Framework*, has been designed, developed and implemented at CSIRO Resource Futures.

A model of the fisheries sector that keeps track of primary seafood production through to ultimate human consumption and utilisation has been developed. Associated labour, energy and materials with production are also calculated. A simple fisheries population model was adopted for the key driver of fisheries productivity for reasons of utility, generality and simplicity.

## Introduction

Many current Australian environmental concerns stem from activities begun many years ago and whose effects can be slow in emerging (e.g. dry-land salinity and land clearing, acid-sulphate soils and drainage, river flows and irrigation, erosion and livestock grazing, greenhouse emissions and industrialisation) or activities that impact on naturally slowly changing stocks (e.g. fishing of orange roughy). Furthermore, there is an increasing recognition of the integrated and systemic nature of modern society and the world economy, where people in one part of the world can influence people and the environment elsewhere (e.g. irrigation of the Murray-Darling and water users in Adelaide, land use and estuarine habitat, consumer habits of Japanese and availability of Southern Bluefin Tuna).

In an attempt to describe these long-time delay and large-scale effects, a model that effectively captures the slow-moving and integrated nature of the whole Australian economy was conceived and developed at CSIRO Sustainable Ecosystems. This model and the incorporation of the fisheries sector within it, is described further in the following sections.

## Scenario modelling and the design approach

### *Scenario Modelling*

Commonly, a scenario is defined as a "sketch, outline, or description of an imagined situation or sequence of events" (Oxford English Dictionary, 2nd Ed, 1989). Essentially it is a logically constructed picture of the future. Scenarios have become particularly popular in planning, in military affairs, business and government (Schwartz, 1996).

Scenarios are tools for exploring the future and a method for handling the complexity and uncertainty inherent in investigating possible future states of a large system. It is suitable for handling large and complex systems, when it is impractical, if not nigh impossible, to accurately model the entire system or explore all its possible configurations (present or future). Scenarios are used in three traditional ways (Dunlop et al, 2002):

- Choosing between alternative futures (Which of these scenarios are most desirable to us?)
- Wind-tunnel testing of strategy (Is our strategy/policy robust in these possible futures?)
- Helping to predict (Which observables may be lead indicators of unfolding scenarios?)

The approach adopted in this study is broadly known as scenario analysis or modelling, a technique whose purpose is *not to predict, but to explore alternative futures*. The essence of scenario modelling is to construct plausible stories about the future. These qualities make it a powerful method of dealing with uncertainty and complexity in systems, when it is impractical if not nigh impossible to explore all of the system's "phase space" (possible configurations). Consequently, it is an appropriate tool for examining the long-term evolution of large-scale, socio-economic systems, such as nations like Australia. ROBBERT Associates have created the *whatIf?* ® software tools to apply a particular method of scenario analysis known as the *design approach*.

## The design approach

The design approach has two meanings, as explained by its originators: "the act of designing alternative futures through repeated simulation; and the use of design information, like engineering studies, to construct models which form part of the simulation framework used in support of designing futures" (Gault *et al.*, 1987). It is a philosophy for building computer based simulation frameworks, which represent socio-economic systems, and for using the simulation framework to design alternative futures through repeated simulation.

It differs from conventional macro-economic modelling, projection and prediction with its emphasis on the involvement of the user who forms an integral part of the system. It avoids global optimisation or equilibrating mechanisms and consequently gives the user complete control to explore possible future states of the system. Importantly, it allows the exploration of possible futures that are unlikely to be considered in predictions based on the projection of current trends.

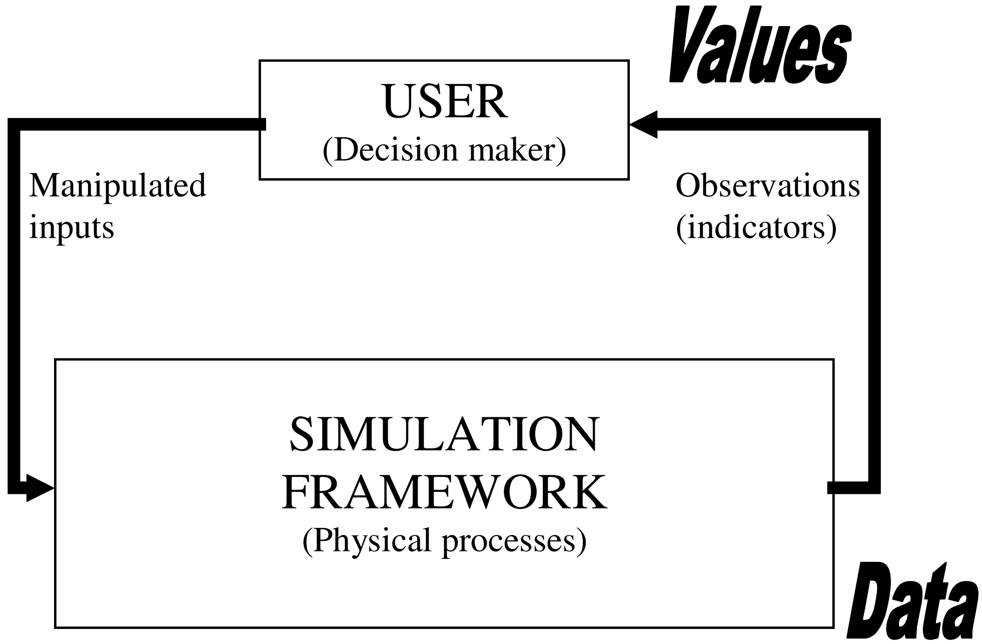
Furthermore, the design approach forces the user to explicitly make the policy decisions necessary for the user to exercise control over the system. These then form a transparent record of how the future, resulting from the user interacting with the system, was arrived at. Thus learning about the system occurs not just from the final scenarios, but from the *process* of constructing these scenarios.

## Implementation of the design approach

The design approach consists of two distinct components: an open simulation framework that represents the physical processes of the system and the user (acting as decision maker) which is the source of novelty and learning (illustrated in Figure 3.1). The simulation framework keeps track of the stocks of physical entities (e.g. people, boats, fish biomass) and flows of energy and materials (e.g. fuel expended, fish caught).

Importantly, the feedback loops of the simulation framework are left incomplete and importantly, the framework imposes no global optimisation or equilibrium conditions, so that the exploration of possible futures is not constrained. As a result, physically inconsistent or socially unacceptable outcomes may develop. Control is given to the user to complete these feedback loops and explicitly choose to resolve any tensions between provision and requirement so that policy decisions are made transparently. The process of repeated simulations, both to resolve tensions within scenarios and to explore new scenarios, provides the user with learning and new information regarding the system and its behaviour.

The necessary involvement of experts and stakeholders in the modelling procedure is one of the clear advantages of this type of simulation. This ensures that the methodology is transparent and affords each of the participants, part-ownership of the entire modelling process. This creates a cooperative environment and inclusive atmosphere and tends to lead to consensus views. This is a very valuable attribute when dealing with complex problems such as fisheries management and policy.




The user makes the decisions for settings and values of input variables which determine other variables of the physical processes in the framework. Other variables, acting as indictors, inform the user which he/she uses to make necessary adjustments to the inputs. So the user is completing the information feedback loop and explores the implications of decisions and changes in the environment. In this way we can separate data from values. The main aim is to produce different, physically realistic scenarios representing various policy positions. The user learns both from the final scenarios produced and the iterative process of producing these scenarios through resolution of various tensions. The modelling approach is considered to be the whole process of reaching the different scenarios. This provides the user with learning about the system dynamics, constraining factors and possible options.

**Figure 3.1** An illustration of the design approach to scenario modelling.

### *The paradigm of physical analysis*

Essentially, sustainability is an issue of *physical* sustainability. By definition, human societies are composed of people, and people require physical things such as food, shelter, transport, warmth and clothing. These resources ultimately come from our environment. Thus the environment must be able to continue to provide these resources for as long as human society demands them i.e. sustainably. Furthermore, no matter how human societies change economic functioning, lifestyles, cultures and/or technology, the world will still operate on physical laws. Thus it makes sense to attempt to model the physical world on which we all depend.

The approach of physical accounting and modelling offers a complementary approach to standard and more widespread financial accounting or econometric modelling. Underpinning *each and every* financial transaction in the economy is a chain of physical transactions and activity that *has to occur* to actually bring that ultimate good or service to the shopkeeper's counter and the consumer's plate[12] (Dunlop *et al.*, 2002).

The design approach to physical analysis as described here offers a further advantage in that there is a clear separation of the user (as the arbiter of choice and values) from the physical world (described by the data and simulation model) in the framework (illustrated in Figure 3.1). This separation of values

[12] The total collection of all physical transactions underpinning the financial economy is called the *physical economy*.

from data means that the "messiness" of modelling people's behaviour and preferences (as done in economic analysis) is avoided. This allows the user, acting as society, to make explicit and transparent choices, which adds to the understanding of Australia as a system.

Although not exclusively a physical attribute, another important aspect of physical analysis is the concept of *historical binding*. This can be described as follows: since the present is a consequence of the "path" taken in the past, and the future possible paths are constrained by the present, the future is somewhat bound by history. One important physical aspect of this historical binding of socio-economic systems are the lifetimes and age structure of key stocks such as the human population, buildings and the fishing fleets and the behaviour of slow moving variables such as life expectancy and total fertility rates.

## The Australian Stocks and Flows Framework

The Australian Stocks and Flows Framework (ASFF) is the name of the simulation framework that represents the physical functioning or physical metabolism of Australia. The process of a user (or users) interacting iteratively with ASFF is called the *ASFF approach*. Essentially, the ASFF approach is the implementation of the design approach to the Australian context. It is a methodological approach to understanding the current physical state of the nation, appreciating how we arrived at the present from the particular pathway taken in the past and exploring the possible pathways for Australia into the future (CSIRO, 1999).

### *The Simulation Framework*

ASFF is a highly disaggregated simulation framework which keeps track of all physically significant stocks and flows in the Australian socio-economic system (Poldy 2000). In this context, stocks such things as people, trees, fish biomass, buildings, vehicles, boats, infrastructure, air, water and energy. Specifically, it is the *quantity* of these physical items which are accounted for, measured in numbers or their appropriate SI unit (eg. mass, volume, length). Flows represent the rates of change of these stocks and are things such as people born, fuel expended and fish caught.

The framework itself consists of a simulation model and a database.

### *The simulation model*

The simulation model is both hierarchical and integrative, consisting of a number of connected modules or calculators, each describing a sector of Australia's physical economy. A simplified schematic of the hierarchy is shown in Figure 3.2. It essentially shows the groupings based on people (Demography) and their physical environment (Materials & Energy) while keeping account of the overall mass and energy balance (the Land/Air/Water Resources and Balance of Trade).

Each calculator deals with the stocks and flows relevant to a sector and with the physical processes through which they interact. Calculator assumptions are based on technical and scientific understanding of the processes involved and are intended to provide a plausible representation in physical terms of the workings of the sector. Indeed, it is a criterion of validity for the calculator, that a professionally informed person should be able to follow the structure of the representation and conclude that it and the values of parameters are plausible and appropriate to the level of aggregation of the treatment.

The "tree" diagram shown in Figure 3.2 does not show integrative nature of the simulation model. Some of these sector linkages (i.e. the information flows between calculators) are shown in Figure 3.3. This figures illustrates how materials and energy flow **uni-directionally** through the model. This is the important attribute that facilitates the user in completing the necessary information loops by manipulating input variables as illustrated in Figure 3.1 without the confounding effects of hidden feedback loops.

### *The database*

The database consists of about 800 variables, generally in 5 years steps covering the period from 1941 to 2001. Each variable is itself a multi-dimensional *data object*, being disaggregated by important attributes. For example, the *single* variable 'population' gives the number of persons by state by gender by age, in 5 year steps from 1946 to 2001, a total of 320 time series.

The database is not a static object. A variety of data comes from a variety of sources, not all of which are the same or consistent. In many cases, data simply do not exist. Initially, the available data is entered and organised within the database. The database is then run in conjunction with the simulation model so that missing elements may be generated in the database and any inconsistencies may be resolved by modification of the database. This process of constructing a complete (no gaps) and consistent (no internal differences) database that fits the simulation model is known as *calibration*.

It is important to note that *complete and consistent* does not mean *true*. However, the powerful attributes of this approach is that

(1) the model and process is transparent so that sector specialists view and critique the underlying process model
(2) the model provides an integrating context within which disaggregate variables are constrained vertically to sum to their aggregates and horizontally to be consistent with variables to which they are related.

There are a number of key variables whose validity is accepted, at least provisionally. Examples of key variables include population, housing and labour force data, production and trade of major export commodities and energy demand and supply. Therefore, there exist a number of key variables with data values that are effectively fixed and to which other variables are constrained to be consistent with[13].

In conclusion, the calibration process is complete when we have a database whose variables agree with historical observations (where they exist) and are internally consistent within the simulation model. Variables for which observations do not exist are constrained to plausible ranges which are derived using their relationships to other model variables.

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[13] Even where some variables are highly uncertain, their membership of the framework point to areas of the model that require further study and data acquisition, providing the best hope for progressive improvement.

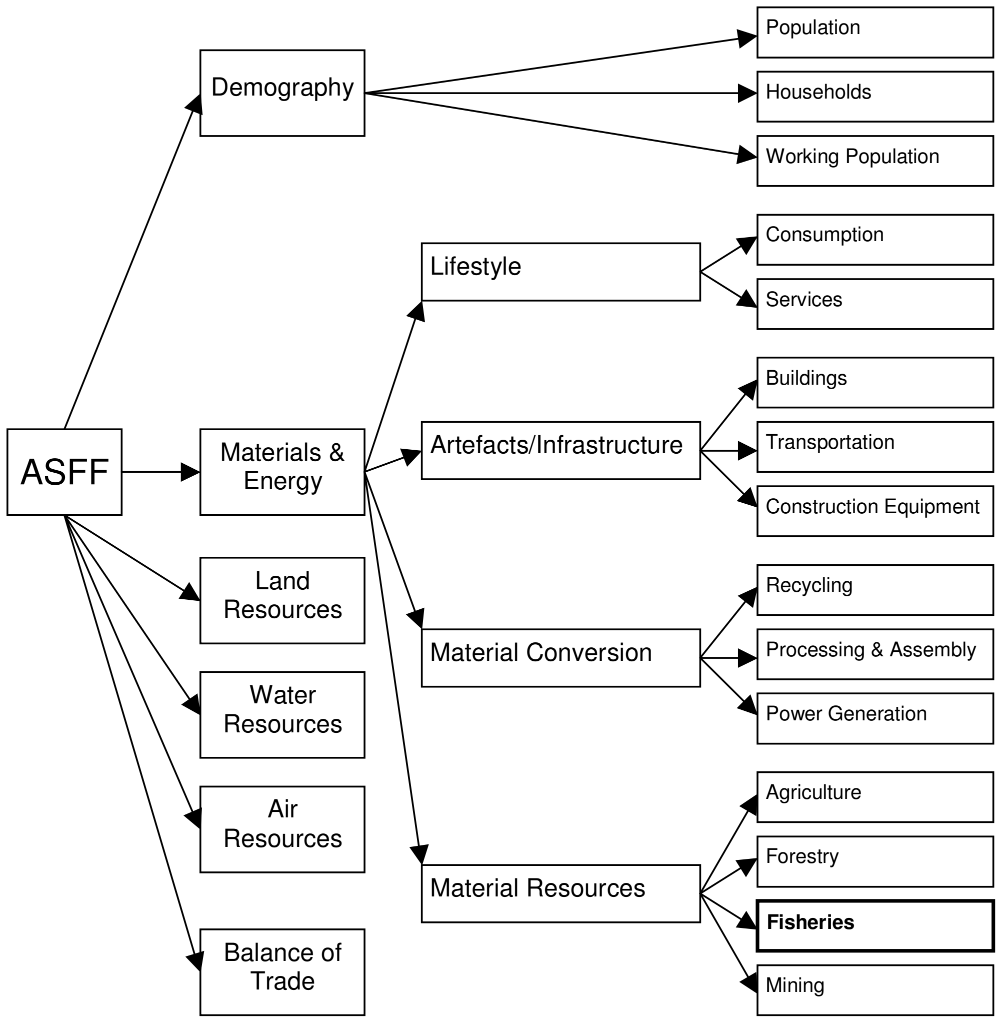



**Figure 3.2** Simplified schematic of the ASFF hierarchy (the integrative connections are not shown for clarity)

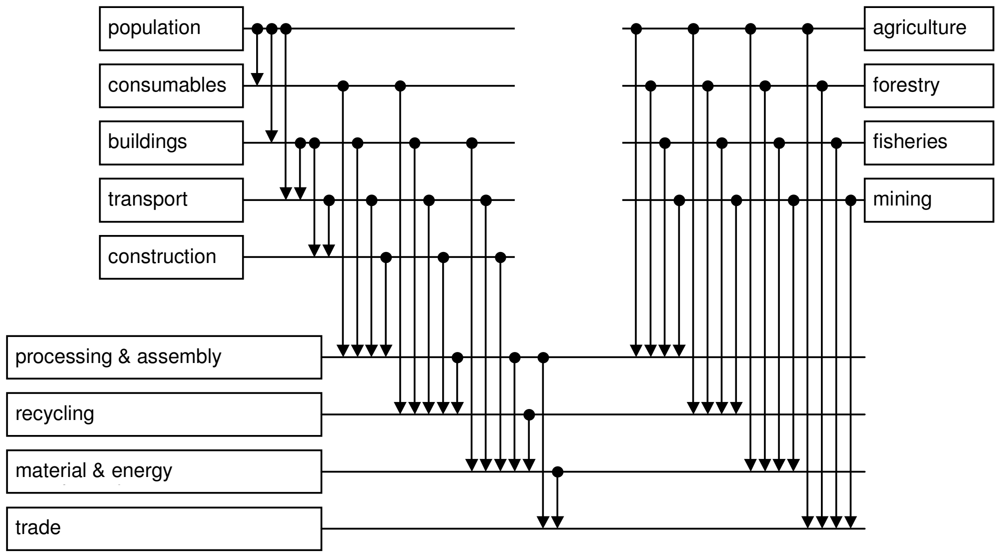



**Figure 3.3** Schematic diagram displaying the flow of information of selected modules
This figure illustrates some of the connections absent from Figure 3.2. The arrows represent information flow from one sector to another. The figure also shows the one-way nature of the flow of materials and energy within the framework modelling process. The user provides the upward arrows completing the loop in the system.
An example of how to interpret the diagram is as follows:
Changes in Population directly influence Consumables, Buildings and Transport.
Consumables directly influence Processing & Assembly and Recycling.
So Population has a (secondary) indirect effect on the latter.
Recycling directly influence Material and Energy Transformations.
So Population has a (tertiary) indirect effect on this sector (via the Consumables through to Recycling sectors). However, Population also has multiple secondary effects on this sector via the Buildings and Transport sectors.

# Fisheries in ASFF

The fisheries sector is treated within ASFF as one of its modules, also known as *calculators*. A description of the original formulation of this calculator is given in the document, "Review of the Australian Stocks and Flows Framework Workshop 12: Forestry and Fisheries" (CSIRO, 1999b), albeit, in an earlier phase of development. The major change to the calculator from this formulation has been the treatment of the harvesting of wild commercial fish stocks.

## *Calculation of long-term capacity*

The question of the ultimate capacity of the fisheries sector is a difficult one to answer accurately. Problems of data quality and quantity as well as model understanding (all discussed in previous chapters) hamper precise quantification. Two general methods for calculating the potential of Australia's waters are (Iverson, 1996):

1. Examine the historical trend in landings and extrapolate based on general understanding of the fishing practices and expected species harvesting rates (a top-down approach)
2. Calculate the primary productivity of regions of water and via a model of the ecological web, determine the harvestable fraction of desirable organisms (a bottom-up approach)

As explained in the following, the approach taken in this study is the first method with the modification of utilising a simple model of biological productivity to assist in projecting future states. Capacity was calculated on the basis of historical catch data (usually over a period of thirty years or more), since this provides a lower limit to the capacity, in conjunction with estimates from current assessments. Although this has obvious limitations, it has the advantage of being an open and understandable process for stakeholders.

### ***The Fisheries Calculator***

A schematic diagram of the major variables and routines is given in Figure 3.4 to Figure 3.6. Barrels (upright cylinders) represent stocks, pipes (sideways cylinders) represent flows, hexagons represent parameters and rectangles represent procedures.

This calculator deals primarily with the treatment of 158 entities called 'fish units' which are specific combinations of fisheries (in the sense of management units) and taxonomic families. These 'fish units' are the basic biological unit that are modelled within ASFF and which the fishermen harvest. The calculator determines the actual catches from these fisheries based on a requested catch, the effect of catches on the stock levels, and the stock levels throughout the simulation. It also determines the effort (in boat days) required to provide the actual catch, as well as evolving the boat stock needed to meet this effort and the material, labour and energy inputs for the fishing activity. These inputs are also calculated for the fish farming activity in Australia, though the levels of production of fish from fish farming is not modelled but specified exogenously.

The demand for fish in the ASFF is expressed in terms of 'fish kind', which specifies the tonnes requested of fresh water fish, tunas, other marine fish, crustaceans, and molluscs. The supply of fish and the modelling of fish stocks is in terms of 'fish units', a 'fish unit' being a family within a particular fishery, usually in a specified region. Each of the 'fish units' is a member of one of the fish kinds. The correspondence between fish units and fish kinds is given in 'fish category'.

Procedure (1), Consolidate Requested Catch, takes the requested catch and consolidates them into one variable, total catch requested. Procedure (2), Evolve Fishery Stock, determines the actual catch, the effort required to produce this catch, and the resulting fish stocks time period by time period. The initial condition of the fish stocks for the calculation is given, in tonnes for each fishery, by the base fish stock in the first time period of the simulation and by the fish stock at the end of the previous time period for each time period thereafter. The following steps are then used to complete the calculation:

1. The total catch requested for each fish kind is divided between the fish units giving a catch requested for each of the 158 fish units.

2. The creation of new fish unit biomass (*Recruits*) is calculated from the current stock, the growth parameter (the inverse of the *RecTime10to90*) and the virgin biomass (*maxStk*). The requested catch is harvested from the existing fish unit biomass up to the maximum amount available (the current stock).

3. The resulting production for each fish unit is outputted to total fish produced (*totFshPrd*), and the boat days needed for each fishery is outputted to the effort required (*effInd*). Total fish produced summed across fish units does not necessarily equal the total requested catch - depleted fish units which could not supply the requested amount may have prevented the requested total being achieved.

4. Next the fish stock levels are calculated for the time period. For each fish unit, the fish stock at the end of the period is the fish stock at the start plus the growth of the stock, less any fish harvested from the fishery, as given by total fish produced. The growth of the stock is calculated from the starting fish stock, the maximum stock, the minimum stock, and the reproduction rate at the minimum stock level. The final fish stock is outputted to fish stock, which once this process is complete for all time periods gives the stock size of each fish unit throughout the simulation.

Procedure (3), Calculate Domestic Catch and Domestic Commercial effort, determines from the total fish produced by fish unit, the foreign catch, domestic catch and effort required for the domestic catch.

Procedure (4), Report fish production by jurisdiction, fishery and family is a procedure for displaying intermediate results.

Procedure (5), Required Domestic Commercial Boat Stock, calculates the fishing boat requirements for the commercial catch. The domestic commercial required effort (in boat days) with the boat day intensity, gives the number of boats required for the total catch. The mapping of fis to bt (fish unit to boat type) specifies the boat type required for each fish unit. This is used to give the total commercial domestic fishing boat requirements by boat type (used in procedure (6) to evolve the boat fleet). It is also used to determine the total commercial required effort (in boat days and by boat type), which is used in procedure (7) to determine the operating requirements of the boat fleet.

Procedure (6), Evolve Domestic Boat Stock, uses the procedure described in the evolution of stocks description above to determine the evolution of the boat stock through the simulation. Starting with a base boats stock, of boats by type and age, the boat life table parameters give the fraction of boats each age group that are retired in each time period, resulting in boat discards. The initial stock for each time period less the discards is compared to the commercial domestic fishing boat requirements (by boat type) for that period and any shortfall determines new boats required. New boats are added to the fleet at age zero and the age of all existing boats is incremented. This gives the boat stock, by boat type and age, throughout the simulation.

Procedure (7), Commercial Domestic Boat Stock Operations, calculates the labour, energy and operating materials inputs required to operate the boat fleet. The fishing labour intensity gives the labour required per boat day of effort for each boat type, hence with the required domestic commercial boat effort, the wild fisheries labour is determined. Similarly, the boat day energy intensity and the required domestic commercial boat effort give the total energy in joules required to operate the boat fleet. This energy is provided by a number of fuels as specified in the fishing energy share, and for each source a energy conversion coefficient fishing is applied to determine the total energy for wild fishing, for each boat type and by energy type.

Procedure (8), Consolidate Production, adds the domestic production of wild fish from fisheries (private and commercial) to the fish farm production. Fish farm production is the tonnes of each fish kind produced by fish farms, and is specified exogenously. The production of fish from farms is only modelled in the ASFF in terms of the inputs required, including the feed for fish farm production, to supply the specified production.

Procedure (9), Fish Farming Operations, determines the inputs required to supply the given fish farm production. Fish farm labour intensity, fish farm energy intensity and fish farm operating materials intensity specify the people, tonnes of operating materials, and joules of energy required to produce a tonne of each fish kind. This gives fish farm labour and fish farm operating materials. The fish farm energy conversion coefficient is used to determine the amount of fuel energy of each type required to supply the energy needs according the conversion efficiencies for each fuel, giving the total energy for fish farm.

Procedure (10), Consolidate Operations Requirements, adds the operating requirements for fish farms to those for the fishing fleet to give the total operating requirements for the sector for labour, energy and operating materials.

**Figure 3.4** Fisheries Calculator

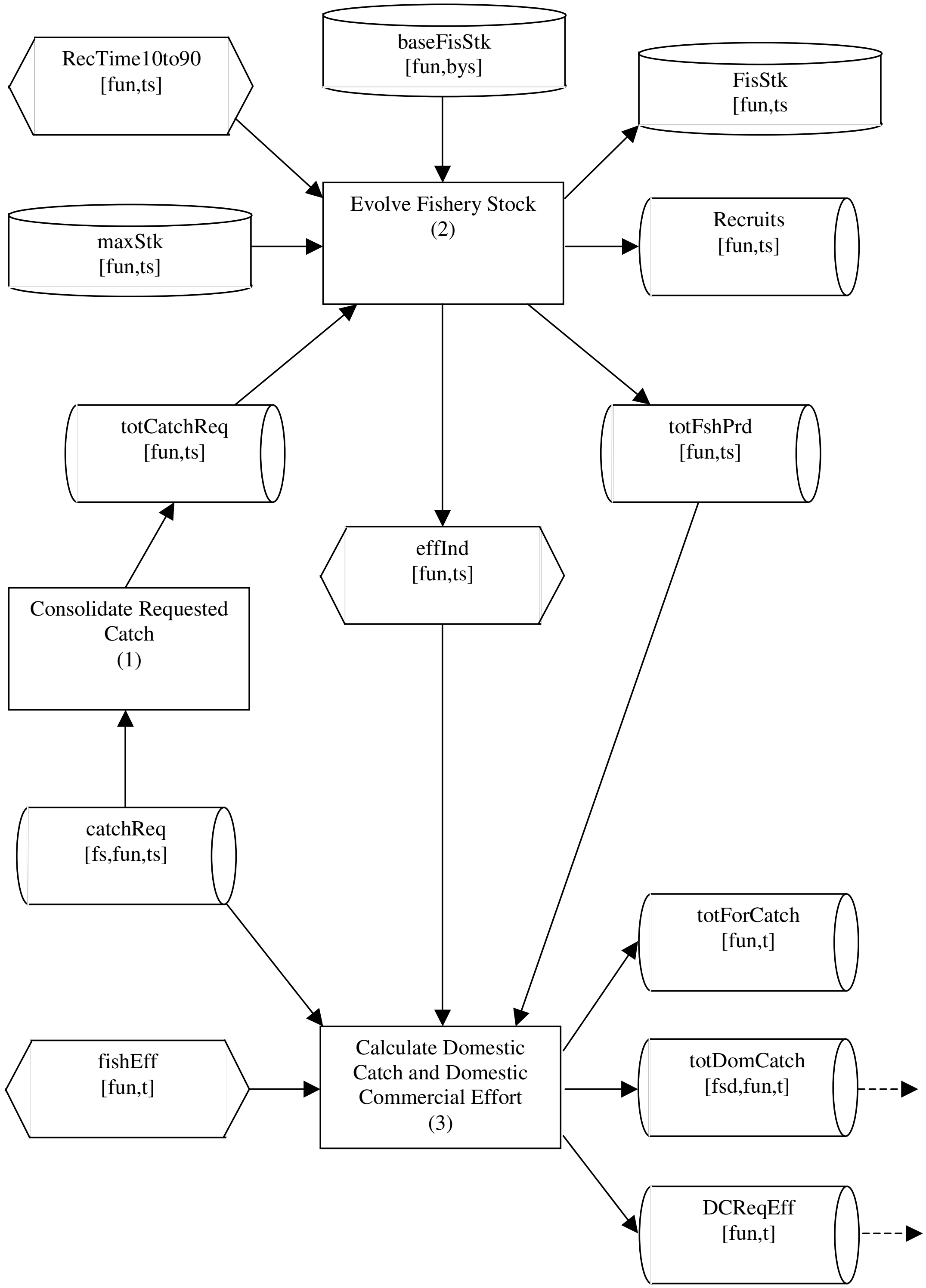


**Figure 3.5** Fisheries Calculator (continued**)**

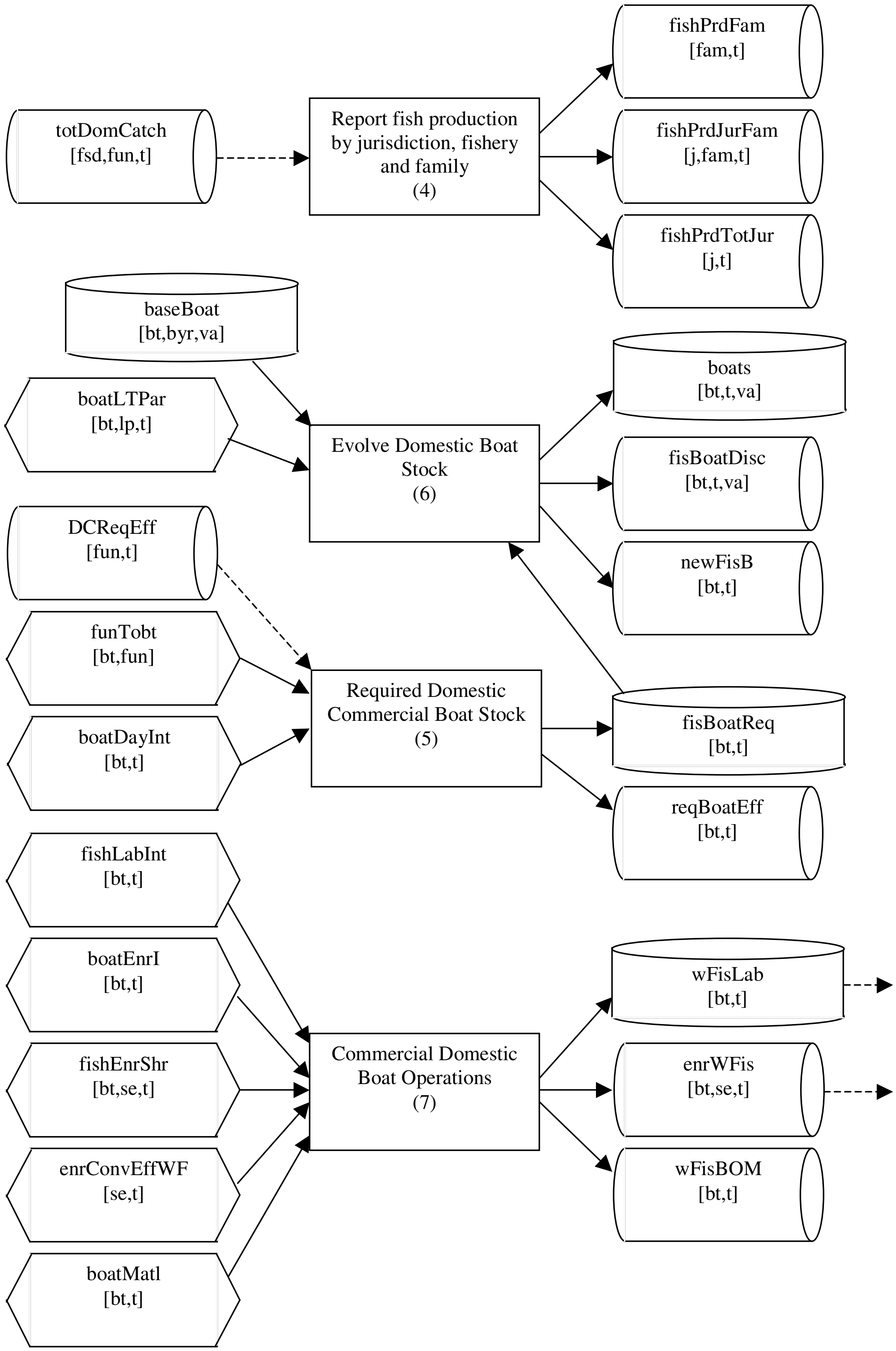
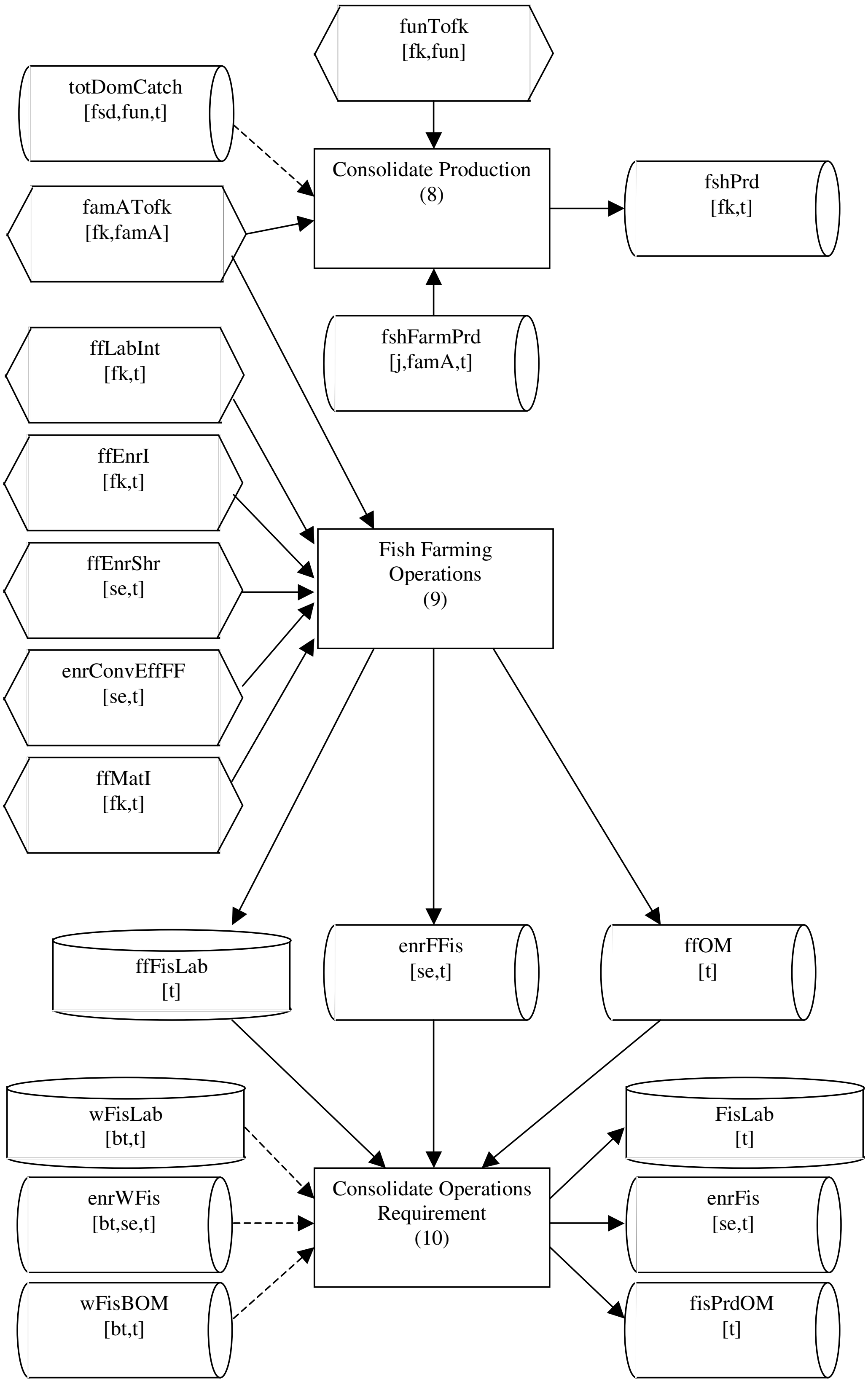


**Figure 3.6** Fisheries Calculator (continued)



## Fisheries modelling

### *Population modelling*

One of the fundamental issues in performing any simulation of fisheries is the modelling of the biological productivity of marine species. In the original implementation of ASFF, the fish population was described using the Schaefer Model (Schaefer, 1954; 1957), the simplest example of Biomass Dynamics Models (BDM), which themselves are the simplest type of population model. These models use only a single indicator, the biomass, to describe the population. It explicitly doesn't consider characteristics such as age, size, growth or recruitment, or the differential effects of fishing gear or the ecosystem.

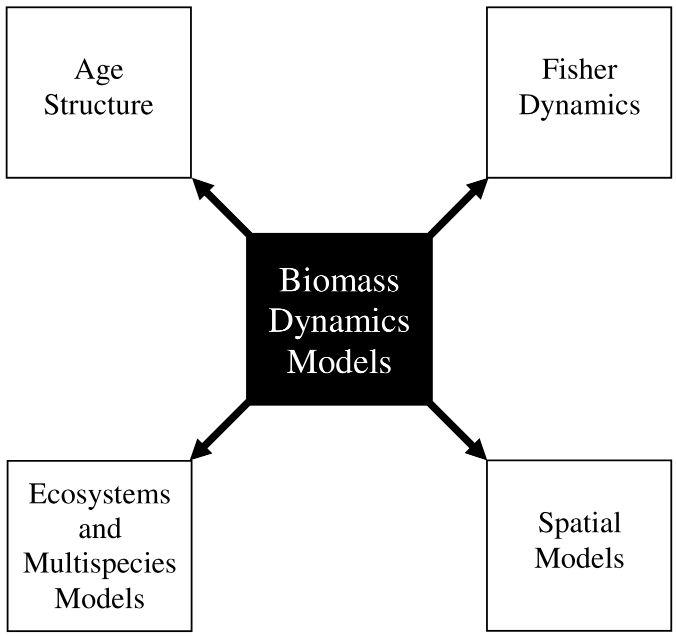



**Figure 3.7** A simple representation of the various extensions to biomass dynamic models (Source: after Hilborn and Walters, *Quantitative Fisheries Stock Assessment*, (1992))

Other models can generally be seen to be extensions of them as illustrated in Figure 3.7. These extensions, which were each considered for updating of the current model, are listed below (Hilborn & Walters, 1991):

1. *Fisher Dynamics Models* – These treat the fishery as a system that includes fishers but they don't match the philosophy of the approach of not modelling behaviour (e.g. Sumaila, 1999).
2. *Spatial Models* – These increase the complexity by including spatial information (e.g. Giske *et al.*, 1998).
3. *Ecosystem Models* – These models consider the relevant ecosystem and environmental data (e.g. Walters *et al.*, 1997).
4. *Age Structure* – These models improve the treatment of the fish biology by considering age-structure data of each fish population (e.g. Magnússon, 1995).

As extensions, these approaches have several things in common:

- they are more complex and difficult to model
- they introduce more unknowns and parameters
- they require more and/or better quality data sets

The main challenge with these models is that the data required to support the increasing number of parameters associated with the increasing complexity of the model are simply not available for many species and fisheries, across Australia. Furthermore, by including more complex data they give the impression of more thoroughly representing the fishery, but in reality this apparent precision is mostly not justified. Finally, given the lengthy time periods being considered, it is unlikely that these models would be an improvement significant enough to justify the time and effort required to acquire the data and construct the models. Even if this was done, it is doubtful that *combining* a variety of models of variable type and quality would be robust or an improvement. Therefore, the Schaefer Model was retained as the basic model of fish populations (although it should be noted that this does not preclude using more complicated models in specific fish populations at a future time if it is deemed desirable) (Pella 1969; Walters 1969).

The Schaefer Model (described in more detail in the next section) essentially assumes growth of the biomass in the form of a logistic curve with depletion occurring through fishing. It has several advantages that make it more widely applicable to the available data:

1. **Simple to use and widely understood**.
2. **Minimal parameterisation**: Only two parameters are required (although pseudo-biological), the intrinsic growth rate, *r*, and the virgin biomass, *k*. Although these are only pseudo-biological, this offers great simplicity and minimises the number of parameters required.
3. **Minimal data requirements**: The only necessary data is the production data or catch i.e. the model is driven by catch data alone. This important attribute allows for the maximum use of the available data, which is mostly catch data, and *often only* catch data. Effort data is desirable but not absolutely necessary to provide projections of future populations. However, any effort data available can be used to check for consistency and further fine-tune the model.
4. **Widely applicable**: In practice, it can sometimes be more sensible to treat groups of species as a single biomass. This model is almost as useful and meaningful when applied to groups of species as it is for single species.

The simplicity of the model is both its central strength and its main drawback, often being criticised as being too simple, perhaps unrealistically so. It is also difficult to modify or improve the analysis when new information becomes available. However on balance, and in the context of a national-scale model of fisheries, it is believed the benefits detailed above, outweigh these apparent weaknesses.

In summary, the approach taken here is to use the best analysis and expert opinion currently available to provide the information to construct a plausible *biomass generator* (based on the Schaefer model) for modelling the biomass of specific fish populations. This will not necessarily be able to reproduce known historical biomass, but does provide a reasonable platform for projections into the future, with a current biomass, an estimate for the growth rate of that biomass and an estimate of the long term potential for that biomass. More detailed models could not be justified on theoretical or pragmatic grounds and would distract from the main purpose and strengths of ASFF. This model will never replace the detailed analysis and modelling required for management of specific fisheries. It doesn't deal with short-term fluctuations but only long-term trends. The former is for prudent management to deal with in the context of the longer view.

### *The Schaefer Model and the logistic curve*

This model is essentially the logistic growth model extended to include catch:

$$\frac{dB}{dt} = rB\left(1 - \frac{B}{k}\right) - C \tag{1}$$

where $B$ is the biomass, $r$ is the intrinsic growth rate (units of inverse time), $k$ is the maximum (or virgin) biomass and $C$ is the catch rate[14]. Furthermore, $C = qEB$, where $E$ is the fishing effort and $q$ describes the efficiency of the fishing gear (proportion of stock $B$ taken by one unit of effort). It implies that the catch per unit effort ($U$) is an index proportional to stock abundance, or

$$U = C/E = qB \tag{2}$$

One can easily derive equilibrium properties (i.e. when $dB/dt = 0$). One of the most persistent errors made is to try to estimate yields by assuming the data comes from stock at equilibrium (which is rarely the case), resulting in an overestimation of yield (Hilborn & Walters, 1991). Ignoring this for the moment, the maximum sustainable yield (MSY) is equal to the maximum slope of the graph in Figure 3.8, which occurs at 50% of the virgin biomass. Setting $B = k/2$ with $dB/dt = 0$ and C = 0 in equation (1) produces MSY= $rk/4$.

Assuming the catch is zero, the solution to this differential equation is

$$B(t) = \frac{k}{1 + e^{-rt}} \tag{3}$$

Since this theoretical equation extends infinitely in both temporal directions, it takes an infinite time for the biomass to reach the maximum biomass, $k$. Thus it is practically useful to introduce the definition of "time for full recovery" of a population as *the time for the biomass of that population to recover from 10% to 90% of virgin biomass assuming no fishing*.

Using Equation (3) and the definition of full recovery, it is simple to determine that the length of time for full recovery, $t_{FR}$, is

$$t_{FR} = \frac{2\ln 9}{r} \cong \frac{4.39}{r} \tag{4}$$

Note that this equation requires only the growth rate to be computed. A table of growth rates and their respective recovery times are given in Table 3.1 and a graph of a typical logistic curve is shown in Figure 3.8.

The differential equation can be converted into a simple difference equation (Walters and Hilborn, 1976):

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{k}\right) - C_t \tag{5}$$

where $t$ is a time mark, $t$+1 is the next time mark, $r$ is the unit-less growth factor for the time interval $t$ to $t$+1, and $C$ is the catch for $t$ to $t$+1. This formulation is the most convenient for computational purposes.

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[14] In fact, the model permits the Schaefer parameters, $k$ and $r$, to change with time, which would allow for unlimited resources. However, as a starting point, these parameters are assumed to be constant.

**Table 3.1** Table of growth rates and the related "recovery times"

| $r$ (/year) | $t_{FR}$ (years) | $r$ (/year) | $t_{FR}$ (years) | $r$ (/year) | $t_{FR}$ (years) |
|---|---|---|---|---|---|
| 0.01 | 439.4 | 0.1 | 43.9 | 1 | 4.4 |
| 0.012 | 366.2 | 0.12 | 36.6 | 1.2 | 3.7 |
| 0.015 | 293.0 | 0.15 | 29.3 | 1.5 | 2.9 |
| 0.02 | 219.7 | 0.2 | 22.0 | 2 | 2.2 |
| 0.024 | 183.1 | 0.24 | 18.3 | 2.4 | 1.8 |
| 0.03 | 146.5 | 0.3 | 14.6 | 3 | 1.5 |
| 0.04 | 109.9 | 0.4 | 11.0 | 4 | 1.1 |
| 0.05 | 87.9 | 0.5 | 8.8 | 5 | 0.9 |
| 0.06 | 73.2 | 0.6 | 7.3 | 6 | 0.7 |
| 0.075 | 58.6 | 0.75 | 5.9 | 7.5 | 0.6 |

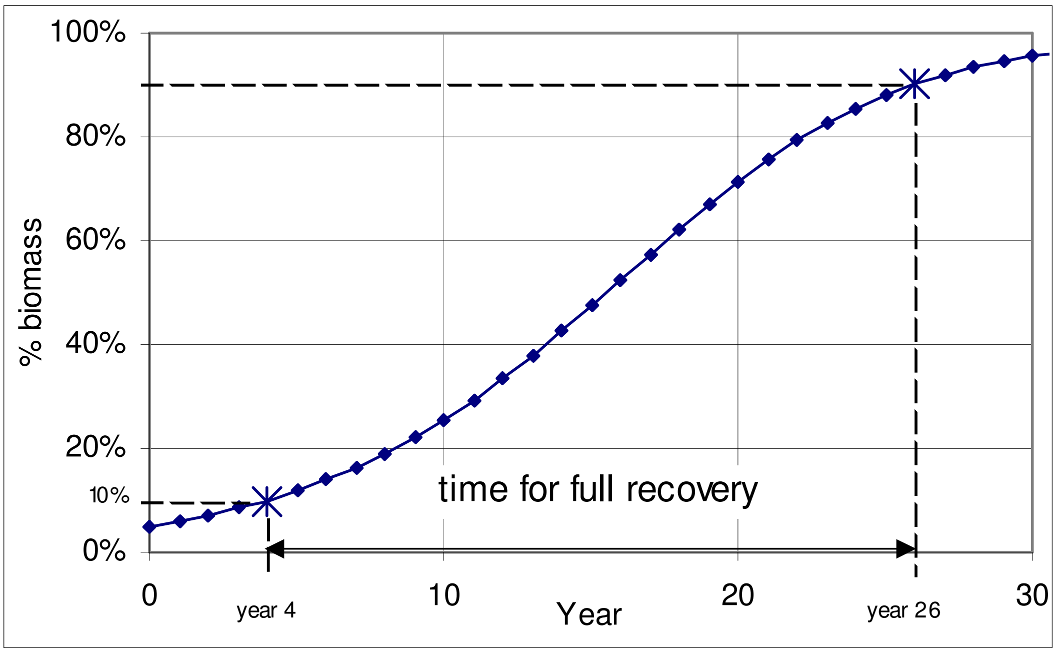


**Figure 3.8** An example of logistic growth that assumes $r = 0.2$ which results in a "time for full recovery" of 22.0 years.

## *Parameter Estimation*

### *Estimating* k*, the virgin biomass*

An estimate for the lower limit for the value of $k$ can be determined by the following simple argument:

1. The equilibrium model tells us that the equilibrium MSY = $rk/4$.
2. It is generally agreed (Hilborn & Walters, 1991) that the equilibrium model consistently overestimates the actual MSY.
3. Thus it can be argued (as long as the fishery hasn't seriously declined during its history) that this sets a lower limit to the virgin biomass.

Thus if we assume that the equilibrium value of MSY, $MSY_{equil}$, consistently overestimates the actual MSY, $MSY_{actual}$, we can represent this argument in symbols:

$$MSY_{equil} = \frac{rk}{4} \Rightarrow MSY_{actual} \le \frac{rk}{4} \tag{6}$$

If it is apparent that the population hasn't "crashed" at any time during its history, it can further be argued that the average long-term annual catch, $\overline{C}$ , must be less than or equal to the actual MSY, implying it is less than or equal to the equilibrium MSY. In symbols this means:

$$\overline{C} \le MSY_{actual} \Rightarrow \overline{C} \le \frac{rk}{4} \tag{7}$$

This can be rearranged to provide an estimate for the virgin biomass based upon average long-term annual catch:

$$k \ge \frac{4\overline{C}}{r} \tag{8}$$

In practice, we parameterise virgin biomass in terms of the historical average catch and the intrinsic growth rate, replacing '4' with '*n*' in the final equation. The parameter $n$ can be considered as an indicative threshold where $n \ge 4$ implies sustainability and $n < 4$ implies unsustainability.

The upper bound is harder to set but there should be sensible limits. There is a reasonable certainty that some values will be much too high for the observed catch and effort. It will generally require expert opinion to identify this value. As an initial estimate we may set $k = 4C/r$ . It is recognised that this is a conservatively low estimate but follows from taking a precautionary stance. Otherwise, if alternative and suitable detailed analysis is available, the estimates of the time series of historical biomass can be compared and matched to these other analyses.

The lower limit for $k$ can also be found computationally by testing various values of $k$ and finding the bounding values between consistent sustainability of historic catches and collapse during the course of the catch history.

### *Estimating* r*, the growth rate*

The growth rate, $r$, is a pseudo-biological parameter that measures the increase in biomass per unit time and is technically the unrestrained growth of biomass (or the rate of biomass increase for small biomass). This parameter is not generally known or measured so it is imperative to obtain an estimate by alternative means.

One of the simplest approaches is to assume a distribution over age classes for the virgin biomass of a population, a functional response of the population to exploitation down to 10% and calculate the recovery to 90%. The approach adopted is described below and illustrated in Figure 3.9:

**Assumptions:**

- Rectangular distribution for biomass against age class (dashed line), where $l$ is the lifespan for an individual of the species.
- Fishing depletes all age classes equally in biomass (dash-dot line).
- Fishing ceases completely and species allowed to recover for $n$ years (solid line). It is assumed that the fecundity is unchanged by the size of the spawning population.
- Constant $dB/dt$

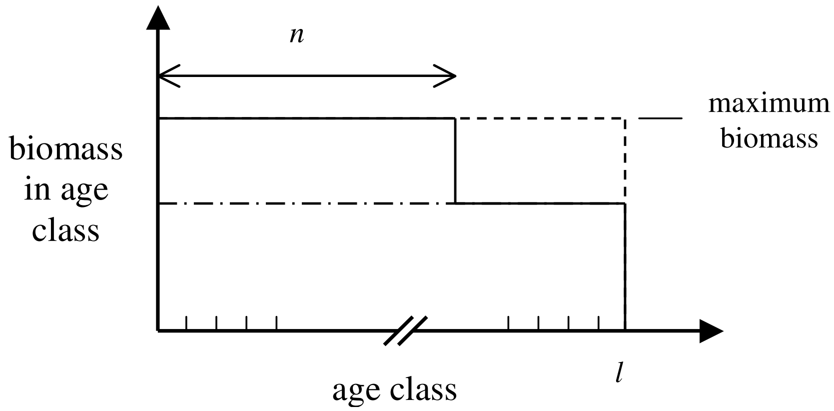


**Figure 3.9** Graph of a very simple model of age-class distribution and its response to fishing.

Based on these assumptions, it can be shown that the fishery will recover from 10% to 90% levels in $l \times 8/9$ years. This is obviously a very crude estimate, but it seems to roughly accord with common sense and expert opinion.

## *Estimating EPUC, effort per unit catch*

Effort per unit Catch (EPUC) is more normally known by its inverse, Catch per unit Effort (CPUE). The latter is often calculated for species and fisheries (Ricker 1940). However, the data are not universally available, and usually only collected in fisheries of significance, commercial or otherwise. Furthermore the interpretation of raw CPUE is problematic, and has to be adjusted for changing gear technology, improving fisher knowledge, changing environmental conditions, etc.

The focus here on EPUC reflects the reliance on more prevalent catch data compared with effort data. By assuming the Schaefer model and the given catch data, one can make an estimate of the effort required in fishing from year to year. On the basis of purely physical considerations, the effort should be related to the density: *half the density, twice the effort* -

$$EPUC_{relative} \propto \frac{1}{\rho_{relative}} = \frac{B_0}{B} \qquad (9)$$

where $B_0$ is some standard reference value (the virgin biomass or perhaps the initial biomass) and B is the current biomass.

By normalising to a reference or baseline value, one can derive a value called the relative effective EPUC. The reference value is somewhat arbitrary such as the first data point or an average. This essentially measures the apparent change in effort (relative to a baseline) assuming all other factors remain the same. Obviously this doesn't track changes such as fishing technology and fishermen's expertise. Thus, it cannot be easily compared with actual EPUC. However it can be used to observe how EPUC theoretically could have changed over long periods of time. These estimates are based on two assumptions: constant density and random fishing. This calculation is convenient as it only requires the known catch data to compute it.

## *Application of the model to sample fisheries*

Overall, this approach consisted of constructing a Schaefer model for each fishery population of interest, with the primary concern being the estimation of credible values for the two Schaefer parameters, *k* and *r*. The main aim was to produce a plausible model of biomass generation in response to future exploitation rather than to attempt to accurately reconstruct the historical biomass. Our primary concern is the future response of a large number of fisheries (and particularly the aggregate view) over a long-time period. This focus meant that we are less concerned with the exact history of fishery biomass (except where it informs us of the model parameters) than the present situation and the future. The long-term view also means that we tend to ignore relatively short-term random, episodic or seasonal variations.

Initially, data for a number of fisheries with good quantitative data and analysis were collected and analysed using this approach. These fisheries were chosen so that the approach could be validated with more complex modelling approaches. Fisheries chosen sampled different groups (fish, crustaceans, molluscs), habitats (freshwater, estuarine, coastal, marine) and jurisdictions (commonwealth, state or territory) and single versus multi-species fisheries. The chosen fisheries included Southern bluefin tuna fishery, Western Rock Lobster fishery, Southern Shark fishery (both gummy and school sharks), South-East fishery (various species), South Australian abalone fishery, Southern Rock Lobster fisheries in various states, barramundi fisheries and black & yellowfin bream fisheries in various states.

### *Applying the model to data from the Northern Prawn Fishery*

The Northern Prawn Fishery (NPF) is one of the Australian fisheries with good quality and quantity catch and effort data extending over a period of decades. The main species of interest are banana prawn (two main species) and tiger prawn (two main species) with the remainder mostly endeavour and king prawn. The data was summarised in *Northern Prawn Fishery and Kimberley Prawn Fishery Data Summary 1999* (A. Sharp *et al.*, 2000) and a recent stock assessment reported in *Northern Prawn Fishery Assessment Report, 1997 & 1998* (Taylor and Die (ed), 1999).

Our approach is not to consider the taxonomic family as the fundamental unit, and not the individual species (unless there are significant parametric differences between species within the same family). Thus the biomass of all of prawn species is aggregated as the Penadie family.

The main data sets available are the historical catch (Figure 3.10) and fishing effort (Figure 3.11). In principle, using the catch data and assuming that the population can be described by the Schaefer model, the annual standing biomass can be reconstructed for various values of virgin biomass, $k$, and growth parameter, $r$.

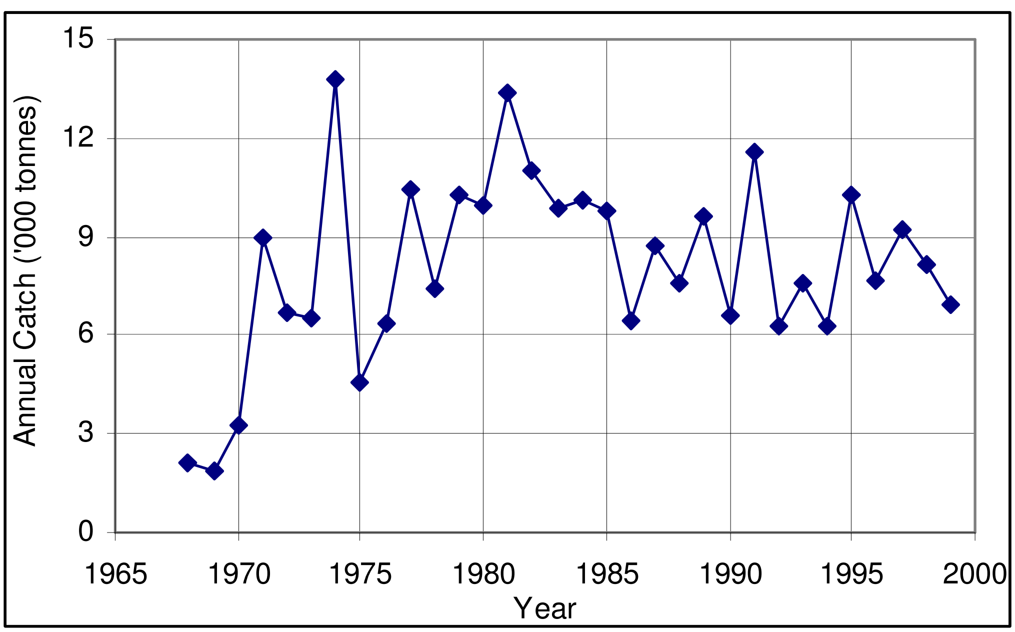


**Figure 3.10** Prawn catch in the Northern Prawn Fishery, 1968 to 1999. Source: A. Sharp *et al.*, 2000

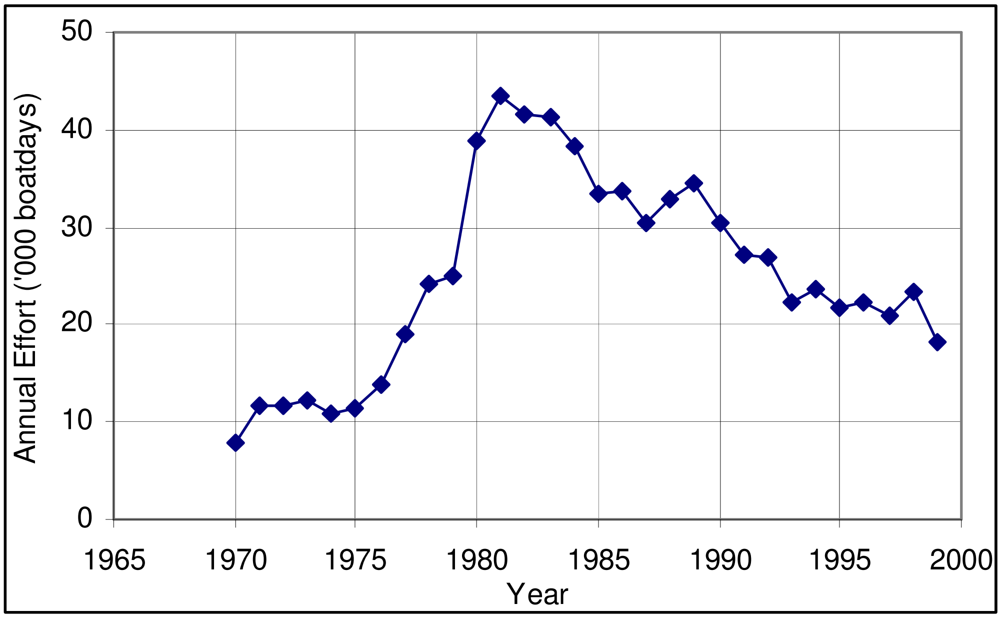


**Figure 3.11** Fishing effort in the Northern Prawn Fishery, 1968 to 1999. Source: A. Sharp *et al.*, 2000

In order to estimate the two Schaefer parameters (*k* and *r*), information from an expert source (in this case the report, *Northern Prawn Fishery Assessment Report, 1997 & 1998* (Taylor and Die, 1999)) is compiled (Table 3.2). In this case, explicit estimates for *k* and *r* are not given. However, the lifespan of the prawn species are in the range of 1.5 to 2 years (Caton and Mcloughlin, 2000) implying a *time-for-full-recovery* of approximately 1.8 years, indicating a starting value for *r* of approximately 2.5 year$^{-1}$. Once this value is specified, a minimum value of *k* is required to ensure the fishery hadn't collapsed during the historical period. This can be found by trial and error or automatically computed.

Since explicit estimates for *k* and *r* were not available, starting from the values specified initially, the two parameters were adjusted to match the expected total long-term yield of approximately 8,500 tonnes. In this case, there was additional information (Table 3.2):

- estimate of standing biomass of tiger prawns as 7,000 tonnes in 1995 so that the total biomass is larger than this (perhaps of the order of a factor of two)
- estimate of virgin biomass of tiger prawns as 23,400 tonnes so that the total virgin biomass is larger than this (perhaps of the order of a factor of two)
- effort data which allows a comparison between the relative nominal and model Effort-per-unit-Catch [15] (Figure 3.12)

[15] The nominal EPUC is simply the effort (in boatdays) divided by the catch (in tonnes). The relative EPUC (either nominal or model) is the value of EPUC in later years relative to the value of EPUC in the first year.

**Table 3.2** Key information from the *Northern Prawn Fishery Assessment Report, 1997 & 1998* (Taylor and Die, 1999).

| Fishery | Species | Year | Information | |
|---|---|---|---|---|
| NPF | All | 1999 | ELTAY ~ 8,500 tonnes | |
| NPF | Banana | 1999 | ELTAY ~ 4,000 tonnes | |
| NPF | Tiger | 1999 | ELTAY ~ 4,000 tonnes | |
| NPF | Other | 1999 | ELTAY ~ 500 tonnes | |
| Banana | All | 1974 - 1999 | historical average yield ~ 4,000 tonnes (2,000 to 8,000) | |
| Tiger | All | 1990 | ELTAY ~ 6,000 tonnes | |
| NPF | Tiger | 1996 | MSY ~ 3,700 to 4,300 tonnes | |
| NPF | Tiger | 1995 | MSY ~ 3,631( tonnes | |
| NPF | Tiger | 1995 | Standing Biomass ~ 6,986 tonnes (3,030 to 16,225) | |
| NPF | Tiger | 1995 | Virgin biomass ~ 23,399 tonnes (18,218 to 34,118) | |
| NPF | Tiger | 1995 | Biomass at MSY ~ 10,943 tonnes | |
| NPF | Banana | 1999 | ELTAY ~ 4,000 tonnes (2,000 to 8,000) | |
| Tiger | Tiger | 1986 - 1999 | Landings ranged between 3,000 and 5,000 tonnes | |
| | | | | |

**Key** ELTAY: Estimated long-term average yield; MSY: Maximum Sustainable Yield

A plausible and reasonable reconstruction of standing biomass (Figure 3.13) was found for

- $r$ = 1 year$^{-1}$ (=> *time-for-full-recovery* = 4.4 years => *lifespan* = 4.9 years)
- $k$ = 37,300 tonnes
- *MSY* = 9,300 tonnes

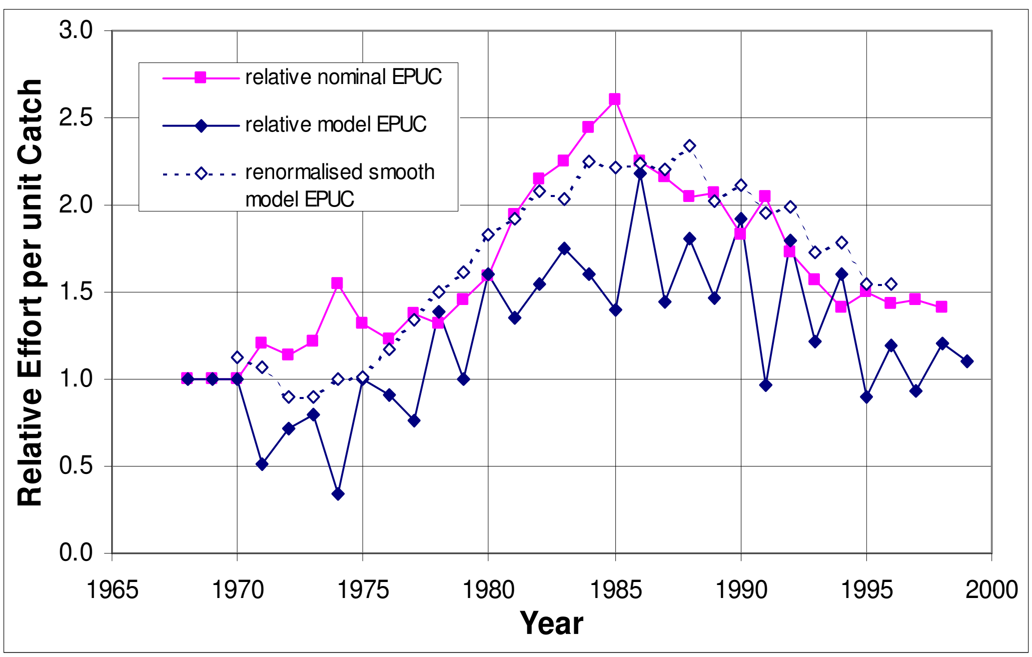


**Figure 3.12** Relative nominal and model Effort-per-unit-Catch (EPUC). The open symbols with dashed line shows the model EPUC after being renormalised to equal average (or total values) with the nominal EPUC (and smoothed for clarity using a 5-year average).

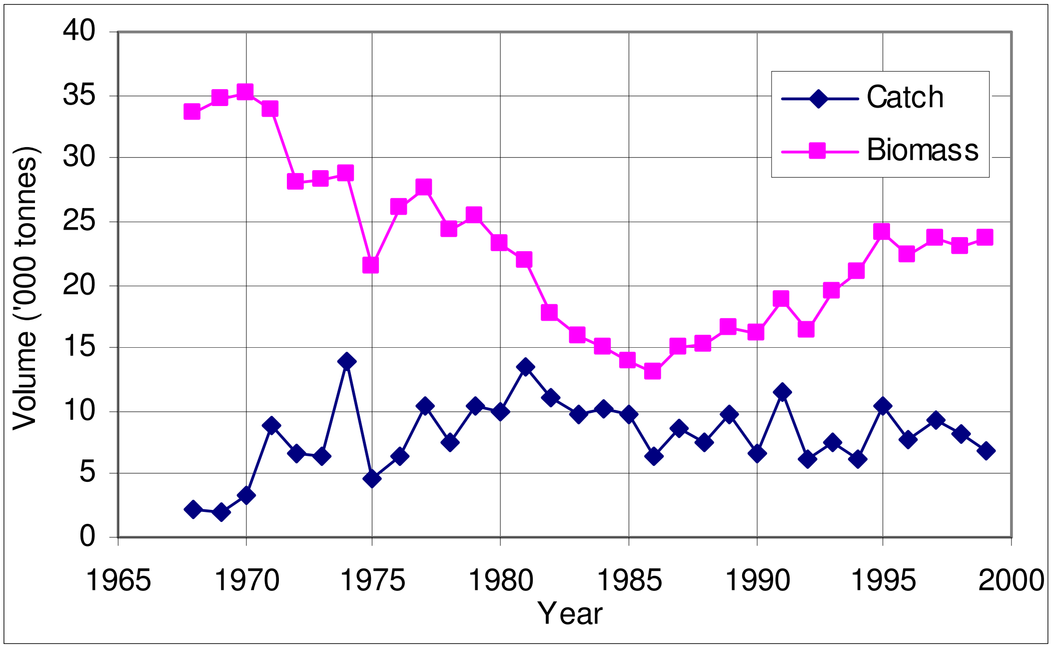


**Figure 3.13** Annual catch and reconstructed prawn standing biomass.

A number of points should be made:

- The virgin biomass is about 20% smaller than anticipated. This is reasonably good given the simplicity of the approach.
- The *time-for-full-recovery* is about 2.5 times larger than our starting value. This indicates that recovery of prawn stocks takes longer than might be expected, given their average lifespan. This concurs with the analysis that suggests suspected recruitment over-fishing of prawns has occurred, which would extend the recovery time of the biomass (Taylor and Die, 1999).
- The *MSY* is about 10%larger than previously estimated. Again, this is quite good given the simple model used.
- On the face of it (Figure 3.12), the relative model *EPUC* is slightly larger (and marginally phase-shifted) compared with the relative nominal *EPUC*. However, renormalising the modelled EPUC to make the average EPUC of both the nominal and model data equal shows that the two data sets are closely aligned. Although informative, the matching of these two set of points is not critical given the uncertainties and factors influencing the calculation of effective effort (eg. effort creep). In fact, it is remarkable that they match so well.
- It is extremely doubtful that the standing biomass calculated here for 1968 to 1999 is the true historical standing biomass for that same period. Fluctuations in numerous factors (e.g. recruitment, habitat) result in changes that a simple model like this one cannot account for. However, it should be remembered that this model is **not meant** to accurately calculate the historical standing biomass, but simply to be a practical **biomass generator** in the future. We assert that the estimates of the virgin biomass, growth parameter and *MSY* are well within the bounds of believability.
- The data quality and quantity for the Northern Prawn Fishery is better than nearly all other fisheries in our model. As such, there is a higher probability of accurately determining the values of the key parameters in this case than most other fisheries in the model. In some of those fisheries, the only data available was catch data over a relatively short time period, so that educated guesses for values had to be made.
- The example of the Northern Prawn Fishery was one of the better examples where the model appeared to match the data and information reasonably well. There are other examples where the model is a poorer fit to the data. However, the estimates of the Schaefer parameters were generally found to be credible.

## Basic structure and organisation of data

In the previous section, the Schaefer model must be applied to a particular fish population. Normally, this basic biological unit is a species of interest. Our approach is to consider the basic biological unit, called a *fish unit*, as the combination of a taxonomic family and a “Fishery”, which are management units as defined by the appropriate commonwealth or state/territory fisheries agency that administers it. In this initial round of analysis, we selected 158 fish units as being the most significant to model.

It was decided to structure the data in this manner (rather than in an explicitly spatial form) because fisheries are well understood by managers and fishers alike, the data is usually collected and reported in this manner and fisheries are already a partial spatial descriptor, since they usually cover a defined geographic area. This made it easier to collate and organise the data (although it comes at some cost of absolute modelling rigour). It also allows the stakeholders to more readily validate the model since they recognise the data at this fishery level.

However, this approach is not as restrictive as one might initially believe. Usually, there is only one species of any particular family that is significant in any specific fishery. Therefore, essentially the fish unit is being modelled at the level of a species. Where multiple species of the one family in the same fishery are important, the model has been adjusted to be able to ascribe a fish unit to each separate species.

Another obvious issue with this approach is the problem of a single species stock that is caught in multiple fisheries (eg. Australian salmon caught in NSW, VIC and SA). Modelling each fish unit separately produces significantly different results compared to modelling the stock as a single biological unit. Although this does not occur frequently, the model is being adjusted to account for such species.

Australia is broken up into seven jurisdictions (Commonwealth, State or Territory), each of which administer a number of fisheries (Figure 3.13). *Fish units* are a particular family (or species) of significance within a specified fishery. Catch and effort statistics are compiled or constructed for each of these fish units. They are treated as single biological units and modelled using the approach described previously to determine their Schaefer parameters ($k$ and $r$). Each fishery may also have one or more methods of fishing (and the related effort) associated with it.

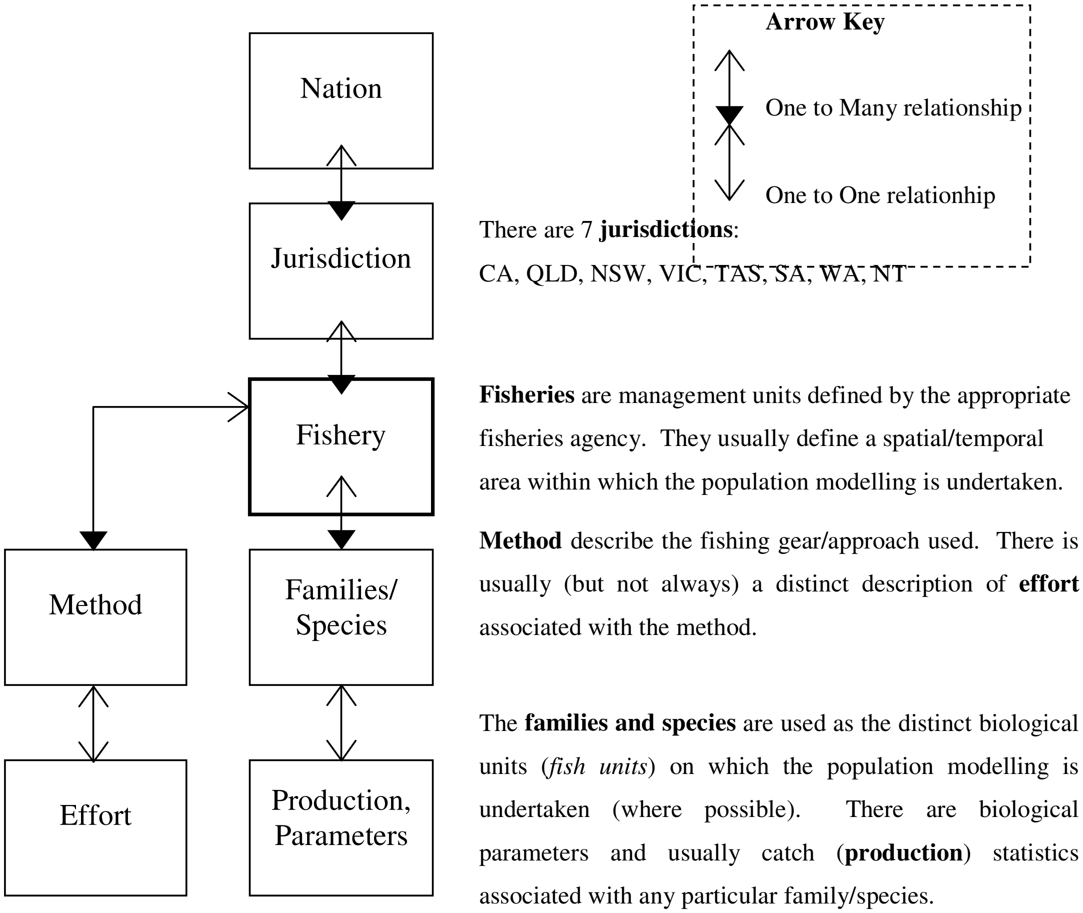


**Figure 3.14** A diagram showing the hierarchy of data types. The arrows indicates the nature of the relationship between data elements with a thin arrow head indicating "one" and a solid arrowhead indicating "many".

## References

CSIRO (1999a) CSIRO Resource Futures Program, Review of the Australian Stocks and Flows Framework: Methodological Basis and Structural Outline.

Conroy, J., B. Foran, F. Poldy and T. Quinnell (2000). Future Options to 2050: DIMA Workshop Report 00/03; Report to Department of Immigration and Multicultural Affairs, CSIRO Wildlife and Ecology, Canberra. Workshop 12: Forestry and Fisheries

Dunlop M., G. Turner, F. Poldy, and B.D. Foran (2002) Decision Points for Land and Water Futures, Land and Water Australia

Gault F.D., K.E. Hamilton, R.B. Hoffman and B.C. McInnis (1987) The design approach to socio-economic modelling, *Futures*, February, p3-25.

Giske J., G. Huse and Ø. Fiksen (1998) Modelling spatial dynamics of fish, *Reviews in Fish Biology and Fisheries*, Vol 8, p57-91.

Hilborn R. and C.J. Walters (1991) Quantitative fisheries stock assessment : choice, dynamics, and uncertainty.

Magnússon K.G. (1995) An overview of the multispecies VPA - theory and applications, *Reviews in Fish Biology and Fisheries*, Vol 5, p195-212.

Pella, J. J. and P. K. Thomlinson (1969). "A generalised stock production model." *Bulletin Inter-American Tropical Tuna Commission* Vol 13, pp. 419-496.

Poldy, F., B. Foran and J. Conroy (2000). Future Options to 2050: Australian Stocks and Flows Framework; Report to Department of Immigration and Multicultural Affairs; 00/04. Canberra, CSIRO Sustainable Ecosystems (previously Wildlife and Ecology), Resource Futures Program, National Futures.

Ricker, W. E. (1940). "Relation of "catch per unit effort" to abundance and rate of exploitation." *Journal of Fisheries Research Board of Canada* Vol 5 p. 43-70.

Schaefer M.B. (1954) Some aspects of the dynamics of populations important to the management of commercial marine fisheries, *Bulletin Inter-American Tropical Tuna Commission*, Vol 1, p26-56.

Schaefer M.B. (1957) A study of the dynamics of the fishery for yelowfin tuna in the eastern tropical Pacific Ocean, *Bulletin Inter-American Tropical Tuna Commission*, Vol 2, p247-285.

Sharp A., J. Malcolm and J. Bishop (2000) Northern Prawn Fishery and Kimberley Prawn Fishery Data Summary 1999.

Sumaila U.R. (1999) A review of game-theoretic models of fishing, *Marine Policy*, Vol 23, p1-10.

Taylor B. and D. Die (ed) (1999) Northern Prawn Fishery 1997 & 1998 Fishery Assessment Report.

Walters, C. J. (1969). "A generalized computer simulation model for fish studies." Trans. of the American Fisheries Society 98: 502-572.

Walters C., V. Christensen and D. Pauly (1997) Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments, *Reviews in Fish Biology and Fisheries*, Vol 7, p139-172.

## Species codes and database

The numeric codes identifying marine species and groups inhabiting in Australia have undergone several changes over time. A set of three and four digit alphanumeric codes was is use at the Department of Primary Industries and Energy (DPIE) for many years. The CSIRO independently utilised a six digit code also known as "FISHLIST" or the "Australian Species Code". Most recently, CSIRO Marine Research have been constructing Codes for Australian Aquatic Biota (CAAB), using FISHLIST as the foundation. The current eight digit codes consist of a 2-digit category prefix (Table 3.3), followed by a 3-digit family (or equivalent) group and end with a 3-digit taxon number within that family. Further information can be found at the website http://www.marine.csiro.au/caab/.

**Table 3.3** Major categories in the Fisheries 2020 project database

| CATEGORY CODE | CATEGORY NAME | CATEGORY DESCRIPTION |
|---|---|---|
| 23 | Mollusca - non-Gastropod groups | Bivalves, Cephalopods, Chitons, etc. |
| 24 | Mollusca - Gastropoda | Gastropods (univalve molluscs, slugs, snails etc.) |
| 25 | Echinodermata | Echinoderms (seastars, sea urchins, crinoids, etc.) |
| 27 | Crustacea - non-Malacostraca | Copepods, ostracods, barnacles, and minor crustacean groups |
| 28 | Crustacea - Malacostraca | Malacostracans: isopods, amphipods, euphausiids and decapods (prawns, lobsters, crabs, etc.) |
| 37 | Pisces | Fishes |

These CAAB codes have been used as the unique identifiers of species and species groups. and families (see Appendix B). The basis nomenclature of common names, scientific names and eight-digit code have been converted into an Microsoft Excel spreadsheet and used as the fundamental source of species identification. All incoming data is required to be labelled with a unique CAAB code. Further project-unique codes have been created to account for other useful groupings and data of unknown specifications.

The species tables found in Australia's Fisheries Resources (Kailola et al., 1993) and Fishery Status Reports 1999 (Caton and McLoughlin, 2000) provided an excellent basis for the species database. This basic database has been expanded to (currently) include 112 families covering 288 species that inhabit Australia.

Kailola P.J., M.J. Williams, P.C. Stewart, R.E. Reichelt, A. McNee and C. Grieve (1993) , Australian Fisheries Resources.
Caton A. and K. McLoughlin (ed.) (2000) Fishery Status Reports 1999: Resource Assessments of Australian Commonwealth Fisheries.

# Chapter Four - Recreating Australian Fisheries History

## Chapter Summary

Production, consumption and trade are considered *primary quantities* as they represent the major stocks and flows of the fisheries sector. Labour, energy and vessels are the important associated physical parameters (or *secondary quantities*) that are measures of activity in the fisheries sector. The primary source of fisheries data are Australian fisheries agencies, either via direct requests or their publications.

Production data play a central role, being the most widely available, arguably the most reliable and most unambiguous data type. They guided the adoption of a simple population model that is basically driven by catch data. Although the overall approach has some limitations and drawbacks, we argue that they are manageable and that the transparency of the approach allows for scrutiny and criticism, to continuously provide improved data reliability and model enhancement. We also content that the aggregation of assessments of 158 fish units masks minor errors with any one species. As no bias were detected in the approach this aggregation method appears robust.

## Introduction

Data were collected from a variety of sources. The aim was to construct a dataset that encompassed 85% of the volume and 85% of the value of fisheries product that is produced in Australia. The initial criteria for including data on a particular species was based upon the same criteria that the BRS set for inclusion in its own species tables i.e. whether it met the average threshold of 100 tonnes or $1,000,000 in annual production in recent years (BRS, 2000). (In an associated paper (Kearney 2003) additional data was used to increase the number of fish units covered to 220.)

In many respects, in a model such as ASFF, the data must drive the development of the modelling framework. Given the scale of the model, the entire economy of a nation, it is unlikely that resources would be provided to independently collect all the data required, except in specific focussed tasks. In addition, given the need to calibrate and validate the model over the past half-century, it is necessary to rely on the data already collected. Thus, the past and present availability of data dictates, to a certain degree, the direction of development of the model. For this reason, the development of ASFF is sometimes described as an exercise in *structured data analysis*.

## Primary quantities

We identify *primary quantities* as those that represent the major input and output flows of the fisheries sector at the national level. These are the quantities that keep track of the fundamental quantity of interest (in this case, fisheries product) as it moves through the Australian economy. Essentially they are the ultimate sources and sinks of fisheries product in the Australian market.

### *Production*

Production, by definition, is the ultimate source of fisheries product. Here, we are interested specifically in the domestically produced goods, as opposed to international fisheries production. Therefore, it sets the ultimate constraint on the size of the domestic fisheries sector and represents the supply side of the "flows equation".

Production over time is one measure of the productivity (and its trends) of the seas and aquaculture operations. It is an indirect indicator of the status of the fish biomass and more generally of the health of the ecosystem, especially with species that are very dependent on the habitat for successful recruitment and growth. By definition, it is one measure of the impact of fishing on the ecosystem.

There are four main sources of fisheries product:
1. wild capture sector
2. aquaculture sector
3. recreational sector
4. traditional sector

### *Consumption*

Consumption, by definition, is the ultimate destination of fisheries product. More specifically, this refers to the product consumed domestically only, as opposed to product destined for overseas markets. It is one of the main drivers of the fisheries sector and represents the requirement side of the "flows equation".

Consumption can be classified for two basic uses: food and non-food. Food is generally fresh, chilled or frozen *or* processed (canned, smoked, other). The primary non-food use is as feed (in the form of fishmeal) for livestock and aquaculture. Other non-food uses are ornamental (aquariums), fish oils (for animal feed and humans), nutraceuticals and pharmaceuticals.

One interesting investigation was the trend in consumption patterns, including trends in per capita consumption of seafood and other foodstuffs. Also, a number of different factors that (may) influence consumption patterns are of interest:
1. Gender (male : female)
2. Age (Children : adults : elderly)
3. States/territories of origin
4. Metropolitan and rural
5. Country of origin (Australia, East Asia, Other)
6. Location of meal (home or outside)
7. Tourism factor (local : domestic tourists : international tourists)

### *Trade*

Trade are the flows into (imports) and out of (exports) Australia. The size of these flows determines the size of the supply of fisheries product available for domestic consumption.

A number of issues surrounding each flow are of interest:
- Exports
  - Types of export product
  - Consumption potential of export markets
  - Impact of exports on local fisheries
  - Impact of exports on domestic market
  - Competition in the international market for buyers
- Imports
  - Types of import product
  - Supply potential of import countries
  - Impact of imports on source country and fisheries
  - Impact of imports on local market
  - Competition in the international market for sellers' product

## Secondary quantities

We identify *secondary quantities* as those that are related to the fisheries products as they move through the Australian economy. These are those quantities that are indirectly related to the flow of fisheries product. Essentially, they are the accompanying activity or consequences of the movement of fisheries product in the Australian market.

In our current version of the model, we have only detailed models of the activity related to production. In the next stage of fisheries research key elements of the processing and distribution chain will be included and analysed.

### People / labour

People are involved at nearly all areas of the fisheries sector and at nearly all stages of the production chain. The production chain can be viewed in the following way:

- Primary production
  - Wild capture sector
  - Aquaculture sector
  - Recreational sector
  - Traditional sector
- Processing and wholesaling
  - fresh, chilled frozen product
  - other processed product
    - canned
    - smoked
- Retailing
  - fishmongers (selling fresh, chilled and frozen fish)
  - shops and supermarkets (selling above and other processed product)
  - restaurants and takeaways (selling prepared meals)
  - specialist shops (selling fishing equipment and boats)

Currently, our most detailed information relates to the primary production stage. This is because this was our primary focus and because as you move along the production chain, the activities of people generally become more dispersed and are not as readily associated to the movement of fisheries product. Although very crude, it is one measure of the input of effort into a fishery.

Exact quantification of the labour involved in the primary production (as with any measure of effort) is problematic. The pragmatic approach (which we adopt) is to compile historical data on raw figures on full-time (F/T) and part-time (P/T) employment the associated volume of fisheries production. The raw labour figures can be converted to effective full-time employment (EFT) using the appropriate scaling factor.

### Boats / vessels

Boats and vessels (with their associated fishing equipment) are the primary capital investment for commercial wild capture and recreational fishers. They also have significant life spans which are important to include in a long-range study such as this one. Thus they are important from the points of view of accounting for effort and infrastructure.

The basic quantity is the number of vessels. Further information can be gained from the size of the boat (in length, volume and/or engine power) which can also be related roughly to the number of fishers. Like number of people, it is a crude measure of the input of effort into a fishery.

### Energy / fuel

Energy, mostly determined by the amount of fuel consumed, is a further indicator of fishing effort undertaken. It is also one of the major quantities of interest in the overall ASFF model, being fundamental to all physical activity and material flows in the model. Eventually this is translated to joules required per tonne of fish landed.

### *Effort*

Effort is the quantifiable measure of the amount fishing activity undertaken in the course of taking a specifiable amount of catch. In standard fisheries population modelling, it is usual to acquire both data on both the catch taken and the effort expended, in order to evaluate the time-dependent biomass. Effort is measured as an indicator of abundance, in the absence of more direct (and more expensive) methods such as independent surveys, since fishers can be used as regular collectors of data. Thus, generally speaking, effort data is usually a useful quantity to compile. However, there are a number of issues in using effort data in this modelling approach.

#### *The problems with effort data*

Firstly, given the national scale and long timeframes under consideration, the quantity and quality of effort data was good for only a few fisheries, average of several more and poor or nonexistent for the remainder.

Secondly, even where it does exist, it is often a measure that is specifically related to different methods of fishing (e.g. shots in trawling, pots in lobster fishing, km-lifts for gillnetting) which are then difficult if not impossible to standardise. Furthermore, even if there is a common measure, such as time in hours or days, it is not simple to make comparisons (e.g. How does an hour of abalone diving relate to an hour of trawling? Is it physical fishing time or more general boating time?). There are also some nuances to consider, such as with fisheries with quota systems, as the effort recorded cannot be directly related to abundance because the quota system distorts the fishing behaviour and allocation of effort.

Lastly, even within a constant type of method and measure of effort, the units themselves may change relative value over time, a common example being “effort creep”. This is the effect of improving fishing technique, due to factors such as improving technology (like global positioning systems) or fisher knowledge, to reduce the amount of actual effort to obtain the same catch, making it more difficult to accurately determine the index of abundance.

For these reasons, effort data are avoided and the modelling is driven principally by catch statistics. This allows us to make maximum use of the catch data, which is the most widely available. By deliberately not attempting to include effort data, and thus simplifying the population model, it allows us to focus on the aggregate results, rather than individual fisheries.

### *Value*

Given the understandable interest in economic indicators, the value of commodities are a widely reported quantity, as much or more so as the volume. However, it is not a central quantity in the context of modelling material and energy stocks and flows. Thus, although available, they are not generally included in the ASFF structure. However, in some cases, they are the only information available and must serve as a proxy measure for volume (e.g. pearls). Also, prices of commodities are a useful indicator of their relative market value, between each other and over time.

## Major fisheries organisations in Australia

Australian fisheries agencies are the primary collector of data on fisheries. They have had various guises in the past but current labels are given below for each jurisdiction (Table 4.1). These agencies are also usually responsible for management and research into fisheries and aquaculture. Consequently, they often publish statistics and data relating to fisheries on an annual basis and conduct in-depth research into the science and management of fisheries and aquaculture.

**Table 4.1** Major fisheries agencies involved in management, data collection and research for each jurisdiction

| Jur. | Organisation | Acronym | Major tasks |
|---|---|---|---|
| CA | Australian Fisheries Management Authority | AFMA | Management, Data collection |
| CA | Bureau of Rural Sciences | BRS | Data collection, Research |
| NSW | NSW Fisheries | NSWFish | Management |
| NSW | NSW Fisheries Research Institute | NSWFRI | Data collection, Research |
| NT | Department of Business, Industry And Resource Development: Primary Industry and Fisheries Agency | DBIRD | Management, Data collection, Research |
| QLD | Queensland Department of Primary Industries | QDPI | Management, Data collection |
| QLD | Queensland Fisheries Service | QFS | Data collection, Research |
| SA | Primary Industries and Resources, South Australia | PIRSA | Management, Data collection |
| SA | South Australian Research and Development Institute | SARDI | Data collection, Research |
| TAS | Department of Primary Industries, Water and Environment | DPWIE | Management, Data collection |
| TAS | Tasmanian Aquaculture and Fisheries Institute | TAFI | Data collection, Research |
| TAS | Inland Fisheries Service | IFS | Management, Data collection |
| VIC | Department of Natural Resources and the Environment | NRE | Management, Data collection |
| VIC | Marine and Freshwater Research Institute | MAFRI | Data collection, Research |
| WA | Fisheries Western Australia | FishWA | Management, Data collection, Research |

Several commonwealth agencies have responsibility for compiling and aggregating and analysing this data at a national level (Table 4.2).

**Table 4.2** Commonwealth organisations that compile and report national fisheries statistics

| Organisation | Acronym | Major publications |
|---|---|---|
| Australian Bureau of Agricultural and Resource Economics | ABARE | "Australian Fisheries Statistics", "Fisheries Survey Reports" |
| Bureau of Rural Sciences | BRS | "Fishery Status Reports" |
| Australian Bureau of Statistics | ABS | "Australia Yearbook" |

A number of additional organisations are involved in marine and fisheries research (Table 4.3).

**Table 4.3** Australian organisations involved in marine and fisheries research (not complete)

| Organisation | Acronym | Major tasks |
|---|---|---|
| CSIRO Marine Research | CMR | Marine Research |
| Fisheries Research and Development Corporation | FRDC | Fisheries research |
| Australian Institute of Marine Science | AIMS | Marine Research |
| Environment Australia | EA | Environmental research and management |

## Data sources for major quantities

The major single sources consulted in compiling the databases and their coverage with respect to the sectors and quantities are described below:

- **ABARE Australian Fisheries Statistics**
  - **Quantities:** Production, Imports, Exports (Volume and Value)
  - **Period covered:** 1989-1999 (currently at 2000)
  - **Jurisdictions:** States/Territories, CA fisheries
  - **Species:** fairly aggregated
  - **Other:** Some boat and labour information in recent years
  - **Comment:** This is an up -to-date, annual data collection organised by ABARE to report on fishery production at a national scale. It relies on input from the appropriate commonwealth,. state and territory agency. It only disaggregates spatially data at jurisdictional level and major Commonwealth fisheries. Although some species are identified, it is most complete and consistent in reporting at major category types of fish, mollusc and crustaceans. It is useful for calculating average prices. It was introduced after ABS ceased reporting on Australia's fisheries production.

- **ABS Fish Account 1997**
  - **Quantities:** Production, Trade, Utilisation (Volume only)
  - **Period covered:** 1991-1997
  - **Jurisdictions:** States/Territories, CA fisheries
  - **Species:** By species
  - **Other:** Some flows, uses
  - **Comment:** This was a single publication published by the ABS in 1999 as part of their series of environmental accounts with the view to report on a regular basis in the future. It covers a small time period (1991-1997) but reports down to species level at the level of jurisdictions and Commonwealth fisheries.

- **BRS Working Paper: 25 Years of Australian Fisheries Statistics**
  - **Quantities:** Production
  - **Period covered:** 1965-1990
  - **Jurisdictions:** States/Territories, a few CA fisheries
  - **Species:** By species and species groups
  - **Comment:** This was a report of research and compilation of fisheries production for the period 1965-1990 done in preparation of the publication of Australian Fisheries Resources (AFR). It is a detailed database of species by jurisdiction relying heavily on ABS Fishery Bulletins and commonwealth, state and territory agency input and CSIRO Division of Fisheries.

- **BRS/FRDC Australian Fisheries Resources**
  - **Quantities:** Production
  - **Period covered:** 1965-1990
  - **Jurisdictions:** States/Territories, a few CA fisheries
  - **Species:** By species and species groups
  - **Other:** A summary table of species and species groups listing important physical, biological and ecological attributes
  - **Comment:** In addition to the production figures compiled in BRS WP91 described immediately above, this publication provides a general introduction and overview to many aspects of Australia's fisheries resources including production, history, management fishing techniques and habitats. Furthermore, it is contains a comprehensive list and fact sheets of major species and species groups that are important to Australia.

- **BRS Fishery Status Report**
  - **Period covered:** 1998, 1999, 2001 (to be published)
  - **Jurisdictions:** Primarily CA fisheries
  - **Other:** A summary table of species and species groups listing important physical, biological and ecological attributes. Summary table of major fisheries and methods.

- Comment: In recent years the BRS has published this summary of the status of major Commonwealth fisheries.

- **ABS Fisheries Bulletins**
  - **Quantities:** Production, boats, people, trade, apparent consumption
  - **Period covered:** 1962-1985
  - **Jurisdictions:** States/Territories
  - **Species:** By species
  - **Comment:** For many years, the ABS had the responsibility and authority to collect and compile data to report on the fisheries sector at a national level. Starting in 1950(?), the ABS produced annual fisheries bulletins until 1985, when it ceased publication because of problems with data acquisition and validity. It covered many aspects from the volume and value of production, to numbers of people and vessels involved and apparent consumption. It reported at the level of states and territories and species or species groups.

- **DPIE AFS Background fishery Statistics**
  - **Quantities:** Production, boats, people, trade, apparent consumption
  - **Period covered:** 1987-1990
  - **Jurisdictions:** States/Territories
  - **Species:** By families
  - **Comment:** This was a publication put out by the Australian Fisheries Service of the DPIE, partly in response to the cessation of the annual ABS publication. It covered production, consumption, imports and exports and major commonwealth fisheries.

- **FIRDC A Manual of Australian Fisheries Statistics**
  - **Quantities:** Production, Imports, Exports (Volume and Value)
  - **Period covered:** 1985-1990
  - **Jurisdictions:** States/Territories, CA fisheries
  - **Species:** reasonably disaggregated
  - **Comment:** This was a report commissioned by the FIRDC in light of the cessation of the ABS Fisheries Bulletins to provide detailed production data at the level of state and territory and commonwealth fishery. It attempted to fill in the history from 1985 to 1990. Since the previously mentioned reports adequately cover this period, we did not require the data, but it was of some value to cross-check some of our original data and also provides nice continuity on price trends with the ABARE series.

- **State/Territory data requests**
  - **Quantities:** Production, Effort
  - **Period covered:** Various, generally up to the present
  - **Jurisdictions:** States/Territories fisheries
  - **Species:** By species
  - **Comment:** After initial identification of important species in each state and territory, a data request was made to all states and territory fishery agencies in early 2000 to provide data and guidance to the suitability of the selected species. The intention was to get lengthy time series on important species at the level of fisheries within each state. The states and territories were most helpful in providing the information to us where possible.

  - **Fisheries Assessment Reports**
    - **Quantities:** Production, Effort
    - **Period covered:** Various
    - **Jurisdictions:** CA and States/Territories fisheries
    - **Species:** By species
    - **Comment:** Assessment reports on individual fisheries were valuable in providing data on many commonwealth fisheries and a number of state-based fisheries. They provide in-depth analysis of the status of stocks, and in several cases, models of fishery biomass and estimates of fishery model parameters. This extra level of insight was

valuable in formulating the best approach to modelling fisheries at the national scale and providing estimates for the key modelling parameters.

# Data collection and the philosophy of the modelling approach

Most effort in fisheries modelling in Australia goes into individual fisheries or species. Usually, it involves enhanced collection of data (both quality and quantity) combined with more complex models with the aim to more accurately assess the current stock levels and better predict the future stock levels. We believe the approach detailed here is the first attempt to coherently model the entire Australian fisheries sector.

## *The primary role of catch data*

In a very significant way, the data have moulded the modelling approach taken. Given the national scope, the most widely available data are production (or catch) data. Effort data have the problems as noted in the previous chapter in the section "The problems with effort data". Thus it was advantageous to rely solely on the most widely available data.

Using only catch data simplified the model used for population modelling, as described in the previous chapter. While acknowledging the limitations this produces, it offered the advantages of being simple to use, widely understood and didn't distract from the main aim of reporting on the aggregate view of Australia's fisheries by not focussing stakeholders on the modelling of individual fisheries or species.

In accordance with the overall ASFF approach, the fundamental procedures should be detailed enough for experts and stakeholders to recognise and validate (sometimes with caveats) and no more, unless a clear improvement in model accuracy and utility can be shown. The use of catch data to drive the model produces a simple, recognisable model structure and minimal numbers of parameters for experts to debate and discuss.

## *Scaling up and looking forward*

While acknowledging the simplifying assumptions, this approach still allows us to aggregate to continental scales with some confidence. By using the most widely available and applicable data (i.e. catch data), the key Schaefer parameters (Schaefer 1954, 1957; Pella and Thomlinson 1969) of virgin biomass and unrestrained growth rates ($k$ and $r$) can be estimated for each *fish unit* using the best analysis or expert opinion. These dictate the long-term potential for each fish unit, permitting the construction of an aggregate long-term view of fisheries, jurisdictions and ultimately the nation (Lowe 2001).

The key Schaefer parameters, $k$ and $r$, are those that can be estimated from historical data most simply, and also those that are *necessary* and *minimally sufficient* to determine both the long–term trends and dynamics (Walters 1969). This is even possible for the large range of life-spans of species (from less than 1 year to over 100 years) that influence the dynamics of fish stocks. However, the traditional ASFF approach utilised 5-year time steps. The dynamics of short-life-span species like squid or prawns could not be adequately captured in such an approach so the time step was reduced to one year. Although somewhat crude, by not reducing our time step further, we can ignore the differences that arise when comparing calendar years with financial years.

# The creation of history

The ultimate purpose of data collection is to fit the data within the ASFF modelling framework. More specifically, this data is used to create a self-consistent data history.

An obvious and important aspect in the process of producing useful scenarios of the future is the correct construction of the present and the past. In order to model the past, historical databases need to be constructed from the relevant data (either directly or inferred from associated data). Unsurprisingly, there are errors or gaps in the database, arising from mistakes or uncertainties in original data, or simple absence of original data. There is little that can be done to correct this since (by definition) it is data already collected and is the best data available[16]. Even after the input of expert opinion in the process of making judgements on past data, it is likely that significant portions of the historical dataset will be in error or still missing.

As explained previously, the next step to deal with this is to fill the gaps in the historical data and use the associated variables related via the process models to assist in creating a complete and consistent history.[17]. This is a key strength of the ASFF modelling approach – the cross-validation of related variables within a transparent modelling framework. Although this does not necessarily make the historical database correct, it offers a methodology for creating a plausible history with the maximum confidence. In this way, the uncertainty caused by the availability and reliability of data is minimised.

Finally, as far as we are aware, this project represents the first attempt at consolidating data from across Australia and using it in a national-scale model. The approach is open to, and actively invites, scrutiny and criticism, so that the data quality can be improved and the model constantly enhanced as a tool for exploring national-scale, long-term issues for Australia.

### *The process*

The process of creating this history requires the following steps:

1. Data to be collected.
2. Data to be organised.
3. This data to be fitted to the specified framework variables and parameters.
4. This data to be used to complete the historical dataset where data are missing.
5. The constructed historical dataset to be made compatible and self-consistent.
6. The constructed historical dataset (in conjunction with the model) to be able to recreate historical data series.

All of steps 1 and 2 and much of steps 3 and 4 are done in a spreadsheet program (Microsoft Excel™). This is the initial gathering and manipulation of the data into a useful set. The remainder of steps 3 and 4 and all of steps 5 and 6 are performed using Robbert Associates SAMM™ program (Robbert Associates 2003).

In practice, data covering the historical period is almost always patchy. Typical problems include:

- data only being available at state or national rather than local or regional levels;
- data only being available for some areas;
- data only being available for some time periods;
- data only being available for some components of a variable;
- data only being available for an aggregation of variables, or levels of a variable;
- data from different sources not being consistent, either because they simply do not agree or because they are actually measures of different things; or more frequently,
- no usable data are available for a variable.

However, even when there is patchy or no actual data for a variable, it is rare that nothing at all is known about a variable. Most of the procedures outlined below use some sort of related information to help fill gaps in a variable.  The following briefly describes the range of calibration techniques:

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[16] It is worth noting one of the advantages of the ASFF approach is that it points to data that should be collected in the future for the improvement of the model.

[17] This does not prevent later addition of historical data and recalibration of "history". In fact, this is one of the positive attributes of the ASFF modelling approach – it transparently creates a historical database in such a way that allows for improvement via open scrutiny and modification.

- Data Input and Cleaning
  A trivial first step is to read-in, clean and format the raw data. This may involve removing any obviously spurious data elements.
- Harmonising
  In cases where there is more than one source of data for a particular variable it is necessary to resolve any discrepancies and possibly combine the data sets. Often this applies to overlapping time series.
- Interpolating & Extrapolating
  Most data sets do not cover the entire historical period of the calibration. Consequently it is necessary to fill in the missing time gaps, which usually means extending backwards to the start of the history period.
- Disaggregation
  In many cases, data is available over longer time series at more aggregated levels, and it is then necessary to spread this aggregated data across the dimensions of the variable (such as spatial regions). In other cases of disaggregating variables, more information can be used through the relationship with a variable that is already disaggregated.
- Framework Constraints - Intermediate variables
  Some input variables of the simulator framework relate one output variable to another in a relatively simple way. When the output variables both have been filled with data, it can be a simple matter to generate the data for the intermediate variable.
- Using data and theoretical information
  In other complex situations, were less data are available, theory or contextual information can play a significant role in constructing data for a variable.

## *Specific historical calibration issues*

The historical calibration issues can be divided into two (related) aspects:

- the applicability and validity of the simple Schaefer model; and
- the availability and reliability of data.

### *The applicability and validity of the simple model*

The Schaefer Model is utilised extensively to determine levels of wild fish stocks. It is the simplest form of Biomass Dynamic Models, which themselves are amongst the simplest class of models used in ecological population modelling. This was chosen deliberately for a number of reasons.

Firstly, the range of quality of data, from extensive and accurate to mostly missing and highly uncertain, tends to drive the selection towards a simple model like the Schaefer Model that can be applied most widely to the available data [18]. Secondly, given the long-time frames being explored, it is unlikely that more complex models would perform significantly better at projecting the possible biomass over periods of decades. Thirdly, it is unlikely that aggregating results from a variety of models of variable type and quality will produce more credible results (again, especially over the long-time frames). Fourthly, applying a more complex model can often give the illusion of a level understanding about the system that is greater than that in reality. Using a transparently simple model forces the modeller and other observers to acknowledge the inherent uncertainty in data and models.

The definition of a fish unit, although useful from a managerial and data availability perspective, is somewhat artificial. One difficulty arises when several species of the same family exist within the one fish unit. In this situation the Schaefer Model is being applied collectively to several separate populations, each of which probably have different Schaefer parameters. A related problem is the situation when the same population of the same species is sometimes caught in several fisheries and even jurisdictions. In this case, the application of the Schaefer Model to separate parts of the same population will have different dynamics than if the model was applied to the entire population.

In both cases, the current solution is to approximate the dynamics by determining *effective* Schaefer parameters (which are even less loosely connected to biological and ecological parameters) that result in a reasonable aggregate picture. In the future, there is the possibility to overcome the problems by

[18] Although, the ASFF framework can easily accommodate more detailed models in the future if deemed necessary.

having flexibility in the definition of the fish unit so that it may also represent individual species and cross fishery boundaries.

## *The availability and reliability of data*

There are two over-riding data sets that provide constraints that are related, namely nationally aggregated data (such as the ABS (2001)/ABARE (2000) and FAO (2000a) Australia production totals) and actual catch or production data for individual fisheries (or fish units). An important element of the calibration process is to construct the full historical dataset such that actual fish unit production is reproduced and the aggregation of this data sums to the national figures. A further check or constraint is provided by considering the final balance between nationally aggregated provision (through domestic production and imports) and requirements (for domestic consumption and exports). It is important to note that complete agreement with all data sets or consistency checks may not be possible due to errors in one or more data sets.

As discussed above, an important aspect of producing useful scenarios of the future is ensuring that the historical datasets are reliable. It has been explained how uncertainty in constructing these historical datasets is minimised, by gathering data from a variety of sources and making the datasets self-consistent and cross-validated by ultimately fitted into the structured data framework. However, despite this process, significant uncertainty can still exist.

**The virgin biomass of fish units**

One of the key issues in fisheries is the capacity of the fisheries to provide fish in the present and the future. One of the main indicators of this capacity is the actual historical fish unit production. However, even with complete and accurate catch data, this can be misleading as it depends on the historical desirability of the species (was it in demand?), environmental variability (are there environmental reasons for changing capacity?) and possible system disturbance (has human or ecological disturbance shifted the capacity?).

Given the centrality of fish unit production to future scenarios, the effect of uncertainty in past production capacity is of vital interest. In the model, annual production depends on both Schaefer parameters, the virgin biomass and growth parameter. To reduce complexity, only the variation of the virgin biomass has been considered thus far.

This issue was explored in the initial stages of analysing the nation's wild fisheries stocks (fish, crustaceans and molluscs) and results presented in the publication, *Exploring Options for the Long Term Future of Australia's Fisheries Using a Scenario Modelling Approach* (Lowe *et al*, 2001). In order to observe the influence of virgin biomass on future production, two histories were explored. One is a conservative estimate of the virgin biomass, that uses the lowest possible virgin biomass for each fish unit that is consistent with the known historical catches (the low-estimate history) and the other is a best-knowledge estimate of each fish unit virgin biomass, based on current information (the best-estimate history). On the basis of these two histories, scenarios exploring future possibilities were developed and these are explored in Chapter Six - .

**Missing production data, particularly 1941–1961**

Historical data on the production of individual fish units was available from a combination of several sources for the period of about 1965 onwards. For some selected fish units data were available over a more extended period, such as southern bluefin tuna back to 1950. Where occasional data gaps were present simple linear interrelation was used to fill these. This simple procedure was sufficient given the trends in existing data and mindful of the purposes of the study, which is not concerned with detailed management of individual fisheries.

The data coverage over the historical period is generally appropriate for this study since the lifetime of the majority of fish species considered is shorter than the 35–40 year period of the historical data. (More generally, this is an important feature of the stocks and flows approach since the creation and/or deletion of a physical stock over the historical period determines the age structure or profile of the stock at the beginning of the scenario period.) In the case of this fisheries study, the historical data determines the parameters of the Schaefer model, namely the virgin biomass and growth rate.

In addition, the generally low level of commercial and recreational catch in the early part of the historical calibration period (1941 to 1961) also minimises the effects of any early fish production on future production possibilities for the scenario period starting in 2001. In particular, during World War II a relatively negligible level of inland, estuarine and coastal fisheries was maintained, and commercial marine fishing was severely restricted at the beginning of the calibration period.

However, the stocks and flows approach requires a complete set of historical data back to 1941, and that this data is internally consistent within the physical accounting framework. Therefore, production levels for all fish units were smoothly extrapolated back to near-zero levels in 1941 by assuming an exponential growth in the level of production. This amounts to an assumption that the lack of fishing during the war had allowed all of the stocks to recover to maximum amounts due to reduced exploitation. Further work on providing more realistic estimates of the early production rates is outlined in Chapter Seven - .

**Conflicting data definitions for national totals**

Some uncertainty arises from differences in data definitions, specifically whether volumes are recorded as live weight or edible/product weight. The ABS (2001), FRDC (1999) and ABARE (2000) have generally historically recorded product weight while the FAO data has been recorded as live weight. This difference particularly shows up in comparison of import and export volumes.

This is a classic calibration issue, and highlights the issue of confidence in different and possibly conflicting data sets. In this case, it appears that the FAO data is derived from Australian agency data and uses a conversion factor for estimating the live weight. It is possible this conversion factor could be regionally based and may contain inaccuracies for Australian species and fish preparation processes e.g., the difference between gutted fin fish such as tuna or coral trout and a filleted fin fish.

Early attempts were made to derive a set of calibration coefficients by comparing live weight from product weights using the historical FAO (2000a,b) data and ABS data. Proportions of product weight to live weight varied historically and for different fish types and species, and for import and export volumes. For example, for exports this fraction had been assumed to be 40%, 60% and 20% for fish, crustaceans and molluscs respectively. For imports, this fraction had been assumed to be 45%, 40% and 40% for fish, crustaceans and molluscs respectively. The difference might be argued from the point of view of the different product types in exports and imports. This detailed process did not lead to satisfactory balance over the history period of the aggregated provision (domestic production, including aquaculture, plus imports) against requirements (domestic consumption and exports).

In contrast, adopting a single conversion factor (of 2/3 of live weight) for all fish units and for both exports and imports resulted in quite satisfactory balance of aggregated provision and requirement (see below), as well as producing import and export volumes from the FAO that compare favourably with the Australian agency data.

For the sake of simplicity, we have assumed steady proportions of product weight to live weight into the future based on this historical comparison.

**Offset between FAO total production and ASFF**

The graph of Figure 4.1 shows the raw ASFF simulation compared with the FAO data on Australian total wild capture production. A fairly consistent offset is evident, with the FAO data greater than the raw ASFF numbers by 10,000 to 36,000 tonnes. Almost without exception the larger discrepancies occur prior to 1965 where a simple exponential function was used to project production back to 1946, as described above. After 1965 the difference can be attributed to the ASFF simulation modelling a finite number of fisheries units, which accounts for the majority (but not all) of the total fishery resources.

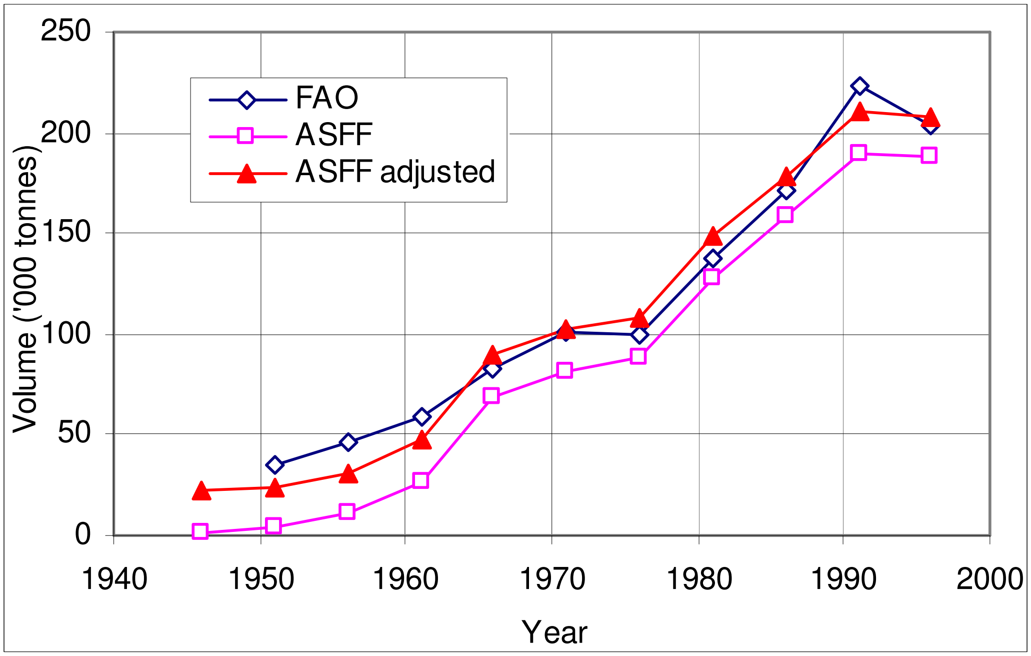


**Figure 4.1** Comparing the ASFF and FAO historical data

Therefore, a simple method of offsetting the ASFF data by the average difference of 20,500 tonnes was used to bring the ASFF data into line with current knowledge making the deviation range within ±12,000 tonnes. While this is indeed a relatively crude method, it suffices for the level of fidelity currently required in the modelling.

**Provision-requirement balance**

Having derived historical data that matches individual fish unit catch and nationally aggregated total production, a final "top-down" or system check can be made. If waste or other losses are negligible, then the simple expression of mass balance embedded in the physical accounting of ASFF implies that the nationally aggregated provision (through domestic production, including aquaculture and imports) should equal total requirement (for domestic consumption and exports).

The numerical difference between the national provision and requirement is graphed in Figure 4.2. The difference is not extended to the early historical period where the crude exponential approximation was used. While positive values are physically plausible and could be ascribed to waste or losses that have not been recorded or otherwise accounted, they may also indicate data errors. Negative values are not physically reasonable, since consumption and exports cannot have been greater than production and imports, and therefore indicate the presence of errors in the data or accounting system.

It is important to place the implications of this historical discrepancy between provision and requirements in the context of the magnitude of total provision or total requirement (see Figure 4.3). Either quantity is of the order of 150–200 and 450–500 kt in about 1960 and 2000 respectively. The discrepancy is therefore less than ±10% of the provision and requirement flows. This indicates that the discrepancy can reasonably be attributed to small errors in to two large numbers that are being subtracted.

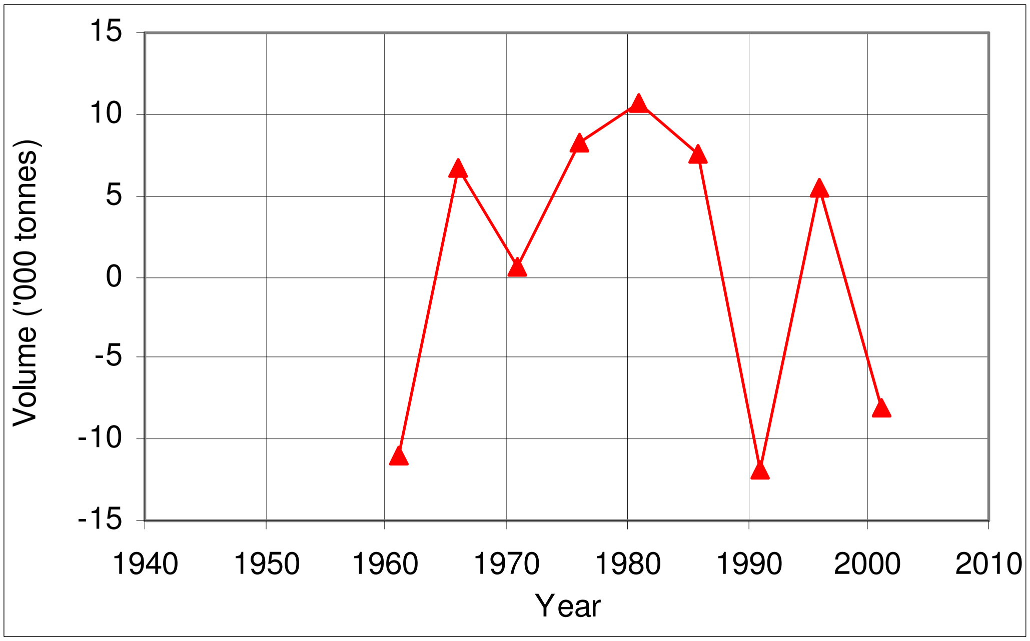


**Figure 4.2** Difference between nationally aggregated provision and requirement (i.e., total provision less total requirement).

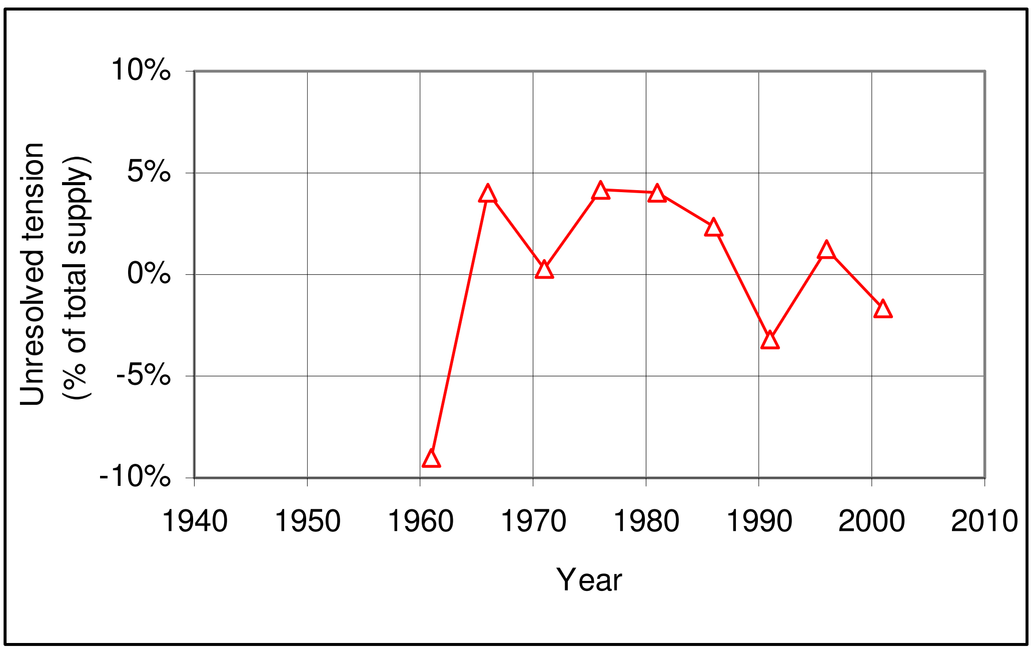


**Figure 4.3** Difference between nationally aggregated provision and requirement as a percentage of total provision (or requirement).

There is also a further possibility for accounting for the apparent discrepancy which relates to the stock and flow concept. Implicit in the simple accounting relationship in ASFF described earlier (pp. 40-42) is the assumption that flows of fish supplied to Australia are not stored for consumption (or exported) in a later time period. Given the perishable nature of seafood and the value attached to fresh seafood, this is a reasonable assumption. Nevertheless, it is technically possible that imports of fish used for animal and aquaculture feed are stockpiled. Positive values in Figure 4.2 would then represent additions to such a stock, and negative values draw-down of the stock. This possibility is plausible on the basis of the additions and deletions being a relatively small proportion (less than ±10%) of the flow of fish for feed.

## References


ABARE (2000) Australian Bureau of Agricultural and Resource Economics, Australian Fisheries Statistics 1999.

ABS (2001) Australian Bureau of Statistics, Australia Now.

BRS (2000) Bureau of Rural Sciences, Fishery Status Reports 1999.

FAO (2000a) FAO Fisheries Department, Fishery Information, Data and Statistics Unit, FISHSTAT Plus. Universal software for fishery statistical time series. Version 2.3.

FAO (2000b) FAO Fisheries Department, The state of world fisheries and aquaculture 2000.

FAO (2002) FAOSTAT: FAO online Statistical Databases. Accessed at webpage www.fao.org.

FRDC (1999) Fisheries Research and Development Corporation, Fishery Snapshot.

Kearney, R. E., B. Foran, F. Poldy and D. Lowe (2003). Modelling Australia's Fisheries to 2050: Policy and Management Implications, Fisheries Research and Development Corporation.

Lowe, D. B., F. Poldy, B. Foran and R. E. Kearney (2001). Exploring Options for the Long Term Future of Australia's Fisheries Using a Scenario Modelling Approach. MODSIM 2001 Congress, Australian National University, Canberra, ACT, Australia.

Pella, J. J. and P. K. Thomlinson (1969). "A generalised stock production model." *Bulletin Inter-American Tropical Tuna Commission* Vol 13, pp. 419-496.

Schaefer M.B. (1954) Some aspects of the dynamics of populations important to the management of commercial marine fisheries, *Bulletin Inter-American Tropical Tuna Commission*, Vol 1, p26-56.

Schaefer M.B. (1957) A study of the dynamics of the fishery for yelowfin tuna in the eastern tropical Pacific Ocean, *Bulletin Inter-American Tropical Tuna Commission*, Vol 2, p247-285.

Robbert Associates (2003) http://www.robbert.ca/ Robbert Associates Ltd., 338 Somerset Street West,Third Floor, Ottawa, Ontario, Canada, K2P 0J9

Walters, C. J. (1969). "A generalized computer simulation model for fish studies." Trans. of the American Fisheries Society 98: 502-572.

# Chapter Five - Drivers and Uncertainties of the Future

## Chapter Summary

The focus in this study has been to establish an understanding of the magnitude of challenges and opportunities conferred by the key high-level drivers and uncertainties that are most closely related to fishery management. In this sense, the major flows of the fisheries sector in Australia are domestic consumption, domestic production, exports and imports. Each of the major flows (or their components) of fisheries products are plotted and described in terms of historical trends and feasible forward projections.

Domestic consumption is the simple product of population and per capita consumption. The former is widely accepted as the probable path (or something near it) of future population growth. The latter is based upon simple extrapolation of historical trends reaching a limit based upon international comparisons and rational argument. Domestic consumption exhibits linearly increasing growth until 2020 when the rate of growth begins to decline and consumption beginning to level off in line with the size of the population by 2050.

Domestic production is mostly a combination of commercial wild capture and aquaculture production. Aquaculture production is assumed to increase at the same rate of the last decade until quadruple current production is achieved (around 2045). Commercial wild capture production has been modelled within ASFF and the effect of uncertainty surrounding the estimate of virgin biomass is examined.

Three broadly different fishing management regimes were derived for the management of commercial wild capture production. The *continuous* fishing regime attempts to maintain the catch rate at the average level of the previous decade. A *precautionary* fishing regime modifies this by reducing the catch rate when the biomass has fallen to a critical level. A more proactive management style is explored in the *optimal* fishing regime where catches are adjusted to achieve the theoretical maximum sustainable yield over the long-term.

Import volumes are speculative linear projections based upon historical trends and the reaching of a limit of double current volumes (which occurs around 2035). Exports are assumed to be maintained at contemporary volumes in recognition of current physical and management constraints, while still allowing for increased earnings. Exports and imports are dependent on many factors that are arguably beyond control by the fisheries industry and management so these simple settings are starting points to explore their impact.

Collectively, these settings for the major drivers create three preliminary scenarios that are examined in the following chapter.

## Setting the drivers: consumption, production, export and import

The focal issue under investigation in this report is the capacity of the fisheries sector of the Australian economy to provide fisheries resources into the future. The scenarios were developed in order to explore the implications (and feasibility) of different future provision and requirement situations and how key indicators evolve with time.

The basic equations governing the flow of fisheries product through the Australian economy can be represented simply by

$$\text{Domestic Consumption} = \text{Domestic Production} - \text{Exports} + \text{Imports}$$

$$\text{Domestic Production} = \text{Wild Capture Production} + \text{Farm Production}$$

Therefore, the main drivers (and their components) of the Australian fisheries sector are:

- Domestic Consumption
  - Domestic population
  - Per Domestic consumption
- The production capacity of the wild capture sector
  - Commerical
  - Recreational
- The production capacity of the aquaculture sector
- Exports
- Imports

## Domestic Consumption

Domestic consumption has been and still is a large driver of domestic production. About 80% of domestic production supplied domestic markets in the early 1960s, falling to around 40-60% since the 1970s (FAO, 2002). Total human consumption can be derived from two factors: population and per capita consumption.

### Population

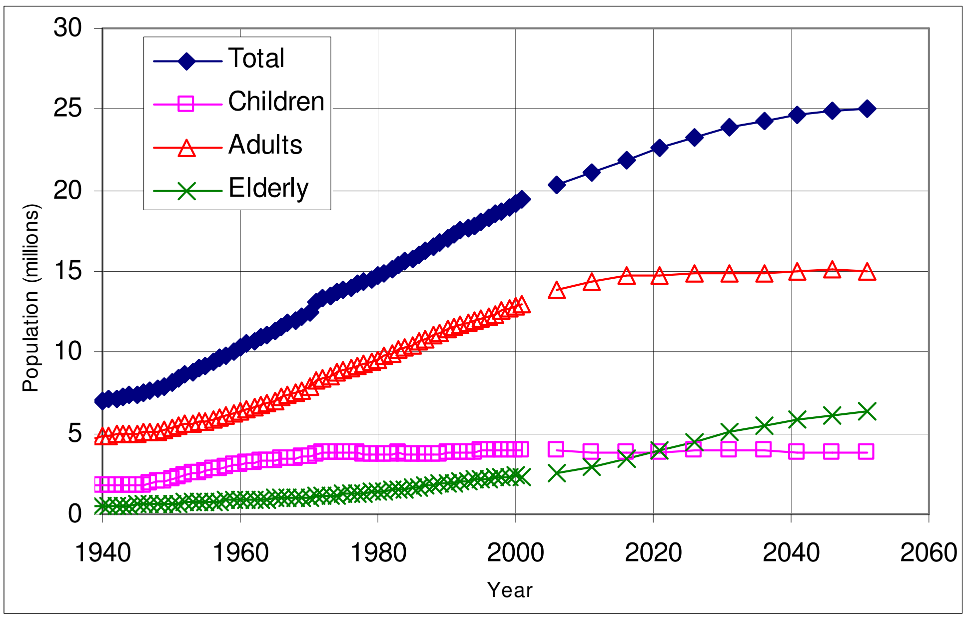


**Figure 5.1** Population of various demographic segments. Source: (Foran, 2002)

The baseline population projection used in these scenarios is reproduced in Figure 5.1. This projection results from a constant net immigration of 70,000 per annum. This is the base-case scenario for the population report (Foran 2002), and a generally accepted "middle road" for population increase. The main features of interest under this scenario are:

- Population growth rates are already in decline.
- The total population reaches 25 million by 2050 and is beginning to stabilise.

Interesting demographic details include:

- Adults (15-64) stabilise at 15 million by 2020
- Children (0-14) have already become stable at 4 million (with a slight future decline)
- Elderly (65-120) rising rapidly from 2.5 million to over 6 million by 2050
- Steady increase in the proportion of females

Currently, the finer demographic details of the strong aging and slight feminisation of the Australian population is not included in the modelling. However, it can be argued that this effect is partially taken into account by considering the overall trend in per capita consumption.

**Population growth**

Within the scenarios, a standard population growth model for Australia is utilised (Poldy 2000, Foran, 2002). In this standard projection, a constant net immigration of 70,000 per year is assumed. In addition to local births and deaths, this results in a steadily increasing population that reaches a total of 25 million by 2051 and is beginning to plateau (Figure 5.1). As well as the trends in total population, demographic changes are of particular interest.

**Table 5.1** Population of different demographic segments at five-yearly intervals

| Year | Total | Males | Females | children (0-14) | adults (15-64) | elderly (65-100) |
|---|---|---|---|---|---|---|
| 1946 | 7.5 | 3.8 | 3.7 | 1.9 | 5.0 | 0.6 |
| 1951 | 8.4 | 4.2 | 4.2 | 2.3 | 5.4 | 0.7 |
| 1956 | 9.5 | 4.8 | 4.7 | 2.8 | 6.0 | 0.8 |
| 1961 | 10.7 | 5.4 | 5.3 | 3.2 | 6.5 | 0.9 |
| 1966 | 11.8 | 5.9 | 5.8 | 3.5 | 7.3 | 1.0 |
| 1971 | 13.1 | 6.6 | 6.5 | 3.8 | 8.2 | 1.1 |
| 1976 | 14.0 | 7.0 | 7.0 | 3.8 | 8.9 | 1.2 |
| 1981 | 14.9 | 7.4 | 7.5 | 3.7 | 9.7 | 1.5 |
| 1986 | 16.0 | 8.0 | 8.0 | 3.7 | 10.6 | 1.7 |
| 1991 | 17.3 | 8.6 | 8.7 | 3.9 | 11.5 | 2.0 |
| 1996 | 18.4 | 9.1 | 9.3 | 4.0 | 12.1 | 2.2 |
| 2001 | 19.4 | 9.6 | 9.8 | 4.0 | 13.0 | 2.3 |
| | | | | | | |
| 2006 | 20.3 | 10.0 | 10.3 | 3.9 | 13.8 | 2.5 |
| 2011 | 21.1 | 10.3 | 10.8 | 3.8 | 14.4 | 2.9 |
| 2016 | 21.9 | 10.7 | 11.2 | 3.8 | 14.7 | 3.4 |
| 2021 | 22.6 | 11.0 | 11.6 | 3.8 | 14.8 | 3.9 |
| 2026 | 23.3 | 11.3 | 12.0 | 3.9 | 14.9 | 4.5 |
| 2031 | 23.9 | 11.5 | 12.3 | 3.9 | 14.9 | 5.1 |
| 2036 | 24.3 | 11.7 | 12.6 | 3.9 | 14.9 | 5.5 |
| 2041 | 24.7 | 11.8 | 12.8 | 3.8 | 15.0 | 5.9 |
| 2046 | 24.9 | 12.0 | 13.0 | 3.8 | 15.1 | 6.1 |
| 2051 | 25.1 | 12.0 | 13.1 | 3.8 | 15.0 | 6.3 |

The population of females and males has been roughly equal in the past, although the ratio of females to males has seen to be steadily increasing from parity (1.0) in 1976 to 1.1 in 2051 (Table 5.1). Perhaps more interestingly, the age breakdown shows a much greater variation. The population of adults (15-64) is seen to increase slightly from current levels (13 million) to stabilise at about 15 million by 2021 while the population of children (0-14) is currently peaking at 3.9 million and will decline gradually but steadily into the future. The most dramatic change is the rapid rise in elderly from 2.3 million in 2001 to 6.3 million in 2051 (Table 5.1).

It raises a number of questions. How will consumption be impacted by …

1. the changing gender balance?
2. the changing age demographics?
3. the source of the immigrants?

These changes not only impact domestic consumption of seafood but also could have an impact on the amount of recreational fishing that is undertaken in the future.

## *Per capita consumption*

In deriving a baseline for Australian per capita consumption of seafood it is useful to consider trends in aggregate data and the associated contextual information.

The rate of any increase in seafood consumption will depend specifically on the underlying combination of drivers. At this stage, although the underlying drivers are not well understood, they can probably be ascribed to factors, such as

- Demographic changes (age, gender, culture)
- Increasing awareness of product and health benefits
- Increasing wealth

Each of these can be discussed in terms of a "story". For example, a rational explanation of the baseline scenario would be the gradual ageing of the population and moderate increase in wealth but consumption limited by the expansion of options as consumers' income grows. In the case of a situation of rapid growth in consumption, this could not arise simply from demographic changes, but probably due to an increasing awareness of the product and its health benefits through improved advertising and marketing coupled with a moderate to rapid increase in personal income.

According to FAO, ( 2002) the apparent per capita consumption of Australians has risen quite linearly from about 13kg/capita in 1960 to about 21 kg/capita in the late 1990s (Figure 5.2). Although a general increase is also reflected in ABS (2000) figures, the size of apparent per capita consumption is quite different (Figure 5.3). Furthermore, the ABS data reveal an apparently rapid jump in consumption around 1990. Two national surveys commissioned by the FRDC show a general increase in total consumption, as well as individually in fish and shellfish consumption (Table 5.2). However, they also report generally higher consumption levels than reported by the ABS.

**Table 5.2** Per capita seafood consumption

| | 1977 | 1991 |
|---|---|---|
| **Fish** | 7.80 | 9.31 |
| **Shellfish** | 2.27 | 2.74 |
| **Total** | 10.07 | 12.06 |

Source: FRDC Snapshots, 1999

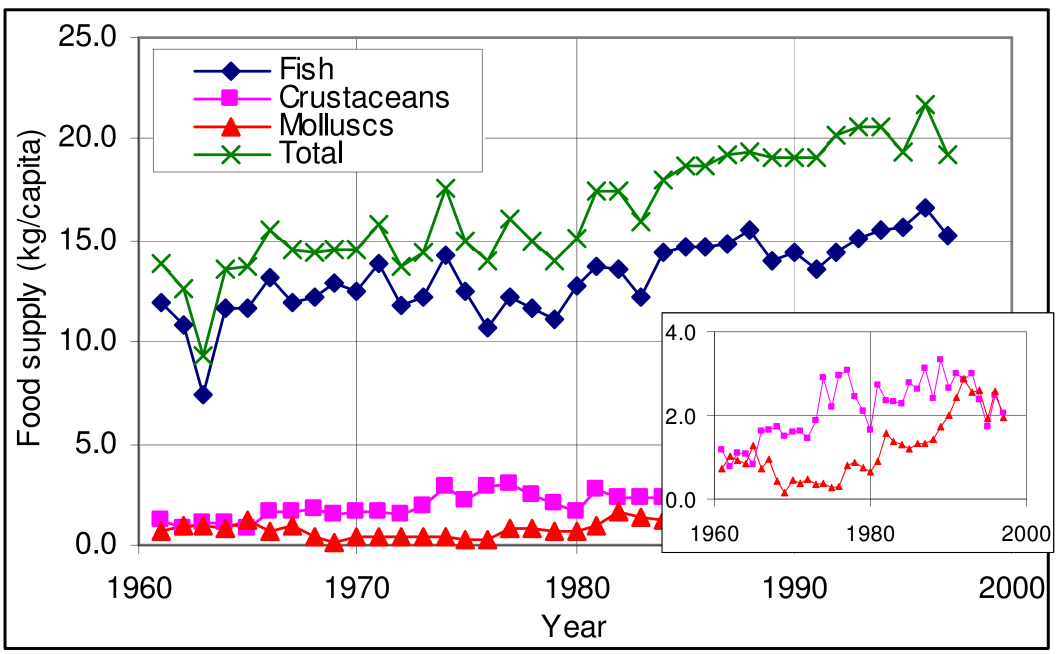


**Figure 5.2** Australian seafood per capita food supply. Source: FAO, 2002

The differences between FAO and ABS data can partly be explained by the difference in definitions. The FAO figures are based on supply of <u>live weight</u> while the ABS and FRDC (1999) figures are based on <u>edible and product weight</u>. Thus it is understandable that the FAO figures are higher than the others.

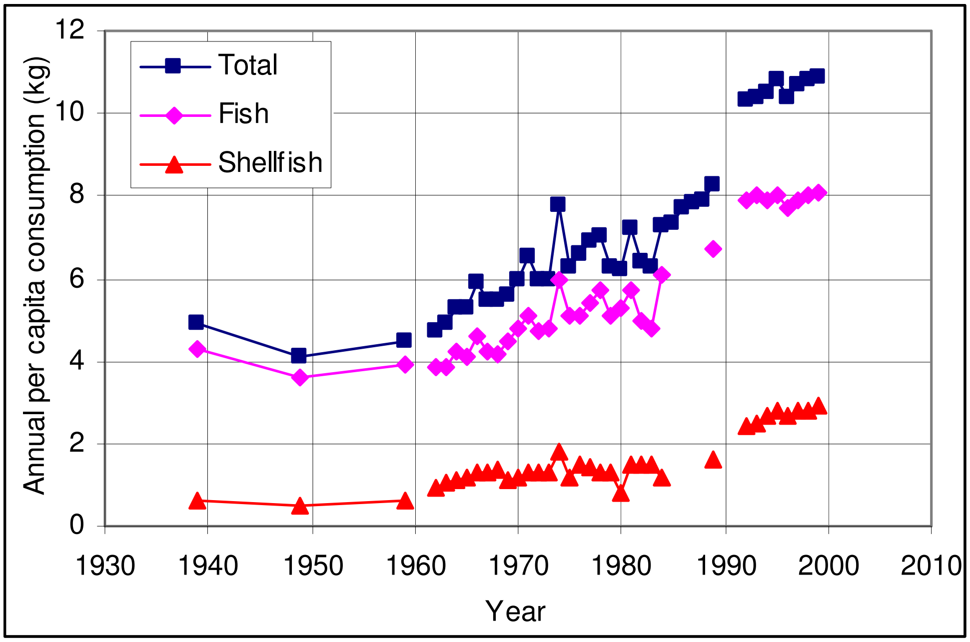


**Figure 5.3** Annual per capita consumption of fish, shellfish and total seafood according to ABS.
Source: after (ABS 2000)

The ABS figures are calculated on the basis of aggregate stocks and flows through the economy whilst the FRDC figures are based on survey data. One would thus expect the ABS figures to represent the upper limit to per capita consumption. One can only conclude that one or more errors are introduced in the assumptions underlying the calculations of the final ABS figures and/or errors, some biasing or statistical variation in the survey methodology underlying the FRDC figures.

Overall, all the data suggest a steady increase in per capita consumption of seafood products since 1960 to the present day.

**Seafood consumption in the context of total food consumption**

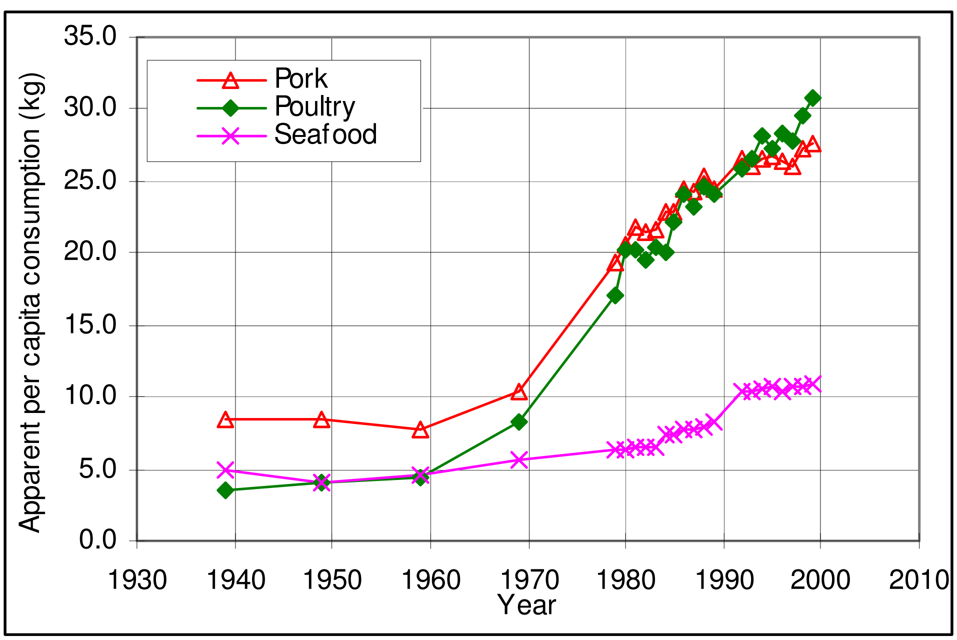


**Figure 5.4** Annual per capita consumption of selected foodstuffs according to ABS. Source: (ABS 2000)

The historical increase of seafood consumption should be seen in the context of general food consumption. Although consumption levels of poultry and seafood were similar in until 1960, they quickly diverged since, with poultry consumption currently three times the size of that of seafood (Figure 5.4). Pork consumption was approximately twice the size of that of seafood in 1970 but has also increased rapidly, almost in line with poultry. The most important reason for these trends has been the significant drop in the availability of pork and poultry brought about by intensive farming techniques.

The possible impact of rising seafood consumption is revealed in Figure 5.5. This graph shows that over a period of sixty years (and especially over the past twenty years), there appears to be a remarkably constant limit to the apparent consumption of meat of about 120kg/person/year. This is regardless of the variation of the consumption of different types of meats. Over the past twenty years, the personal consumption of cattle and sheep products (beef, veal, mutton and lamb) has steadily declined while the consumption of seafood and chicken and pig products and has steadily increased.

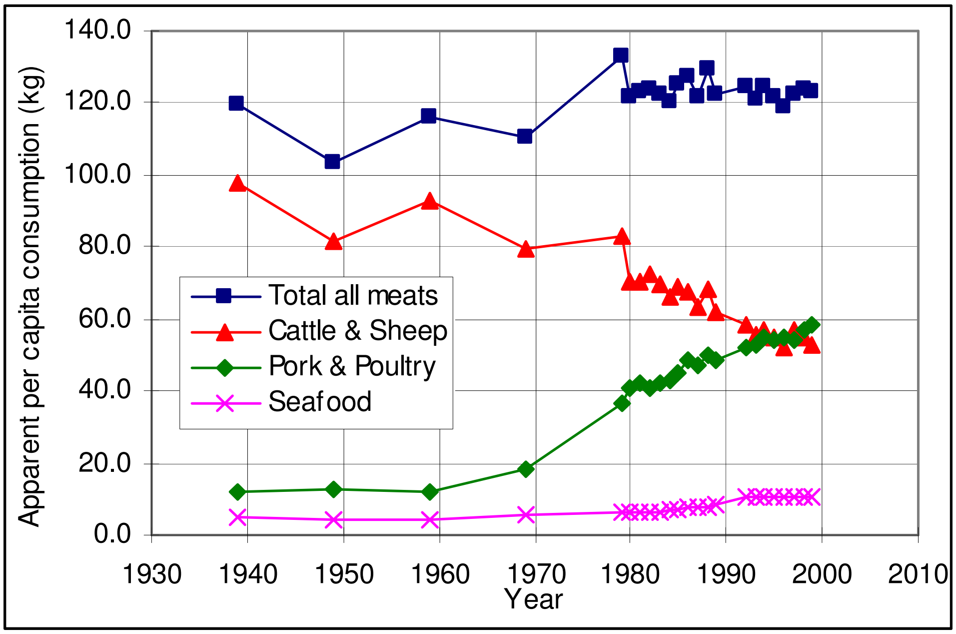


**Figure 5.5** Annual per capita consumption of foodstuffs according to ABS. Source: (ABS 2000)

Applying the proposed scenario projections of consumption to ABS figures indicates that a 25% increase in apparent consumption is equivalent to an increase of 2.7kg while a 100% increase is equivalent to an increase of about 11kg. While a 2.7kg increase in seafood consumption may not influence the consumption of other products significantly, it is more likely that an 11kg increase would require a reduction in consumption of other meats. However, even then it would only be a small change in comparison to the changes over the past twenty years in pork and poultry (a 20kg increase) and cattle and sheep (a 25 kg decrease).

**Baseline per capita seafood consumption**

As discussed previously, the underlying drivers of changing per capita consumption are not modelled in detail. However, the increasing trend can be argued from the combined effects of demographic changes (eg. age, gender, culture), increasing wealth and increasing awareness of the health benefits of seafood.

Given the slow and steady increase over the historical period, 1960 to 2000, it appears not unreasonable to firstly consider a continuation of this trend into the short to medium-term future. Although the FAO data may indicate a possible levelling off, the ABS data indicate still strong growth up to 1999. If the general increase is extrapolated into the near future, the obvious question is whether this trend will continue indefinitely.

As explained in the section "The relationship between consumption and income" in Chapter 1 (p. 8), a very short FAO analysis is suggestive of an upper limit to annual per capita seafood consumption of about 23 kg live weight with increasing income. Thus it is reasonable to set the baseline projection to be a linearly increasing consumption per capita, in line with historical trends until the upper limit of about 23 kg is reached (i.e. at about 20% above current levels). Under current trends, this would be achieved at about 2020 after which it would remain constant (Figure 5.6).

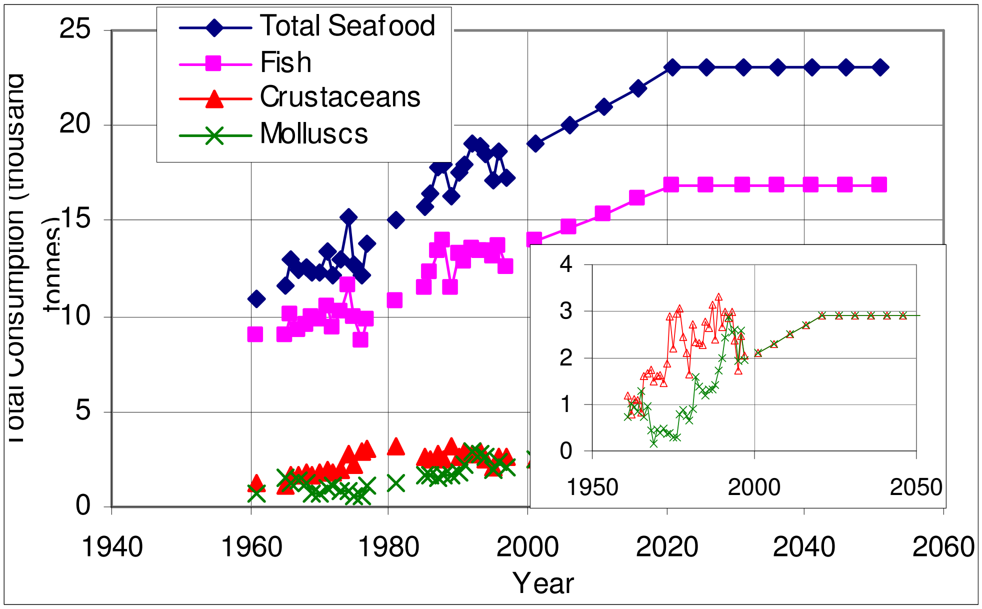


**Figure 5.6** Per capita consumption of seafood by major groups (live weight)

This projection of total seafood per capita consumption necessarily constrains the projections of the components (i.e., fish, crustaceans and molluscs). Since there are still an infinite number of possible solutions, some simplifying assumptions and decisions were made:

- Similar behaviour of the projections of each of the components as for the total
- Fish production was extrapolated first because of the relative stability of the trend
- Mollusc and crustacean consumption was assumed to increase at similar rates

This resulted in the following trends for each of the components:

- Total consumption increases from 21kg to 25 kg by 2020
- Fish consumption increases from 16.8kg to 19.2kg by 2020
- Mollusc and crustacean consumption increases from 2.1kg to 2.9kg by 2020

All consumption stabilises after 2020.

## *Total seafood consumption*

The total seafood consumption is easily derived as a product of population by per capita consumption (Figure 5.7). The main features are:

- Total consumption rising linearly from 400kt in 2000 to 560kt in 2020, slowing subsequently to reach 630kt in 2050. In other words, total consumption increases by another 50% within 40 years.
- Fish consumption rising from 300kt in 2000 to 430kt in 2020 and 480kt in 2050
- Crustacean and Mollusc consumption each rising from 40kt in 2000 to 66kt in 2020 and 73kt in 2050

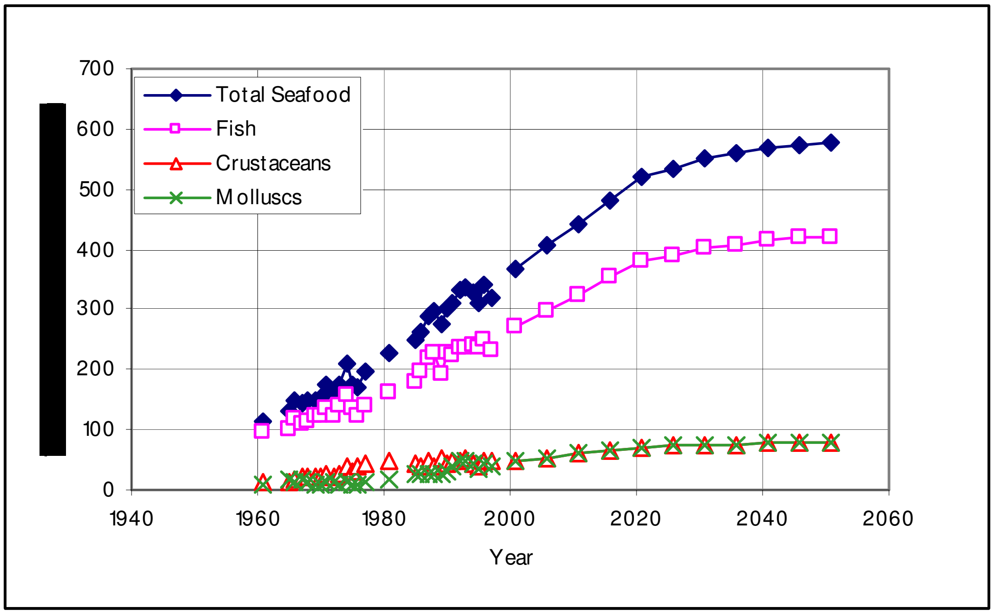


**Figure 5.7** Total seafood consumption by major groups (live weight)

The impact of the levelling of per capita consumption is clearly seen. There is an immediate and rapid decline in the growth in consumption. If this doesn't happen, and per capita consumption increased linearly indefinitely, the total consumption would exceed 750kt by 2050 (assuming base case population)! This would be a near doubling of consumption for only a 20% increase in population! And this would require a per capita consumption of 31kg/person/annum by 2050, well below the 44kg/person/annum currently eaten by Norwegians.

## *Production capacity of the wild capture sector*

The wild capture sector is mostly exploited by the commercial and the recreational segments[19] of the fisheries sector. Three primary scenarios were developed to explore the implications for the Australian fisheries industry of adopting different strategic management options. Sub-scenarios and analysis examine the influence of key uncertainties, such as domestic consumption and the virgin biomass of the fish stock.

The fisheries management regimes are distinguished primarily by the desired catch rate:

- The *continuous fishing* scenario attempts to maintain the catch rate at the average of the previous decade, irrespective of the level of fish stocks. This scenario reflects a management approach where future fish stock levels are not valued or factored into the operation of a free market.
- In the *precautionary fishing* scenario, the same catch rate as the continuous fishing scenario is attempted unless a fishery drops to 20% of its virgin biomass, at which point the catch rate is reduced to maintain the fishery at this level. This scenario engenders a degree of ecological awareness, partly as a balance between active management and the momentum of fisheries production, and partly reflecting competing economic signals (rising catch prices and increased fishing effort).
- A more proactive ecological management approach is explored in the *optimal fishing* scenario. Catch rates are adjusted to achieve the theoretical maximum sustainable yield over the long-term. Even in low stock fisheries this does not necessarily mean closing the fishery, but dynamically capping the catch rate.

These scenarios are implemented through the 'what-if' approach using ASFF by setting the value of the requested or planned catch variable (catchReq, see pp. 40-42) for the set of fish units over the

[19] The traditional segment is significant in specific areas but comparatively small in total compared with the other two segments.

scenario timeframe of 2006 to 2051 (see Figure 5.8). In principle, this variable can be set in a completely arbitrary manner and altered after observing the resultant effect on fish stocks and production.

In the case of the continuous fishing regime the planned catch is simply set at a constant value, different for each fish unit. However, for the precautionary and optimal regimes the mechanism for establishing the dynamic value of the planned catch is more involved. The method supersedes a trial-and-error approach with an iterative algorithm.

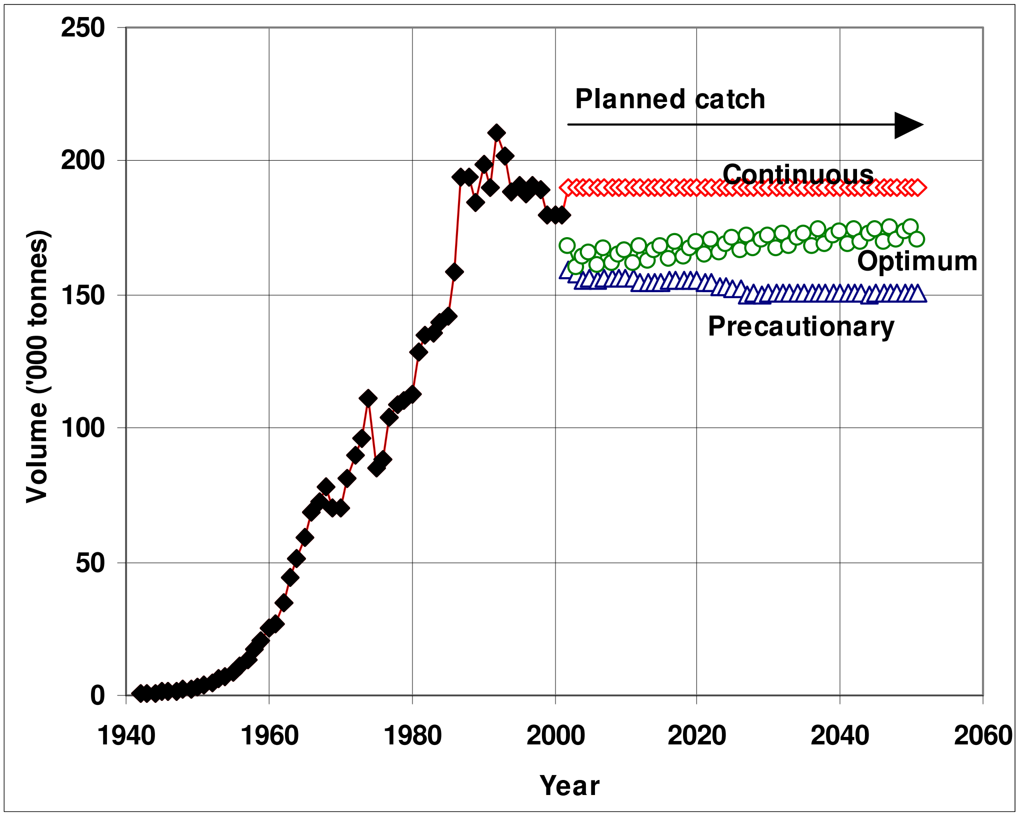


**Figure 5.8** Planned catches for the three scenarios, following the historically observed catch.

## *Continuous fishing regime*

As a starting point for exploration, a simple representation of current demand on fisheries has been utilised. The catch of the past 10 years[20] of individual fish stocks was averaged and used as an approximate indicator of current demand of these fish stocks. This is an attempt to model the broad policy of attempting to continue to achieve the same yields of the recent past. It needs to be emphasised that this is not intended to be an interpretation of current practices or even a proposal of future policy but simply a "jumping-off point" for further discussion. It simply asks the question "Can we supply the same composition of species from the same fisheries of the recent past into the future?" This represents a pessimistic view of the future.

## *Precautionary fishing regime*

This scenario assumes an attempt to continue fishing at constant historical levels unless the biomass reaches 20% of virgin biomass at which it is essentially stable. In practice this means fishing individual fish units at the average annual catch rate of the past decade but arresting any decline below

[20] In practice, the model allows for variable periods, but the period 10 years was arbitrarily used to remove annual variation.

20% of virgin biomass. The algorithm uses a type of damping function to asymptotically approach 20%.

## *Optimal fishing regime*

This scenario that assumes that individual fish units are fished to achieve the "optimum" catch rates of 80% of maximum sustainable yield (MSY). In practice this means that:

- if fish units are above 50% of virgin biomass, they are automatically fished at 80% of MSY; and
- if fish units are below 50% of virgin biomass, they are allowed to recover by halting fishing until above 50% of virgin biomass, at which point they are automatically fished at 80% of MSY. The MSY is determined from the growth rate and virgin biomass (see Chapter 3).

The resulting planned catch rate oscillates about a trend line (in Figure 5.8) due to the use of a one-year time step in the fish unit modelling. This is not sufficiently short for those fish units that have shorter life cycles of several months. This minor artefact could be addressed in future by nesting more refined models within the framework.

## *Bounding the virgin biomass of fish units*

As discussed in Chapter 4, the virgin biomass (and/or the growth parameter) for modelling each fish unit using the Schaefer model is not readily available from direct measurement. Nevertheless, analysis in Chapter 3 showed it was possible to derive some estimates of the virgin biomass and growth parameter from recorded catch data for each fish unit. In this section we present an overview of the analysis based on two estimates for the virgin biomass, namely a low-estimate and a best-estimate.

Both estimates are consistent with historical data, producing the same fish unit and aggregated production. However, future production varies markedly and depends on the fisheries management regime. To understand the variation, three scenarios were used and two are illustrated here. One of the scenarios is the continuous fishing scenario; the other two align with the precautionary and optimum scenarios, called 'slow-recovery' and 'fast-recovery' in the following. The analysis showed there is little aggregate difference in the course of fifty years between the fast-recovery and slow-recovery scenarios, so only the former will be discussed in this section.

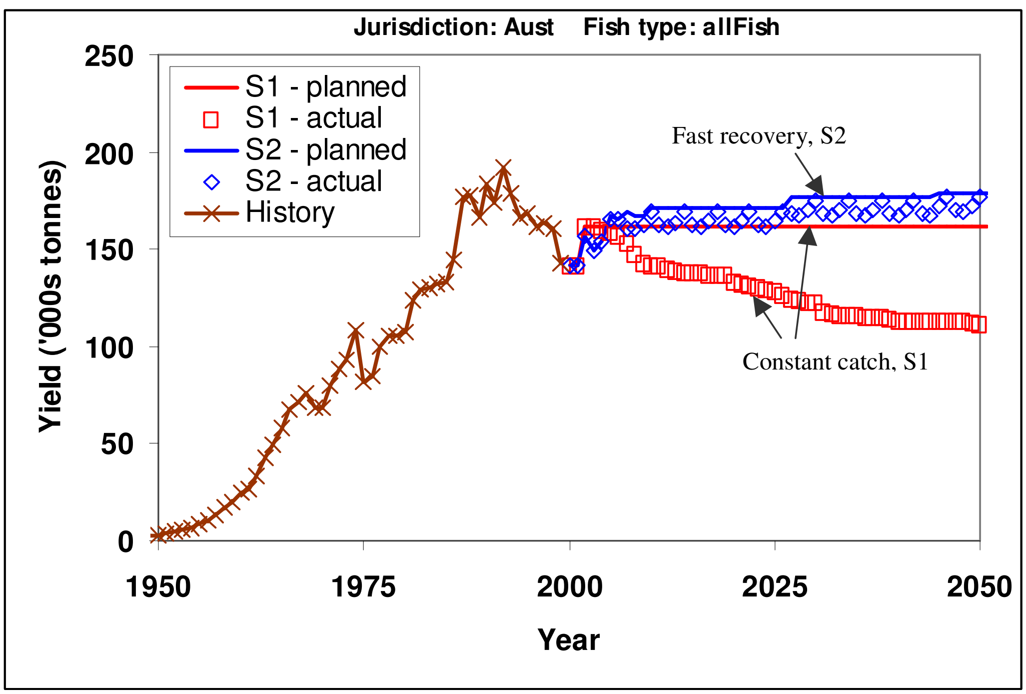


**Figure 5.9** "Best-estimates" for virgin biomass for two scenarios: Scenario 1 (constant-catch) and Scenario 2 (fast-recovery ≡ optimum fishing)

The simulations of the two future scenarios in the case of the "best-estimate" history and "low-estimate" history are shown in Figure 5.9and Figure 5.10, respectively. The historical catch is the same in both figures. Both figures show graphs of both the *planned catches* and the *actual catches* for each history. Planned catches are the targets that the scenario demands from the fisheries while the actual catches are the yields that the fisheries are able to provide.

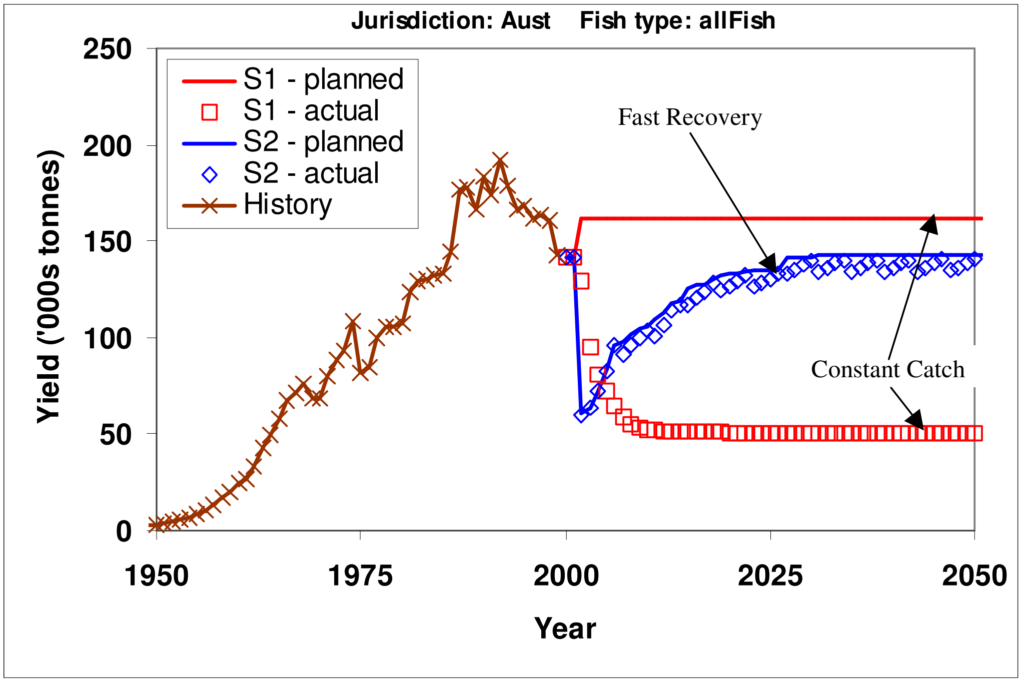


**Figure 5.10** Low-estimates for virgin biomass for two scenarios: Scenario 1 (constant-catch) and Scenario 2 (fast-recovery ≡ optimum fishing)

The "constant-catch" scenario (S1) and the "fast-recovery" scenario (S2) under the assumption of the "best-estimate history" are shown in Figure 5.9. In the "constant-catch" scenario (S1), the actual catch quickly becomes lower than the planned catch, as different fisheries become unable to provide the fish demanded of them in this constant-catch scenario. In the "fast-recovery" scenario (S2), the actual catch equals the planned catch, since by design fishing occurs at rates that ensure recovery of each and every fish unit. There is a fast increase followed by a gradual increase in production[21]. Interestingly, production is projected to increase slightly from current averages in the long term.

The "constant-catch" scenario (S1) and the "fast-recovery" scenario (S2) under the assumption of the "low-estimate history" are shown in Figure 5.10. In this case, more fisheries are at, or already beyond, the point of serious decline. Under the "constant-catch" scenario (S1), although the planned catch is the same as in the previous graph, the actual catch declines faster and further as more fisheries collapse. In the "fast-recovery" scenario (S2), the catch immediately drops, due to the closure of fisheries that are deemed to be overfished. Production then rises steadily, as fish units are allowed to be exploited once their biomass reaches acceptable levels. In the long-term, the sustainable catch reaches recent production levels.

The influence of the virgin biomass on the future scenarios is quite apparent. In terms of long-term annual yield, it has a large impact on the "constant-catch" scenario (50 thousand tonnes compared to 110 thousand tonnes at the year 2050). On the other hand, the impact is much less for the "fast-recovery" scenario (140 thousand tonnes compared to 170 thousand tonnes at the year 2050). This suggests that the "constant-catch" scenario is a relatively risky approach in the face of uncertainty in virgin biomass, with a variance in long-term annual production of over 100%. In comparison, the

[21] The small oscillation is a modelling artefact caused by short-lived (lifespan < 1year) species.

maximum variance of annual yield in 2050 caused by uncertainty in virgin biomass for the "fast-recovery" scenario is of the order of only 20%.

### *Recreational fishing*

The influence of recreational fishing has been modelled by attempting to estimate the historical catch of recreational fishers on the previously identified commercial fish stocks[22]. The catch was estimated by using general estimates of total national catch and demographic statistics in different points in the past. This catch was added to commercial catch to give the total wild catch used to determine fish unit parameters and overall biomass history.

The future influence of recreational fishing has been tied directly to the demographic trends of increasing population and participation rates. In this framework, the relationship between recreational and commercial fishing is obviously reduced to an issue of allocation, and observing the impact of possible recreational capture on the commercial sector.

### *Other mammalian predators*

Mammalian predators (eg. dolphins, porpoises, seals) are of interest because they are no longer targeted extensively by humans (with numbers apparently rising) and compete with human fisherman for some fish stocks. Recently, seals and their diet in South-East Australia was studied by Goldsworthy (2002).

Although, this is far from a comprehensive analysis of the impact of mammalian predators, it has been included as a "case study" of the impact of seals in some of the southern fisheries. The seal population is considered to potentially treble over the next 20-30 years (Goldsworthy 2002) and this projection has been included in the model.

Of course, this projection somewhat "begs the question" of other mammalian predators, other non-mammalian predators and entire ecosystem effects. Although potentially there are some benefits from constructing ecosystem models, the time, effort and expense in doing this across all fisheries is prohibitive. However, the insights of detailed models for specific fisheries may be of some benefit and could be included in the ASFF model.

## ***Production capacity of the aquaculture sector***

Currently aquaculture is a relatively young and small industry sector. At this point in time, stakeholders are unsure of the ultimate limitations to the expansion of the sector. At a 1999 workshop attended by stakeholders from industry, government and research organisations, the vision enunciated was to achieve $2.5 billion in sales by 2010 (O'Sullivan 2001). This represents an approximate quadrupling of current value. While much of this was expected to come about by increasing the value of the final product, it still requires substantial increase in the volume of production. This projected growth provides a guide to the development of scenarios.

[22] Due to the delay in receiving data from the comprehensive national survey on recreational fishing, only about two-thirds off all important recreational species are represented in the current model at this time. Thus, in its current form, the model essentially looks at the impact of recreational fishing on the commercial sector, rather than a comprehensive view of all fishing.

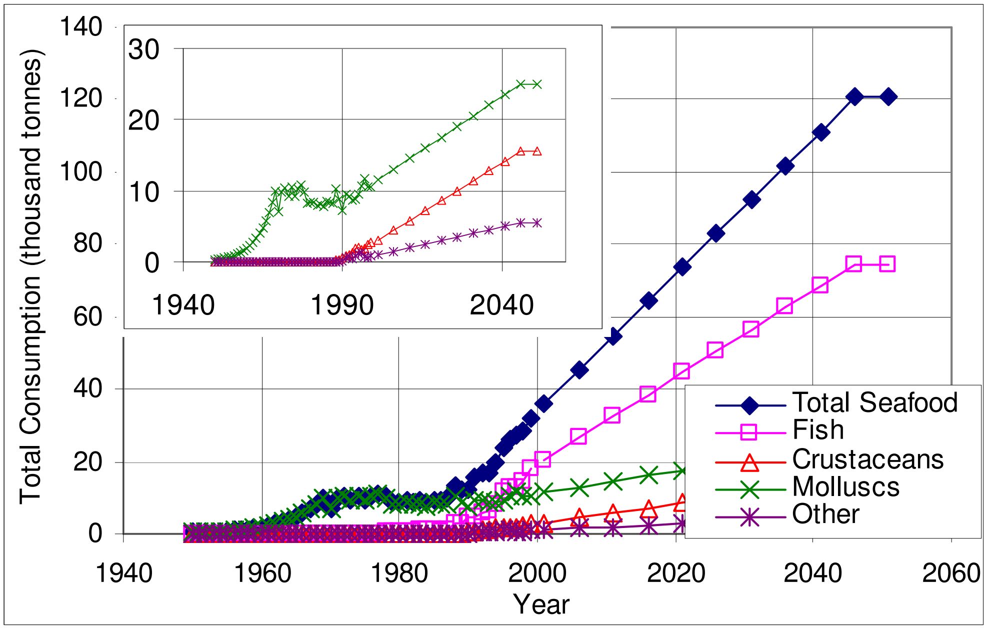


**Figure 5.11** Aquaculture production by major groups

A scenario of large and rapid aquaculture production has been assumed in line with recent history. Over the last decade, total aquaculture production has increased steadily from 12kt in 1989 to 32kt in 1999. Simple linear extrapolation results in at least tripling production to 120kt well before 2050. The scenario assumes production stabilises at this level (Figure 5.11).

Production of the components are assumed to exhibit the same pattern of increase from 1999 to 2050:

- Fish increases from 18,000 tonnes to 75,000 tonnes
- Crustacean increases from 2,800 tonnes to 15,600 tonnes
- Mollusc increases from 10,500 tonnes to 25,000 tonnes
- Other production increases from 900 tonnes to 5,500 tonnes

Thus this scenario assumes:

- Fish to make up the bulk of future production (continuously over 50%)
- A relatively moderate increase in mollusc production
- A relatively large increase in crustacean production

Obviously this scenario is speculative. Both the total production and the mix of the components presented here are one combination of an infinite set. One possible factor for further consideration is the fact that a large component of the recent increase in total production has been fish, and most of that being Atlantic Salmon and Southern Bluefin Tuna. It is debatable whether this can continue into the future, and if not, which fish species could make up the difference.

## *Exports and Imports*

The volume of exports is assumed to be maintained at approximately contemporary levels for all types of seafood. Total seafood exported is held constant at 100 kt live-weight per annum, constituted from 40 kt of finfish, 37 kt of crustaceans, and 23 kt of molluscs.

As Figure 5.12 shows this assumption is a considerable departure from recent trends. The basis for constructing a scenario of constant exports is that the high value species that largely constitute Australian exports are strongly managed to be sustainable (e.g., rock lobster) or are already highly exploited (e.g., southern bluefin tuna) and therefore further increase in volume is constrained. Commensurately, the industry has expressed a strong sentiment that export volumes be stabilised while seeking increased earnings through prices for products of higher value. In contrast to the constant volume assumption, a simple linear extrapolation of the historical trend would see total seafood export volume roughly double by about 2035 to 190—200 kt/yr, and might be considered overly optimistic.

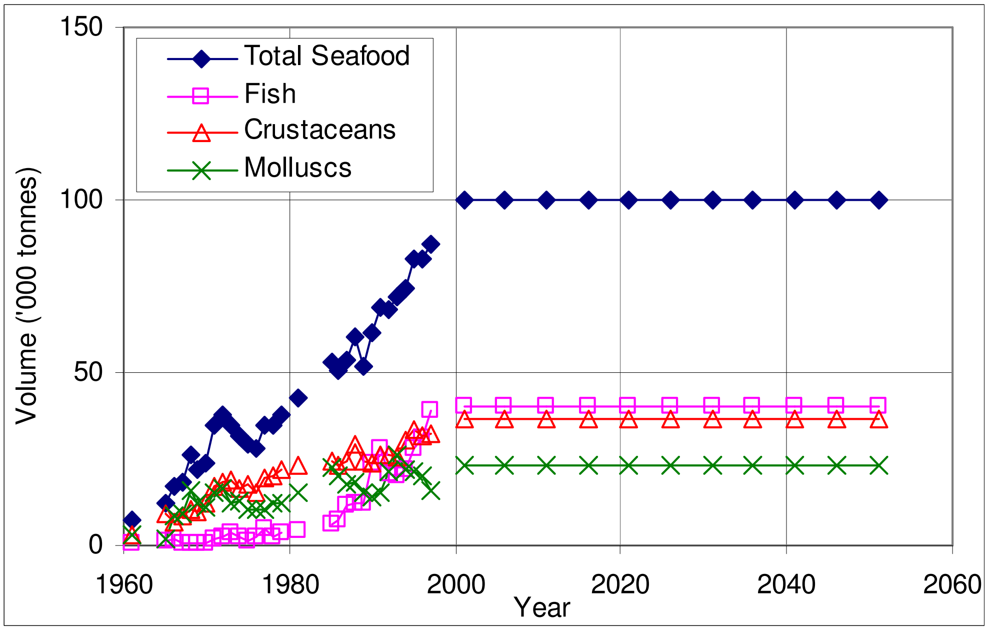


**Figure 5.12** Exports by main groups (live weight)

In the case of imports (Figure 5.13), although they show signs of non-linear increase in the past, they are assumed to extrapolate linearly until approximately double present production is achieved. This occurs at about 2035. Under this assumption, imports are projected to increase from 220kt in 2000 to 415kt by 2035 and stabilised afterwards:

- Fish imports increase from 160kt in 2000 to 300kt by 2035
- Crustaceans and Molluscs both increase from approximately 31kt in 2000 to approximately 57kt by 2035

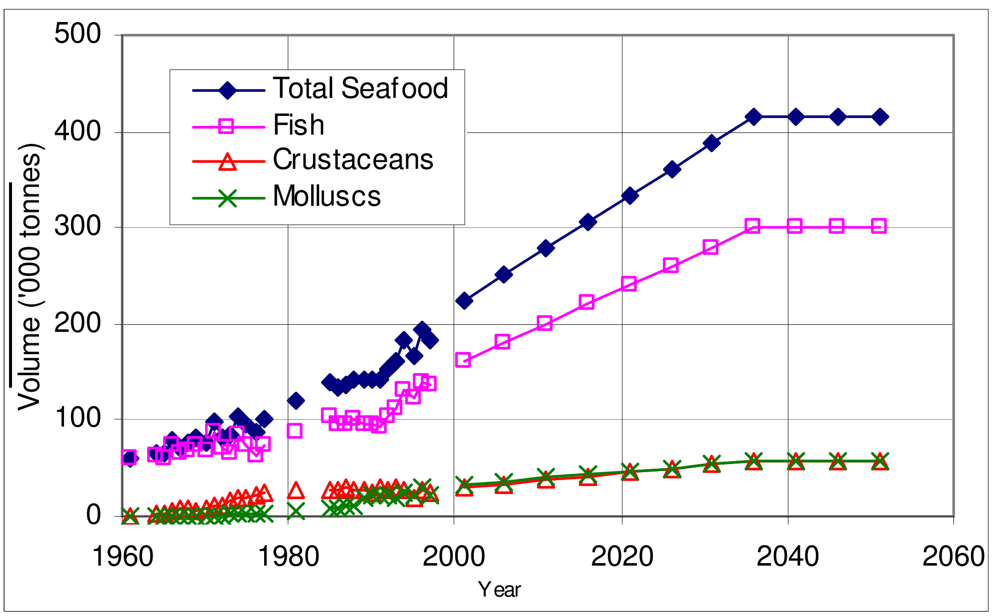


**Figure 5.13** Imports by main groups (live weight)

## References

ABS (2000) Apparent Consumption of Foodstuffs 4306.0.

ABS (2001) Australian Bureau of Statistics, Australia Now.

Foran, B. and F. Poldy (2002). Future Dilemmas: Options to 2050 for Australia's Population, Technology, Resources and Environment; Report to the Department of Immigration and Multicultural and Indigenous Affairs. Canberra, CSIRO Sustainable Ecosystems.

FAO (2002) FAOSTAT: FAO online Statistical Databases. Accessed at webpage www.fao.org.

FRDC (1999) Fisheries Research and Development Corporation, Fishery Snapshot.

Goldsworthy S.D., C. Bulman, X. He, J. Larcombe and C. Littnan (2002) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach.

Poldy, F., B. Foran and J. Conroy (2000). Future Options to 2050: Australian Stocks and Flows Framework; Report to Department of Immigration and Multicultural Affairs; 00/04. Canberra, CSIRO Sustainable Ecosystems (previously Wildlife and Ecology), Resource Futures Program, National Futures.

# Chapter Six - Lessons and Signals from the Future

## Chapter Summary

In this chapter, the assumptions for key drivers are combined and the results from the exploration of the scenarios are presented and discussed.

The three scenarios depicting different management regimes produce substantially different production profiles. In particular, the continuous fishing regime (i.e., attempting annual catch at the average of the past decade) results in continually declining production rates. In comparison, the optimum fishing regime enables marginal increases over the long-term after an initial reduction and recovery period. This results in diverging wild production with the largest difference between the two extreme scenarios of the order of 50,000 tonnes by 2050, with the optimum fishing scenario catching more fish than the continuous fishing scenario.

In addition to wild capture production, a key issue is whether the national requirement (domestic consumption plus exports) can be met by aggregate provision (domestic production, including aquaculture and imports). The sum of these flows shows that the requirement is larger than the provision and this imbalance increases until 2020, with the maximum deficit across the scenarios varying between 50,000 and 55,000 t. At this point, the situation begins to reverse as the imbalance decreases. Variations are examined in a number of the drivers such as imports and aquaculture production to produce a balance between provision and requirement flows.

Some of the key insights are

- Under historical trends (and stabilised exports), there is a near-term imbalance between the larger requirements (domestic consumption and exports) and the smaller provision (domestic production and imports).
- Per capita consumption is a very significant driver in the future fisheries sector.
- Commercial wild capture production cannot repeat the growth of the period 1960-1990 without rapid expansion into under-utilised or entirely new resources.
- Aquaculture production is likely to be a key determinant to local production and thus export capacity in the future.

## Scenario planning

A brief historical survey of world and Australian fisheries production was provided in Chapters 1 and 2. The ASFF modelling approach was described in Chapter 3. This provided the methodological approach to treating history and simulating the future. A database of Australia's fisheries was constructed, as explained in Chapter 4. This provided the grounding in reality of the projections described in Chapter 5, where the major drivers and flows in the fisheries sector were discussed. In this chapter, these possible scenarios are discussed and alternative settings explored, to provide a basic understanding of the potential range of futures for the fisheries sector.

It is worth recalling that scenarios are tools for exploring the future and a method for handling the complexity and uncertainty inherent in investigating possible future states of a large system. It is suitable for handling large and complex systems, when it is impractical, if not nigh impossible, to accurately model the entire system or explore all its possible configurations (present or future). Scenarios are used in three traditional ways (Dunlop et al, 2002):

- Choosing between alternative futures (Which of these scenarios are most desirable to us?)
- Wind-tunnel testing of strategy (Is our strategy/policy robust in these possible futures?)
- Helping to predict (Which observables may be lead indicators of unfolding scenarios?)

The ASFF approach to scenario modelling of Australia was described in Chapter 3. The ASFF approach focuses first on constructing a framework that models the physical entities and linkages of the system, the so-called "physical economy". In doing this, ASFF somewhat constrains the physical phase space (possible configurations) since these physical entities have definite values and relationships which limit current and future possible configurations. This is beneficial since it eliminates physically impossible futures and thus partly reduces the futures to be explored. With a model in place, it then allows the user to test the physical implications and feasibility of broad policy actions.

In the previous chapter, the different drivers and their different projections were discussed. In developing the fundamental scenarios, it is necessary to constrain some of the variables to allow the issues of interest to be explored in more detail without the confounding effects of variable multiple drivers. In this investigation, these *predetermined elements* that underlay all of the scenarios are the domestic population (which impacts recreational fishing and consumption), tourism, seal consumption and exports.

To produce sub-scenarios, some of the drivers are allowed to vary. In developing these scenarios and further analysis, these *levers* are the wild capture production, aquaculture production and consumption. Which levers to use and to what level these are adjusted is properly a question for stakeholders to discuss, and help further refine future scenario development.

## Commercial wild capture production scenarios

The three scenarios explore the changes in commercial wild capture production under the constraint of resource availability (Figure 6.1). The data has been simplified to show the data at five year intervals. Obviously, the history is the same for all three, only diverging some time into the future. Also shown is the planned catch for the continuous fishing scenario. Planned catch for the other scenarios are not shown since by definition they equal the realised catch.

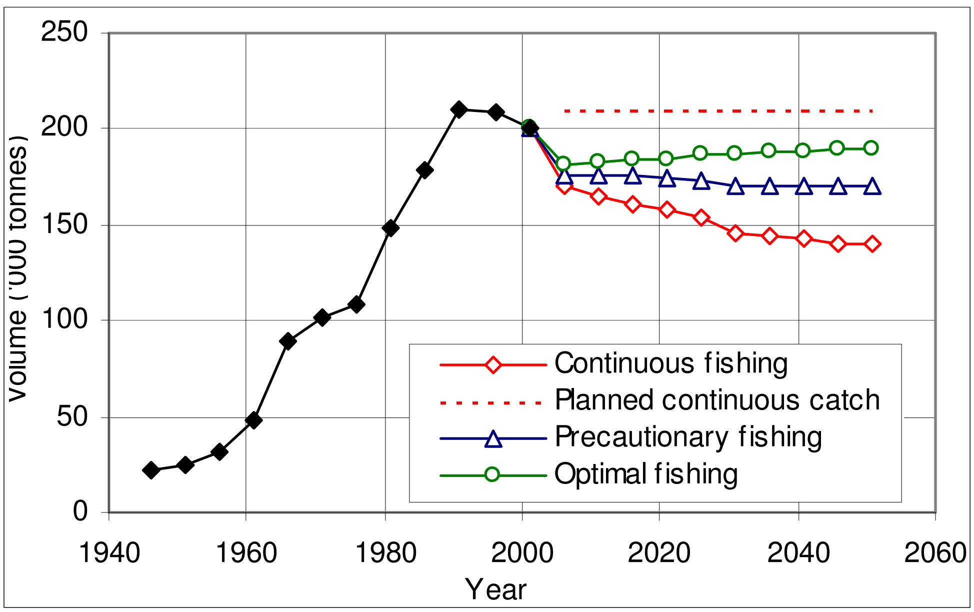


**Figure 6.1** Commercial wild capture production for the three scenarios

All the scenarios show an immediate and substantial drop over the short term of roughly 12% of the current production level. This is associated with over-fishing of those fish stocks already depleted at the end of the history period. The marginal differences between the scenarios are a result of some recovery or maintenance of the biomass during the early years of the scenario period in the optimal and precautionary fishing scenarios.

Clearly all three scenarios demonstrate different long-term trends in actual catch achieved. Continuous fishing shows a steady decline as critical fish stocks are depleted and physically cannot provide the desired yield. Precautionary fishing shows general stability with a slight decline. The most productive scenario is the optimal fishing regime, which shows a small overall increase following the initial recovery period.

Importantly, none of the three regimes are able to reproduce the peak production of the 1990's, despite the sustainability of the optimal fishing regime, and the approximate stability of precautionary fishing.

The planned catch for the continuous fishing scenario is shown to demonstrate the substantial and growing disparity between what is planned and what is caught according to the simulation. At the start of the scenario period the simulated actual catch is 40,000 t/yr less than that desired, and this deficiency expands to 70,000 t/yr by 2050. (It might also be instructive to create a scenario that attempts to continually increase the catch according to past long-term growth rates, which would presumably rapidly deplete fish stocks and correspondingly the annual catch.)

The difference between the three scenarios is shown in Figure 6.2. Defining the Precautionary Fishing scenario as the baseline, there is a steady divergence between the three scenarios. This amounts to an annual difference of 50,000 tonnes and cumulative difference of 1.7 million tonnes by 2050 between the Optimal Fishing and Continuous Fishing scenarios.

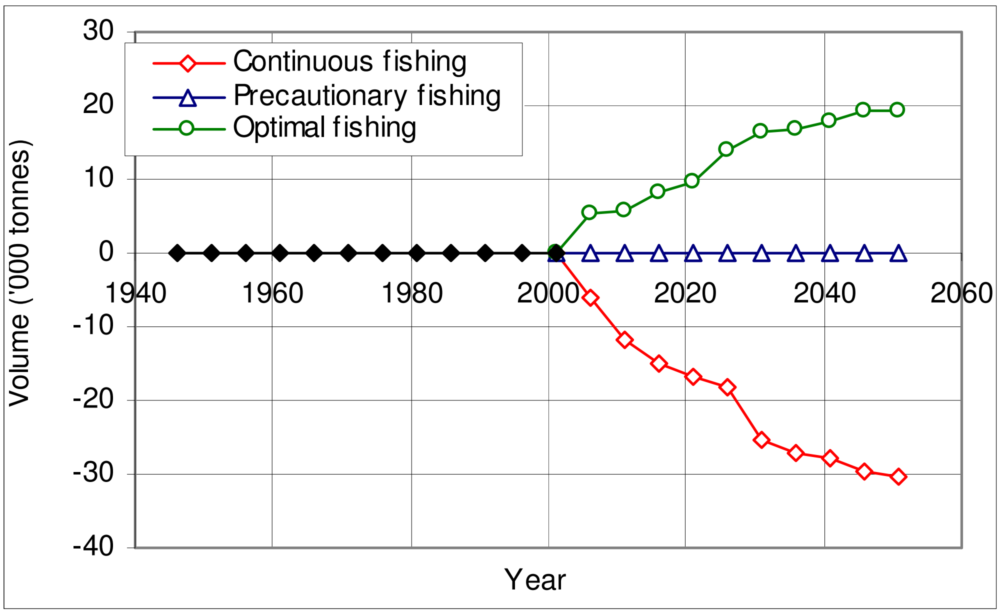


**Figure 6.2** Relative annual production between the three scenarios

## Analysis of scenario results

With the major flows quantitatively described, what remains is the analysis of the feasibility of these separate flows once they are combined into single scenarios. The most immediate concern is whether the provision and requirements match each other, and if not why not. Secondly, one can consider how such imbalances (or tensions) may be resolved by making adjustment to one or more of the flows.

### *Unresolved tension*

One method for analysing the scenarios is simply to calculate the sum of the provision and requirements and consider the result. This result represents the unresolved tensions, or the quantity that each of the scenarios is "out-of-balance". The formula is as follows:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Unresolved tension | = | Provision | | | – | Requirements | | |
| | = | Domestic Production | + | Imports | – | Domestic Consumption | – | Exports |
| | = | Wild Capture Production | | | | | | |
| | + | Aquaculture Production | + | Imports | – | Domestic Consumption | – | Exports |

Thus when the *Unresolved Tension* is positive, provision exceeds requirements and there is a surplus local quantity of fisheries product (potentially a waste). When it is negative, requirements exceed provision and the scenario suggests there is shortfall in the locally available product.

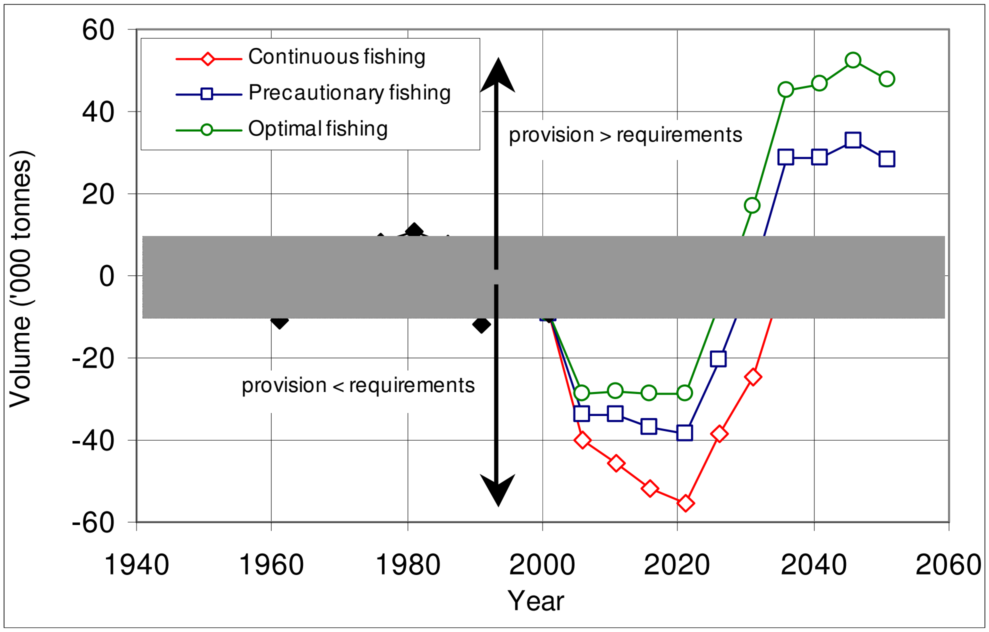


**Figure 6.3** Volume imbalance between total provision and requirement for the three scenarios. The grey band shows the degree of uncertainty in provision-requirement imbalance i.e., within the grey band provision and requirement are balanced within the uncertainty of the supporting data**.**

As the equation for unresolved tension stands, it contains a simplification regarding the use of fish as feed for animals or farmed fish. The source of such fish-feed could be either wild capture production or imports. On the basis of past relatively low volumes of fish for feed this flow has not been included. Ideally another term would be included in the equation for the unresolved tension, namely "consumption" of fish as animal or fish feed (with a negative sign as for domestic consumption). Without this term, the simplified equation represents a conservative estimate of the unresolved tension, so that any consumption of fish as feed would lead to greater negative values in Figure 6.3.

The main features of Figure 6.3 are

- Historically, the data are within margins of error, with provision (production and imports) and requirements (consumption and exports) generally balanced.
- A dramatic and increasing shortfall after the year 2000, indicating that imports and domestic production are not keeping pace with exports and domestic consumption. The continuous fishing scenario is significantly worse than the other two scenarios.
- This decline is rapidly arrested around 2020, when the rise in provision outpaces the rise in requirements.
- By 2035, the provision-requirement imbalance is reversed and there is a stabilisation with provision and requirements changing at approximately the same rate. The optimal and precautionary fishing scenarios achieve more available seafood than is required, while the continuous fishing scenario breaks even.

The explanations for this behaviour can be found in the assumptions surrounding the chosen scenarios.

- With the commercial wild production of all scenarios only slightly changing after the initial drop, the decline is caused by a basic imbalance in the assumed growth of aquaculture production and imports compared with the stabilised export volume and assumed growth in domestic consumption.

- Given the linearly increasing trends in imports and aquaculture production, the turnaround in 2020 is caused by the sudden change in growth of domestic consumption, most of which is accounted for by an assumed stabilisation of domestic per capita consumption.
- The stabilisation of the unresolved tension around 2035 is caused by the assumed stabilisation of imports. The fact that aquaculture production continues increasing for another decade after this point indicates the minimal impact of the growth in aquaculture production in these scenarios.

### *Tension resolution*

Instead of considering the unresolved tensions, adjustments have been made to one or more of the flows to force the equation to balance. There are various ways of resolving these tensions. Since the population growth is considered a given, per capita consumption is rationally described, and wild commercial production is constrained biologically within the ASFF model the obvious choices are imports, exports and aquaculture production.

To achieve a balance between total provision and requirement by changing only the level of imports requires reasonably substantial increases in imports as Figure 6.4 shows. The import volumes are roughly similar irrespective of the wild capture management regime adopted. The imports for a provision-requirement balance are at most about 10—15% higher than the baseline imports. Compared with changing other factors (such as aquaculture production, as shown below) the changes to imports are relatively minor since the absolute magnitude of imports is one of the most substantial flows, and growing. (If exports were to increase linearly at historical rates instead of staying constant as assumed the increase necessary in imports would be more demanding at about 20—30%.)

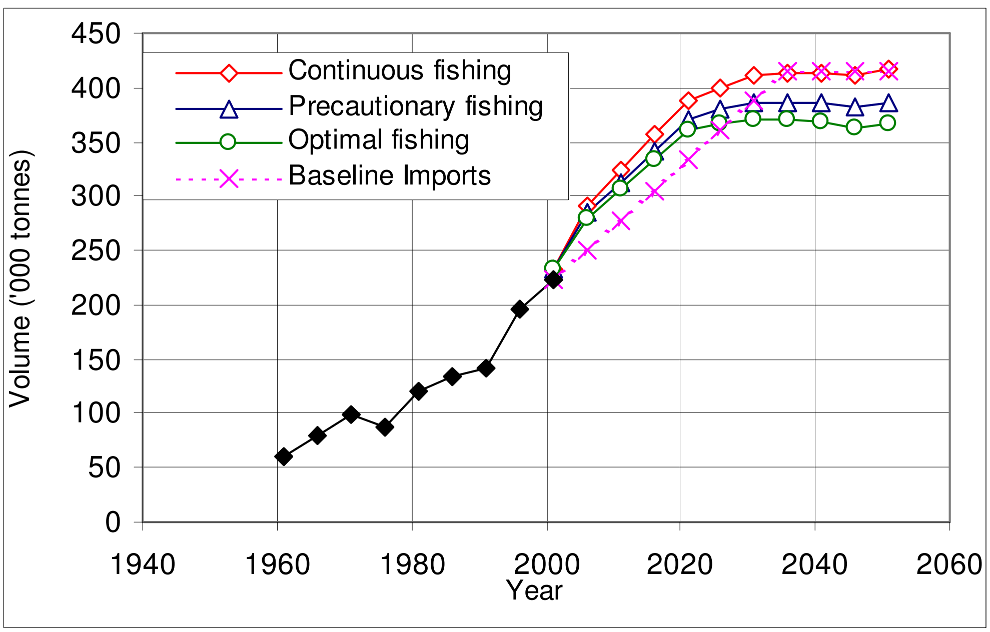


**Figure 6.4** Imports adjusted to account for previous volume imbalance

Examining the rate of change in imports shows that all the alternative scenarios for imports are consistent with past experience. For this purpose, the graph in Figure 6.5 shows the yearly increments in the import volume i.e., how much the import volume increased relative to the previous year. Zero increments mean the import volume is constant. Constant increment means import volume increases linearly. The graph shows the historical account, as well as the baseline scenario and the increments under the continuous fishing scenario that balance total provision and requirement. The growth in imports for the balanced continuous fishing scenario is approximately representative of the other scenarios.

Although the historical data varies considerably there is evidence of a consistent growth in the increment of imports. This could be linear with time as illustrated by the dotted straight line linear fit through the historical data. Alternatively, the graph illustrates the assumption of the baseline import volume reflecting an average of the previous several decades of growth in imports.

For several decades, the growth in imports to resolve the provision-requirement tension under the continuous fishing scenario is somewhat higher than that for the baseline assumption. That is, the graph for the continuous fishing scenario in Figure 6.5 is greater than the baseline scenario, until 2020. Nevertheless, simple extrapolation of the linear trend line suggests the higher growth rate in imports under the more demanding balanced sub-scenario of continuous fishing is in keeping with the historical growth rate in imports.

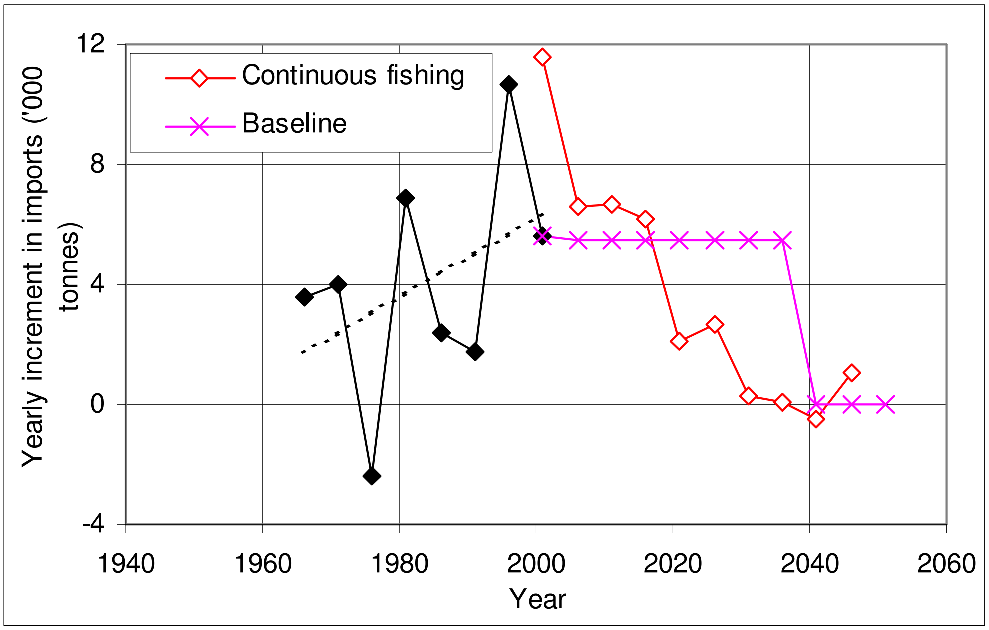


**Figure 6.5** Increments in the yearly imports, i.e., the growth rate in imports (annual rates are shown at each 5-year point). The dotted line shows the linear least-squares fit to the historical data. The curve for continuous fishing is the yearly increment in imports to balance the provision-requirement tension.

In comparison with increases to import volume, adjusting aquaculture production to achieve balanced provision-requirement (Figure 6.6) requires a rather more substantial relative change, reflecting the low base of current domestic aquaculture production. Even for the least demanding scenario (optimal fishing) a doubling or more of production would be necessary within about one decade, compared with about twenty-five years for the baseline assumption. In the subsequent decades increases in demand for production are relatively minor.

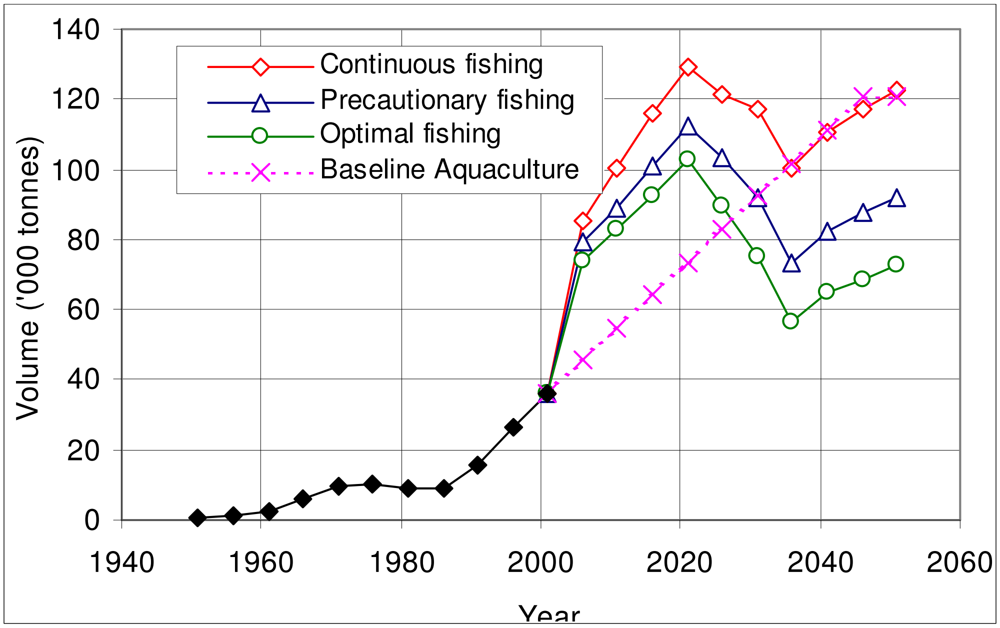


**Figure 6.6** Aquaculture production adjusted to account for previous volume imbalance, compared with the baseline assumption.

Such scenarios for aquaculture present significant challenges. Not least is whether it is technically feasible to increase production at such demanding rates. Part of this question relates to the creation of labour with appropriate skills and the construction of farm infrastructure. It is also necessary to factor in the constraints of farming that involves on-growing of corralled wild catch (e.g., southern bluefin tuna) compared with farm-bred fish. On-growing is dependent on sustained or increased wild catch.

Other issues relate to environmental quality. This potentially applies on and by aquaculture: not only is the quality of water used for fish farming important, but there may also be possible eutrophic effects downstream of fish farms in estuarine settings.

Additionally, increased aquaculture production would likely require increased levels of imports (or use of domestic wild catch) as a source of fish-feed. Naturally this will depend on the make-up of the aquaculture production, since the requirements of finfish, crustaceans, and molluscs are markedly different. It also relies on technological progress made in the area of feed sources such as those based on crops and genetic modifications to incorporate essential oils.

Overall in terms of resolving any provision-requirement imbalance the question of which flows to adjust and by how much is a moot one for this study per se. This question requires debate and discussion amongst stakeholders and experts to the most plausible (or perhaps most interesting) scenarios to consider. This point holds even more strongly for the more fundamental issue of the exact quantities for each of the flows in the scenarios. In this report, initial scenarios have been discussed to prototype the technique and stimulate discussion around these preliminary results.

## *Further analysis of interest*

Additional analysis can be made that can be of interest. In the plot below (Figure 6.7), the total domestic production (wild commercial + aquaculture) is shown. The variation due to the different scenarios is shown and so is the additive effect of aquaculture production. It can be seen that despite a tripling of aquaculture production by 2045, the effect while significant does not enable the total domestic production to continue increasing at the rate that was achieved between 1965 and 1995.

Only with the accelerated aquaculture described above (and shown in Figure 6.6 as the broken line) does the total domestic production grow over the next two decades at a similar rate to historical production.

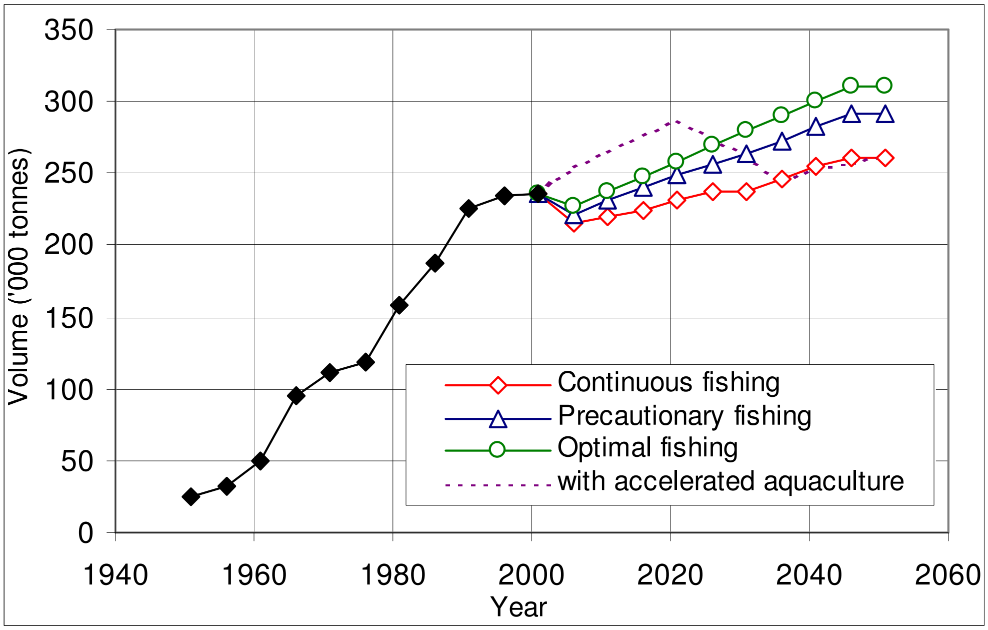


**Figure 6.7** Total domestic production, including tripling of aquaculture production by 2045 (the dotted line shows "total production with accelerated aquaculture" which resolves the provision-requirement imbalance).

Alternative analysis measures the capability of Australia to sustain its exports into the future (Figure 6.8) without regard to maintaining domestic consumption. Essentially this is a graph of the difference between the total domestic production and desired export volume. It shows a historically rising capability that turned around in 1990 and declines for about 15 years.

The features can be explained as follows:

- The peak in 1990 is due mainly to the commercial wild capture production reaching a plateau at this time.
- The decline is due to the basic imbalance between the assumed export volume and the lack of capability of wild fisheries and aquaculture to keep pace with this.
- The recovery after 2006 is due to exports being assumed to remain constant at contemporary volumes.
- The apparent stabilisation after 2045 is caused by the levelling of aquaculture production at this time.

While the graph value is positive, it indicates that domestic production can continue to supply exports. However, any serious decline would have impacts long before the balance is zero because at this point, all local production is being used for exports, thus requiring all domestic consumption to be supplied by imports.

Further, full accounting of fish required as feed for aquaculture or animals could lower these curves. This is because such fish-feed might partially be sourced from domestic wild capture. Given the expansion of aquaculture assumed in the scenarios and typical conversion factors for fish-feed to farm fish weight, it is possible that particularly the curve for the continuous fishing scenario could decrease to such a level that domestic consumption is constrained

Importantly, if the volume of exports were to increase in line with historical trends (approximately linear) rather than remain constant at contemporary levels under the assumption of compensating increasing financial value, then the provision-requirement deficit (Figure 6.3) would increase to some 80–110,000 t/yr. This would draw the curves graphed in Figure 6.8 significantly close to zero, with the implication that domestic production is supplying the expanded export market at the expense of domestic consumption.

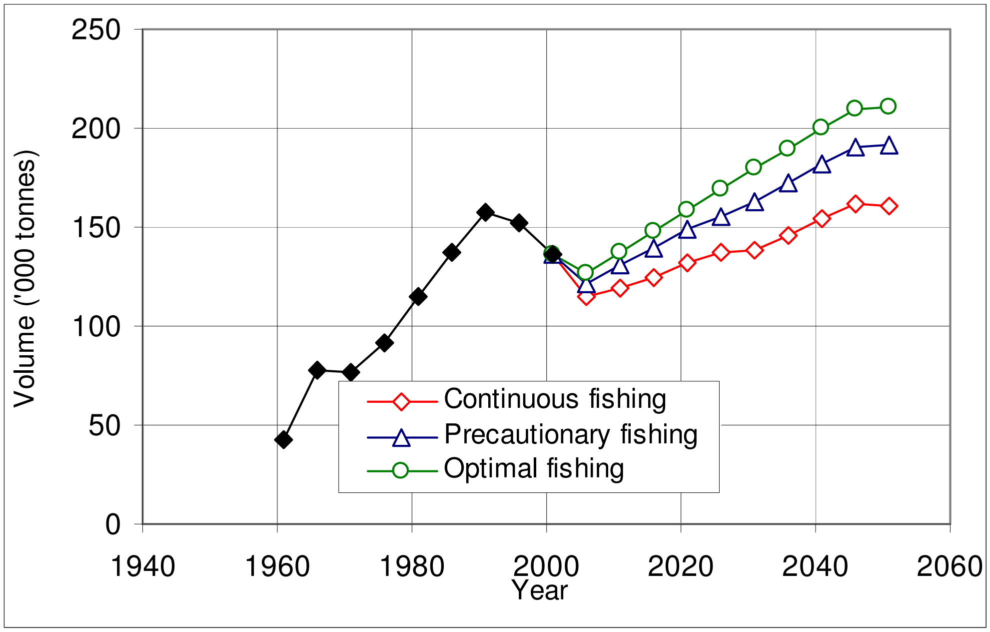


**Figure 6.8** The difference between total domestic production and assumed exports. Domestic supply is made from wild capture and aquaculture production (tripling by 2045). Positive values indicate exports are physically feasible.

## Some immediate implications

While these results need to be discussed and debated amongst stakeholders and experts and further investigation needs to be conducted, these initial results lead to interesting points and questions:

- Using historical linear trends, the future results in a serious and growing imbalance between the larger requirements (domestic consumption and exports) and the smaller provision (domestic production and imports).
    - While it is obvious that this will require a reduction in requirements or an increase in provision to resolve this tension, it is less obvious how this would be achieved at a detailed level. Evidently some role will be played by price signals, although the full implications of market forces are not immediately clear. For instance, assuming a "rational" consumer response, higher market prices would curtail domestic per capita consumption, but might also encourage higher levels of fisheries exploitation.
    - It is relevant to ask which are the "easier paths" and "more likely paths" the industry could follow in order to achieve balance.

- There is a turnaround in 2020, mainly due to the saturation of per capita consumption. This reveals the enormous impact that domestic consumption has on the fisheries sector. To illustrate, a 1 kg/capita/annum difference results in a consumption difference of the order of 20,000 tonnes per year. Limiting consumption to current levels (19 kg/capita/annum live weight) would resolve the tension in the short- and long-term. Any growth above current levels of per capita consumption results in provision-requirement imbalance in the short-term, and the timeframe of the imbalance lengthens as consumption rates increase.
    - The historical per capita consumption data has a subtle suggestion of little change in the consumption rate from about 1990 (see e.g., Figure 5.3 and Figure 5.6). However, given the level of variation ("noise") in this data it is not possible to say definitively whether this is simply a fluctuation or represents a change from longer-term trends. Based on anticipated increases to per capita real income and the association with seafood consumption, among other influences, it is probable that per capita seafood consumption will increase.

    - It is highly unlikely given the analysis provided above that the industry aspire to creating a domestic market such that Australian's "eat like Norwegians". The average annual per capita consumption of Norwegians and Japanese was found to be 44 kg and 72 kg respectively (see p. 8, FAO 2000b). The Norwegian rate is over double the current Australian consumption rate. Such a rate would produce an overwhelming provision-requirement imbalance.

- Commercial wild fishing production cannot grow in the same manner as the last four decades without an expansion into untapped resources. Even under the optimal fishing scenario growth is relatively slow. This could involve under-utilised species or completely new resources. It is the nature of the ASFF model that it mostly captures previously utilised resources so that either of these may be wholly or partially missing within the model. Fish biologists believe that large and resilient stocks of undiscovered marketable fish are not available.

- Aquaculture production is an important determinant of future domestic production (FAO 2000c). As stated in the last point, growth in wild commercial production appears to be relatively limited so that most of the new growth will have to come from aquaculture.
    - Such growth (and full farm production as opposed to "on-growing") will have implications for the supply of feed. This feed could be acquired from traditional sources such as domestic wild capture or imports, or possibly in future from crops enriched with fish-like proteins and oils.
    - So is the growth of aquaculture production at the same rate as the past decade a reasonable assumption? Given that a large portion of the fish production is Atlantic Salmon and Southern Bluefin Tuna, can the volume of these species continue to grow and if not, what fish species can fill the gap? Perhaps the gap doesn't need to be filled as the growth in crustaceans and molluscs has been underestimated?
    - What factors could promote or retard growth in the aquaculture sector? Growth would be spurred on by prices of product, perhaps fuelled by scarcity of product or rapidly expanding markets. It could be retarded by environmental and community concerns or health and disease concerns.

## Concluding remarks–change from past trends is likely

This chapter has brought together a number of seemingly innocuous independent assumptions about near- and mid-term developments pertinent to the Australian fisheries industry, and has shown that these are not all compatible. While the scenarios developed are not necessarily harbingers of doom, the tensions that result between nationally aggregated provision and requirement present challenges (and perhaps opportunities) that should not be ignored. It would be prudent of the Australian fisheries industry not to plan on business as usual. Depending on the particular perspective of what constitutes business as usual, the analysis reported here suggests this may not be a tenable proposition.

Two key issues stand out:

- management of domestic wild capture; and
- rate of growth in import volume.

Further important aspects include:

- domestic consumption; and
- realistic rates of increasing aquaculture production.

Before summarising these aspects, it is worthwhile briefly reiterating important aspects of the approach adopted in this study. The analysis presented provides a first cut at what sort of changes are likely to be imposed on the Australian fisheries industry by bio-physical realities and external forces. Some of these are more certain and can be considered "lessons from the future". Naturally there are other factors with considerable uncertainty and the method used and illustrated in this chapter shows a way to deal with these, treating them as "signals from the future". In either case, the industry and management institutions have a means to explore implications, sensitivities and opportunities in advance of possible challenges. Confidence in this capability is underscored by key features of this study, in particular:

- the Australian industry is embedded in the world context;

- the physical accounting is tied to a uniquely comprehensive database; and
- the bio-physical modelling adopts a conservative, technologically optimistic perspective.

On the issue of managing domestic wild capture, the future of Australian production could diverge substantially depending on the overall management approach adopted. Correspondingly fish stocks may be maintained or incorporate collapse, particularly of longer-lived species. This conclusion is robust given the conservative estimate used for virgin biomass: an informed estimate, which is considerably larger than the minimum estimate that would also be consistent with historical catch data. The analysis points to the importance of monitoring fisheries effort and assessment of standing biomass. Planning for recovery periods in critical fisheries would be prudent.

The other top issue is the rate of growth of import volumes. Import trade is a key variable. The requirement for continued imports consistent with past trends appears certain. More importantly, the nature of the growth—whether linear or compounding annually—will influence both the future role of seafood in Australian diet and trade balance figures within the sector. Any linear or similar increase in import volume cannot sustain higher domestic consumption. Nor can domestic aquaculture fill the provision-requirement gap without having an impact on the requirement for greater imports. Clearly, any scenario that relies on substantial increases in imports raises the question of the associated financial impact. The degree to which this constrains fisheries management will depend on the overall Australian trade balance since an adequate balance of payments should support higher fish imports. Alternatively, a worsening balance of payments may put more pressure on our fish stocks with the potential to initiate a range of stock collapses, particularly in our finfish. Additionally, there is also the more fundamental issue of the on-going potential for world markets to supply the volume in a possibly constrained environment.

Two other factors—domestic consumption and aquaculture production—also have the potential to alleviate any future provision-requirement tension, at least numerically. However, the physical accounting analysis indicates that the level of change necessary in either of these factors to have a substantial impact would require dramatic change from past trends.

While such findings are illuminating, they also highlight the key issues and where uncertainties remain. The following chapter collects and prioritises a range of aspects for further exploration.

## References


Dunlop, M., G. Turner, B. Foran and F. Poldy (2002). Decision Points for Land and Water Futures. Canberra, CSIRO Sustainable Ecosystems, Resource Futures Program, National Futures.

FAO (2000b) FAO Fisheries Department, The state of world fisheries and aquaculture 2000.

FAO (2000c) FAO Fisheries Department, Trends in global aquaculture production, Accessible on webpage http://www.fao.org/fi/trends/worldprod99e.asp.

# Chapter Seven - Further Explorations

Inevitably the scenarios and analysis of the earlier chapters will generate further questions and highlight particular issues. Some will be directed toward implications raised by the scenarios—such as what are the set of interlinked big actions and innovations, many of them "against the tide" that will resolve the big production tensions—while others may be oriented to factors that have been deemed beyond the scope of this first study. This chapter outlines some of these questions and issues, giving a brief account of suggested associated data and modelling refinements.

## Addressing other issues and uncertainties

A useful way to group issues related to the future of the Australian fisheries industry is according to how much control the industry and management bodies can exert, even though a clear distinction about the level of control is not always possible. The benefit of this approach is that it aligns with different management processes. For factors that are substantially amenable to control within the industry sector, the management approach could be more pro-active and can be implemented with more certainty. Such issues might revolve around the industry structure, such as the balance between wild capture and aquaculture, and corresponding skills of workers.

In contrast, factors that are located mostly beyond the industries' control may involve greater uncertainty and evidently imply a more reactive response. A relatively simple example is possible constraints in the supply of diesel fuel for the fishing fleet, and corresponding price changes. Arguably more insidious is the degree to which biological systems once impacted, are beyond control of fishers and management agencies, particularly if the impacts are not immediately evident.

For either type, this report demonstrates the quantitative scenario method as an effective management information tool. The industry will be better placed to act quickly and appropriately since the industry is more likely to recognise threats and opportunities sooner and implement management options that have been explored in advance. The following review is indicative of the range of relevant issues.

### *Factors amenable to more direct fisheries control*

The following issues and factors are more likely to be within the control of the Australian fisheries industry. In a number of cases the present structure of ASFF is sufficient to provide for immediate scenario design and analysis, while other factors would require subsequent development or interaction with other models or analysis.

#### *Aquaculture*

Domestic aquaculture could conceivably contribute to achieving future national provision-requirement balance. However, to rely on this sector places substantial demands on the feasibility of aquaculture for expansion and will depend on the specific species that are exploited. Such a reliance could be examined from the perspective of the underlying stocks and flows, such as fish required for feed, quality and volume of water involved in freshwater farming and competition with other uses, and possible benefits in reduced dependence on fuels for fishing fleets.

#### *Wild capture productivity*

It is not likely that record levels of production will be achieved from existing fisheries, as shown in chapter 6. However, it may be beneficial to explore how more value can be obtained from the same production volume. This might cover analysis of potential flows into aquaculture or other markets associated with by-catch.

The current analysis also highlights the importance of obtaining suitable knowledge about fishery dynamics, characterised through appropriate parameters such as the virgin biomass, for understanding the resilience of fish stocks. This national level overview provides the context for more detailed analysis using species-by-species models operated, for example, by relevant state management agencies.

An understanding of localised impacts and productivity could be computed by applying further analysis on a spatial basis to the comprehensive fisheries data assembled. Various regions might be identified as hot-spots or associated with the source for domestic consumption and export trade.

### *Wild capture expansion*

Given the constraints implicit in the existing fisheries, it may be useful to examine the potential for expansion of the wild capture sector into new fisheries. This might encompass the prospects of international fishing in the three FAO regions containing Australia's EEZ. A broadening of the fishing harvest into more fish stocks implies the need for a full ecological treatment of marine ecosystems. However, we must question how likely it is that significant stocks of currently under-utilised species exist, and recognise that like exploiting oil and gas resources, they will be more distant, at greater depths and more expensive to exploit.

### *Market development*

Domestic consumption evidently plays a significant role in addressing any future provision-requirement deficit, not only in terms of volume but also in preference for different types of seafood. Can the public be introduced to other types of seafood that are more easily managed and produced at greater rates? Such aspects can be partially influenced by the fisheries industry. For example, already there exist "sustainable eating" guides that point fish-food consumers towards species that are short lived and have more resilient life cycles and harvesting regimes. A further stocks and flows analysis may demonstrate the extent and rate of change that would ideally be achieved. This would inform market research in terms of the demographic targets and fish products to be developed.

### *Labour, energy and infrastructure requirements*

Substantial changes in the distribution and nature of labour, energy and infrastructure requirements are implicit in the future scenarios for the Australian fisheries industry. The implications rely most heavily on the extent to which the industry actively develops the aquaculture sector. However, even if this structural change is not pursued there are imperatives for the commercial wild capture sector.

Probably the most substantial of these relates to reliable and relatively inexpensive high quality fuel supply. Other work (Foran, 2002) has documented possible national constraints in domestic oil stocks, and an associated transition to natural gas over the time scale of this fisheries study. This has ramifications for the direct financial prospects of the industry as well as the retrofitting or rolling replacement of the fishing fleet.

The aging demographic may also play a role. Generally, the average age of fishermen is increasing and may have wide implications for the sustainability of some coastal communities. Already such demographics are having impacts in specific fishing townships.

## *Indirect or factors external to Australian fisheries control*

Understanding the implications and degree of uncertainty surrounding external factors is a crucial element of strategically positioning the fisheries industries. This is facilitated by quantifying the relevant 'what-if' questions through a physical accounting framework.

### *Domestic market demand*

While the consumption of seafood by the Australian public can be influenced to some extent by the fisheries industry, a number of factors are clearly beyond the control of the industry. At a gross level a key factor is simply the size of the Australian population, which may vary markedly (by some 20% in 2050) depending on high and low immigration policies (Foran, 2002). Changes of this magnitude are roughly equivalent to those explored in the previous two chapters regarding per capita consumption.

There are also issues associated with the demographic structure of the population, such as settlement patterns (location near seafood production); numbers and proportions of affluent people; and age profile of the population. It is conceivable, for example, that a greater segment of the population in retirement may maintain demand for fish as part of a healthy life choice and increase participation in recreational fishing, sometimes at the expense of commercial operations. As a growing population segments that is well-educated and prosperous, this segment will become a more potent lobbying force.

### *World economic context*

The importation of fish products from the world market plays a key role in current and future Australian fisheries. This is partly associated with the relative size of the various drivers in the Australian context, with imports being several times greater than domestic production and exports. This means that changes in imports that might address domestic provision-requirement deficits are relatively smaller in volume terms than for other drivers. Import volume is also a key factor because a sizable part of imports supplies feed for domestic aquaculture, and therefore any future scenario based on rapidly increased farming of fish must consider trade implications. As the first chapter highlights, any analysis of importing fish products must be sensitive to possible constraints in volumes and consequent competition from other nations. This is particularly pertinent for poorer countries where fish are critical protein components of diet.

Of course, the other side of the coin is that demand for high-value Australian exports may remain strong and even grow. The ability for expansion of exports should be examined on an individual fisheries basis rather than as a national aggregate.

As mentioned elsewhere, the supply of fuel or its price particularly for the commercial fishing fleet is uncertain. Increasingly, the supply of oil will come from imports as Australian production rates peak. It is likely that energy supplies will be augmented with Australian and regional natural gas, but the rate at which this fuel source might penetrate the technology of boat engines is not clear.

### *Ecological constraints*

Localised, regional and global environmental impacts affect the ecological basis of Australian fisheries and constrain their productivity in uncertain ways. Pollution from localised sources (such as major run-off of fertilisers and pesticides from agriculturally intensive areas) and globally persistent pollutants (such as dioxins and other PCBs) may affect the reproduction and lifecycle of fish communities and therefore lower the biomass available. It is conceivable that accumulation of pollutants up the marine food chain could result in products that are restricted from use as human or livestock food. The Schaefer model of fish units, as used in this study, provides limited utility for accounting for these ecological effects. While the growth parameter of the Schaefer model provides the scope for injecting such effects no deliberate account has been made of these effects in the current study.

Similarly, this study has made no deliberate account of density dependent effects or interactions between species except for that contained in the catch history records of individual fish units. Some exploration of ecological interactions has been undertaken for a policy paper associated with this study (Kearney, 2003). This focused on the effects of recovering numbers of seals also harvesting fish stocks in combination with commercial fishing. We acknowledge that this work is preliminary and should be updated when it is possible to assign, more accurately, the impacts of seal foraging to those of a member of a closed ecosystem or to those of an external predator.

The understanding of the risks associated with climate-change induced effects on the on-going ecological status of some fisheries could also be improved. Increasing water temperature and even changes to gross ocean currents may affect the reproductive behaviour and distribution of exploitable species.

It should be possible to make preliminary estimates of the impact of these various factors on the productivity and sustainability of Australian fisheries using the present stocks and flows framework (or with minor modifications) combined with expert input. These estimates may help identify the relative importance of such effects and therefore guide any further development.

## Technical aspects: data and modelling refinement

### *Data refinements*

Several refinements could be made to the historical database that underpins the calibration period. These are unlikely to change the various scenario outcomes substantially, however, they may aid in the understanding and help validate of the stocks and flows approach used in this study by eliminating potential distractions.

By working with state and Commonwealth departments (including ABARE, BRS and ABS) it should be possible to refine the database of individual fisheries production. A first important step is to take the modelled fisheries as they currently exist and have them "reality checked" by comparison with more detailed models and observed data for individual fisheries. This would improve the accuracy of the parameters of the Schaefer model. In particular, it might be possible to create time dependent Schaefer parameters and model individual fisheries without having to explicitly introduce ecosystem models.

One of the more obvious but less serious calibration issues is the discrepancy between FAO and Australian records for import and export volumes. This is the result of reporting volumes in terms of live weight compared with product or edible weight, as outlined in chapter 4. It might be effectively resolved by acquiring further information from the FAO on the factors used to convert Australian product volumes to live weight, or acquiring Australian data on trade volumes.

Commercial fisheries production for the period preceding 1965 is potentially available through ABS data. With suitable allocation to appropriate fish units, this data could be used to improve the early picture of Australian fisheries. The most likely benefit is to provide a better understanding of the production associated small fisheries that have not being individually accounted in this study. Such fisheries are dealt with in an aggregate manner by comparing national production data (such as from the FAO) with the total produced by summing over all of the individual fish units.

### *Refinements to the stocks and flows framework*

A hierarchy of refinements, from simple to more involved, to the fisheries sector of the stocks and flows framework is possible. Simple additions to the framework could account for by-catch made by marine fisheries and the treatment or processing of wastes further down the production line. At a simple level, these changes could be made for direct accounting of these flows without integrating these with other elements of the fisheries framework.

A slightly more complicated improvement would be an enhanced treatment of aquaculture. Some features that could be added include consideration of the quality of feed for fish farming, such as the effective fish protein level, as well as linking some proportion of the import and domestic production of fish for feed directly with the volume of feed required for fish farming. This is clearly an important consideration given the key roles that aquaculture and imports could play in contributing to mitigation of the provision-requirement deficit evident in the scenarios of chapter 6. For instance, a dramatic increase in aquaculture production may demand additional imports on top of those assumed in the scenarios. In a similar vein, the potential use of by-catch and other wastes can be linked with aquaculture inputs.

At the more complex level, it might be instructive to incorporate some degree of ecosystem function in the framework. This becomes more important as the biomass of fish species decreases and the number of species harvested increases. Ecosystem models permit better consideration of the impacts of marine mammals such as seals competing with fisheries activity.

More complex models have the disadvantage of greater data requirements, and it is unlikely that comprehensive data is available at this time. Nevertheless, such models provide the incentive and framework for identifying what data should be collected.

### *Further analysis and coupling ASFF with other models*

The framework could also be expanded in a geographic sense to cover New Zealand and the FAO regions of direct importance to Australian fish species. This would predominantly involve an expansion of the data coverage and using the same stocks and flows framework. There may also be some advantage in a macro-management sense in considering a framework that covers the southern hemisphere trade zone, including Australia, New Zealand, South Africa and Argentina.

Further enhancement of the analysis of Australian fisheries futures could be made by coupling the ASFF fisheries account with other models. Two potential areas of enhancement are ecosystem modelling of fish populations and with economics considerations.

Rather than develop ecosystem models with the stocks and flows framework it is possible to use other mathematical or computer models to simulate fish population dynamics, and take the outputs of these models as inputs to the stocks and flows framework. In practice, a more iterative approach may be necessary by providing, say, the fishing effort from ASFF to these external models. Such an approach would not be practicable when comprehensively accounting for all fisheries in Australia—indeed, this national perspective was a key incentive for using the simple Schaefer model in the first place. However, specific fisheries of interest or concern could be treated in detail using more detailed external models. Alternatively, detailed population models could inform the derivation of effective Schaefer model parameters for particular fisheries.

Such an approach might have the advantage of placing specific fisheries within a national context and therefore increase awareness and acceptance of the importance of adopting 'big picture' accounts. Making use of extant ecosystem models may be an efficient way of identifying whether such model enhancements should be embodied in the stocks and flows framework for all fish units. On the other hand, more detailed population modelling has the potential when not adequately grounded in observations to give the false impression of complete understanding of fisheries production. This could result in over-fishing without sufficient regard for variability and uncertainty.

Economic considerations might also be coupled with the scenarios developed using ASFF. This could be interesting and important given the strong influence of per capita consumption on alleviating any potential provision-requirement deficit as indicated in the scenarios of chapter 6. For instance, it is tempting to postulate that constraints on domestic supply would translate to higher prices that subsequently reduce consumption rates. However, a competing influence should be included that accounts for increased fishing effort driven by higher market prices. Any economic modelling should also factor in apparently irrational behaviour of consumers and producers.

Another way to utilise economic models might be to investigate what economic or market systems such as prices, subsidies, credits or taxes could be implemented to achieve desirable fisheries scenarios.

As for the case of coupling with ecosystem models, a more efficient process might be iterative transfer of data between ASFF and any economic model or analysis, rather than a comprehensive integration of the computer models per se, at least initially.

## Recommendations for further work

Preceding any further work, *highest priority should be given to consideration of institutional arrangements, particularly which organisation should have ownership for the framework of fisheries stocks and flows* developed for this study. Potential candidates include CSIRO Marine, the BRS and ABARE, and will presumably involve FRDC.

The following recommendations take account of both the level of effort required and the benefits to be gained from, or importance of, further work. A table summarising the effort-benefit matrix for the recommendations is given in Appendix D. The recommendations below are grouped according to similar levels of effort-benefit ratio (where for example, high benefit-medium effort is roughly equivalent to medium benefit-low effort). Many of the higher priority recommendations involve further analysis using more detailed and extensive scenarios that leverage the current fisheries stocks and flows framework.

### *High benefit – low effort*

Create and analyse scenarios to better understand the implications of future oil production constraints and demand competition for alternatives such as natural gas. (5)

### *High benefit –medium effort or Medium benefit – low effort*

Reality check individual fisheries with state and federal institutions using further expert input and comparison with extant detailed models and subsequently refine the parameters used to model the bio-dynamics of Australian fisheries. (15)

Analyse key drivers and uncertainties using scenarios for seafood market demand, such as population levels and profiles, to better inform more specific market research. (1)

Examine possible future development of world fisheries production and market demand, as a key factor for addressing future domestic provision-requirement deficits. (4)

Undertake preliminary modification of the stocks and flows framework to explicitly include by-catch and other wastes. This creates the capability to analyse these flows and consider further development of the framework for exploring increased productivity by utilising these 'wastes'. (3)

Develop the stocks and flows framework to incorporate the 'industrial ecology' perspective of utilising by-catch and wastes as inputs to other industry segments such as aquaculture in addition to feed from imports and domestic catch, and explore increases in overall industry productivity. (10)

Create and analyse preliminary scenarios of the impact on fisheries production of ecological effects arising from environmental issues such as climate change and pollutants at the local, regional and national scale. (6)

Further develop the fisheries stocks and flows framework to incorporate ecological impacts of environmental issues on the basis of the preceding preliminary analysis. (7)

Create and analyse scenarios of labour and capital requirements of the fisheries industry segments to develop an anticipation of the lead-time and development effort necessary for possible structural changes such as rapidly increased aquaculture. (2)

Acquire post-1940's fisheries production data and incorporate in the fisheries stocks and flows framework. (13)

### *High benefit – high effort to low benefit – low effort*

Combine the physical analysis of the fisheries stocks and flows framework with appropriate economic analysis or models to explore the effectiveness of various levels of market-based and regulatory management regimes. (8)

Develop stocks and flows ecosystem fisheries models or couple with extant models to examine in detail the effects of stresses such as increased fishing effort and environmental pressures. (11)

Extend the coverage of the fisheries stocks and flows framework to include relevant southern ocean FAO fishing zones for consideration of issues such as foreign fishing efforts and migratory fishes. (13)

Resolve the discrepancy between Australian records and FAO data relating to the reporting of trade volumes as live weight or product weight. (14)

### *Medium benefit – high effort*

Analyse the fish unit productivity on a spatial basis to allow computation of a seafood 'footprint' for both domestic consumption and export trade. (9)

## References

Foran, B. and F. Poldy (2002). Future Dilemmas: Options to 2050 for Australia's Population, Technology, Resources and Environment; Report to the Department of Immigration and Multicultural and Indigenous Affairs. Canberra, CSIRO Sustainable Ecosystems.

Kearney, R. E., B. Foran, F. Poldy and D. Lowe (2003). Modelling Australia's Fisheries to 2050: Policy and Management Implications, Fisheries Research and Development Corporation.

# Appendix A - Review report & project team response

The following review report is presented in whole and without alteration. The review covers both an earlier draft of this report and an associated publication that addresses strategic options for fisheries management. In a number of cases, comments in the review relating to the underlying methods of the associated publication have been covered in this report. For some items in the review, responses from the project team have been embedded at various points using shaded text boxes to identify them as separate from the review.

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***Review of FRDC 99/160: "Assessing Australia's future resource requirements to the year 2020 and beyond: strategic options for fisheries"***

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February 2003

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### *Terms of Reference*

1. Assess all draft outputs arising from the project, including:
   a) The draft final report which is still being written;
   b) The summary publication "Modelling Australia's fisheries to 2050: Policy and Management Implications".
2. Assessing the model that was developed to underpin the project objectives (including the data used).
3. Assessing the assumptions that underpin the model, and the various scenarios that have been modelled.
4. Providing an evaluation of the project and recommending any changes that are required to improve the quality of the science.

## *Summary of findings:*

1. Although this work is set in the context of the ASFF study, it is in reality largely decoupled from it. There appears to be excess demand for all species at all times and for all scenarios and low stock size does not seem to lead to cessation or reduction of fishing.
2. Feedback in terms of changes in quantity supplied/quantity demanded and the influence of this on price and, therefore, on consumption needs to be recognized.
3. There is no real conclusion or set of recommendations as to what the various fisheries agencies are to do.
4. The methods of data compilation and analysis require more detailed description and explanation.
5. The project was very successful in bringing together data for more than 600 fish units, with sufficient data to model 220 of these units, covering fisheries that represented more than 85% of the total Australian annual fish production.
6. It would be useful to obtain formal confirmation by the original custodians, who contributed the data, that the final collated data sets are accurate.
7. Other than for the more important fisheries, effort data were found to be inadequate for the use of those statistical techniques that have traditionally been used in fitting dynamic fishery models for stock assessment.
8. Techniques were developed to calculate estimates of the parameters of the Schaefer surplus production model using the available time series of catch data, in combination with estimates of the longevity of the species. While the formulae developed to estimate the intrinsic rate of growth, $r$, appear reasonably sound, the accuracy of the estimate of the virgin biomass, $k$, is dependent on the catch history for the fish unit.
9. The approach that was adopted, of tuning the parameter estimates such that a match was obtained with published estimates or such that the results were consistent with expert opinion, would have overcome some of the difficulties associated with the estimation of virgin biomass from the catch history. However, this approach is subjective and, thus, is a potential source of error. As recognised by the project team, it would be inappropriate to base management decisions for a specific fish unit on the model estimates derived in this project. Notwithstanding this, by using this approach, the resulting projections are likely to be consistent with current experience, assessments and understanding. In aggregate, the results of the projections can by used to provide direction for fisheries management as they represent the synthesis of expert opinion for the combined set of fish units.
10. Details of the initial estimates, the published values, the expert opinion, and the final parameter estimates need to be included in the final reports.
11. It would be useful to obtain formal confirmation from the Fisheries Agencies/Authorities responsible for the stock assessment of the individual fish units that the resulting parameter estimates and predictions are satisfactory.
12. The term "reality checking" has been used to describe a subjective assessment of the face validity of the trajectory of the "fitted" model. However, model validity (*i.e.* ability of the model to accurately predict future catches) rather than face validity should be the goal. While a consistent approach to parameter estimation has been used, the study appears to ignore the traditional approaches to parameter estimation that might have been applied when adequate data were available.
13. The management scenarios considered in the project were appropriate. They included (a) attempting to maintain the status quo catches, (b) closing the fishery for a fish unit when the biomass falls below a critical level, and (c) active management to achieve a target biomass and thus ensure sustainability (and thereby to obtain an improved economic outcome). The 'cautious' scenario might be improved by using limit reference points ranging between 20 and 40% of virgin biomass, which reflect the quality of the data, and the adequacy of the research and of the management controls for the fish unit. Possibly the most interesting result from these scenarios is the recognition that more than 50% of the 220 fish units examined were classified as overfished or as being in severe or critical condition, and that continued decline in fish production was likely to result unless appropriate management controls were introduced.
14. The alternative scenarios that were considered for the impact of increased prey consumption by seals represented one aspect of the range of uncertainty associated with the growth of the seal and sea lion populations. In the base case, it is assumed that the increased predation is already factored into the parameter estimates for the Schaefer model for each fish unit. In the alternative

scenario, growth in predation by seals was explicitly included in the data set and projections, and parameter estimates for the Schaefer model were determined from the combined “harvest” by commercial and recreational fishers and by seals. However, there are also considerable uncertainties in the extent to which seal predation may increase, and the simplicity of the biomass dynamics models used in the fish futures study precluded consideration of trophic interactions, thereby increasing the uncertainty of the likely impact on commercial fish catches of increasing seal predation. However, the possible magnitude of the impact is reflected in the differences between the projections obtained from the base case and the explicit seal predation scenario (under each of the management scenarios). Clearly, there is the potential for increasing seal predation to severely impact some of Australia’s fisheries.

15. The potential impact of increasing seal predation highlights the need to consider the predation impacts on fish production by commercial fishers of other fish predators, such as cetaceans, dolphins and seabirds.
16. The ASFF provided a useful tool to integrate the outputs from the models of the 220 fish units and to explore various scenarios regarding future population and energy flows. The results are impressive as they represent the first such synthesis of the fisheries of Australia.
17. The report identifies environmental issues as a concern. With the projected increase in Australia’s population, pressure on estuaries and nearshore environments will increase, and it is likely that such development will impact on the environment and on fish production.
18. Increasing population and change in lifestyle will result in demand that is unlikely to be met by catches from wild fish stocks or aquaculture.
19. All scenarios assume “perfect information” for management controls. While this is probably inevitable given the scope of the current study, the point should be noted and discussed (and modified in future work).
20. The study would have benefited from a more rigorous examination of the sensitivity of the fishery models to uncertainties in the assumptions, data and methods.
21. The project has produced useful results and has assisted in focusing attention on the need to actively manage the allocation of fish resources among commercial and recreational fishers and among fish predators such as seals, sea lions, dolphins, whales and sea birds, rather than allowing allocation to be determined without consideration of planning. There would be value in updating and maintaining the database, and in extending the models to explore the impact of population increases and changes in demography on the environment of estuarine and nearshore areas and on the fish stocks that use these habitats.

### ***Australian Stocks and Flows Framework***

Although this work is set in the context of the ASFF study, supply from the wild stocks of fish is in reality largely decoupled from it. Fishery statistics demonstrate that, although aquaculture production has begun to increase, the commercial catches from Australia’s fisheries have reached a plateau (Kearney *et al*., in prep.). Thus, as biological constraints limit the capacity of these renewable natural resources to supply the necessary quantities of fish product, growth in demand is unlikely to be satisfied by greater production from the wild fisheries. While aspects of the economy tracked within the Australian Stocks and Flows Framework (ASFF) may affect the economics of fishing activities, the demand for fish products that is generated by the projected population of Australia and its demography is unlikely to result in increased catch from the commercial fisheries. Indeed, there appears to be excess demand for all species at all times and for all scenarios considered within the study. Accordingly, the decision by Kearney *et al.* (in prep.) to restrict the study of fisheries production from the commercial fisheries to consideration of only a projected population of 25 million by 2050, rather than to consider also alternative future levels of population, is reasonable, as the fisheries are likely to produce identical production for each population projection. Similarly, assumptions regarding alternative demand for fish product are unlikely to affect the levels of commercial catches that are taken but will determine the shortfall of fish product that must be imported to meet the demand.

Although supply from the wild stocks may not be affected by other flows, feedback in terms of changes in quantity supplied/quantity demanded and the influence of this on price and, therefore, on consumption needs to be recognized. The Kearney *et al.* (in prep.) report brings to mind a major computer simulation/modelling study published in 1972 (Limits to Growth by G Meadows *et al.* from

MIT). By and large, it neglected to take into account economic-type feedback as well as institutional responses/feedback to the problems that it modelled (*i.e.,* resource depletion, pollution, population growth). The study was severely criticized, by those who did not want to believe the conclusions, because it neglected feedback. In 1992, the same people re-ran their models with the appropriate feedback mechanisms included. While the results were different from the early study, many of the general conclusions and the overall trend was not. However, it would be appropriate that FRDC project report at least recognizes the role that, say, decreased catches and increased demand will have on price – and how price increases will feed back to dampen demand. In most cases, economic systems <u>tend</u> to equilibrium.

> The influence of price on both demand and supply may be complex, and has been identified in recommendations for further work. We note briefly that experience in other fisheries shows that without sensible regulation increased prices may also stimulate effort to catch more of the economically valuable fish, with the possibility of taking the biomass below sustainable levels. Also some consumers may display apparently irrational behaviour of preference for more expensive products.

As future commercial catches are highly dependent on biological and ecological processes and on the strategies adopted by fisheries managers to sustain the fisheries, many of the assumptions that are made for the ASFF may have little impact on the catches. However, future catches are likely to be highly dependent upon the economic impact to fishers of the cost of fuel and the impact that this might have on fishing effort. The availability of energy and its cost have been recognised as major uncertainties in the report by Kearney *et al*. (in prep.). The fisheries models, which have been developed, make implicit assumptions regarding the economics of fishing such that annual catches are affected only by the available biomass and the assumptions that determine how the allowed catch adjusts to this biomass. Thus, it is assumed that increased costs associated with fishing do not influence the biomass at which fishing might become uneconomic and thereby result in reduced catch. That is, in model projections, low stock size does not seem to lead to cessation or reduction of fishing (on economic grounds).

The ASFF acts as a useful framework within which to build a representation of Australia's fisheries, as it provides facilities to maintain a log of the changes to the system, records details of the various scenarios that are being simulated, and provides the tools to facilitate and integrate the simulations of the large number of component models that describe the various fisheries (D. Lowe, pers. comm.). The projections that are produced by the ASFF are highly dependent upon the assumptions that have been made and, thus, the outcomes have considerable uncertainty (Kearney *et al*., in prep.).

> The computations undertaken with ASFF are simulations that incorporate bio-physical relationships, and transparent settings of key variables. These settings, or assumptions, have been based on analysis of the comprehensive historical database captured in ASFF. Variations in some settings were made to demonstrate possible alternative options for fisheries management and highlight the level of influence.

Little obvious use seems to be made of the regional nature of the ASFF data.

### *Fishery data*

Expectations for the contribution of fishery data were greatly exceeded by the response from fishery agencies throughout Australia, with data for over 600 species being made available. Of these data sets, 220 have been used within the 'fish futures' calculator (*i.e*., fisheries simulation models) providing a unique integration and valuable assessment of the data for Australia's fisheries. However, the details of the methods of data compilation and analysis are poorly described (Kearney *et al.*, in prep., Section 4.4) and a more careful and thorough description should be provided in Low *et al.* (in prep). Inconsistent nomenclature and coding for the different species was resolved through pre-processing of data and recoding species codes to the Codes for Australian Aquatic Biota (CAAB), classifying data which could not be allocated to a specific species to a genus or family level of mixed species. It would be of value to obtain confirmation by the custodians of the original data sets that the resultant collated data sets are accurate.

A biomass dynamics model, the Schaefer model, was selected for use by Kearney *et al*. (in prep.). However, the section describing the Schaefer model is misleading (section 4.3). The second dot point should be removed and the fourth dot point is definitely misleading - applications of the Schaefer model invariably use relative abundance data, not "primarily catch data".

Corrections to terminology have been made and the meaning clarified.

While the Schaefer model is often replaced by more complex age-structured models when analysing the data for a single fishery, additional biological data are required for the development of these more complex models. The form of model selected for use by Kearney *et al.* (in prep.) is appropriate for the types of data that were available for analysis, particularly when it is noted that the simulation must deal with 220 different fisheries, each described by a separate two-parameter Schaefer model. By assuming that each "fish unit" or stock was independent, Kearney *et al.* (in prep.) were able to analyse separately the data for each stock (or combination of species treated as a "stock").

While commercial catch data of relatively good quality were available for the more important fisheries, for others a lower quality was typical and the data required interpolation and error correction (Kearney *et al*., in prep.). Effort data for the various fish units often related to multi-gear, multi-species fisheries. After considering the data that were available for analysis, Lowe *et al*. (in prep., p.70) wrote that "*the quantity and quality of effort data was good for only a few fisheries, average of several more and poor or nonexistent for the remainder*". Preliminary examination of the catch and effort data to determine whether it might be possible to fit biomass dynamics models to these data indicated that, for most fisheries, the effort data were likely to be inappropriate and inadequate for such analysis (B. Kearney, pers. comm.).

An alternative to the statistical model-fitting approach usually adopted by fisheries scientists when fitting a biomass dynamics model to catch and effort data, and which did not need effort data, was required and was developed for the project. The method, which is described by Lowe *et al.* (in prep.), required an estimate of the intrinsic growth rate for the population, *r*. By defining the "time for full recovery" as "*the time for the biomass of that population to recover from 10% to 90% of virgin biomass assuming no fishing*" and then relating this period to the longevity for the species, Lowe *et al.* (in prep.) derive formulae from which an approximate estimate of *r* may be calculated. This estimate is then used, in conjunction with the average annual long term catch to determine a lower bound estimate of the virgin biomass, *k*. Alternatively, the catch history was used, in conjunction with the estimate of *r*, to determine a minimum estimate of *k* such that the historical catches would not cause the stock to collapse. The actual estimate of *k* used in projections was determined from published stock assessments and/or expert opinion (D. Lowe, pers. comm.). For some fisheries, such as the Northern Prawn Fishery, the catches of the various species were pooled and the resultant time series of catches for the combined set of species were represented by a single Schaefer model.

In developing the equations for the estimation of the parameters, *r* and *k*, Lowe *et al*. (in prep.) state that the equilibrium value of MSY, $MSY_{equil}$, consistently overestimates the actual MSY, $MSY_{actual}$. No reference is given to support or explain this statement and it is unclear what they mean by the "actual MSY", however I suspect that the term is intended to represent the maximum average yield, MAY. Reference might be made to the definitions of MAY, current annual yield CAY and maximum constant yield MCY that are used in the New Zealand stock assessment guidelines (http://www.fish.govt.nz/sustainability/research/stock/guide.htm). It is noted by Lowe *et al.* (in prep.) that, in practice, virgin biomass has been estimated as $k = n\overline{C} / r$, where the catches are unsustainable if $\overline{C} < 4$. However, no information is provided to indicate how *n* is determined, and it is assumed that this value is tuned such that estimates match values that have been published or that agree with expert opinion. The accuracy of the estimate of *k*, which is derived from the catch history, is very dependent on the historical pattern of exploitation. For example, if the level of exploitation is such that the average catch rates over the last few decades reflect a very depleted population, an underestimate of *k* will result. On the other hand, a developing fishery, in which effort has increased rapidly and in which catches reflect the fishing down of an accumulated stock of older fish, is likely to yield an overestimate of *k*.

> An extensive process that covered all 220 fish units was used to provide estimates of *n* and hence the virgin biomass *k*. The process involved expert opinion, validation and reality checking against observed catch data.

The catch data for the inshore fisheries, which were used in the analysis and estimation of the parameters for the Schaefer model, comprised the combined catches from the commercial and recreational fishing sectors. Final recreational catch statistics were not available from the recent national survey for use in the analysis. Accordingly, the estimate of the current total recreational catch of 30,000 t was taken from Kearney (2002). However, only 16,000 t of the total recreational catch is represented by the 202 fish units simulated in the project, as the remaining 14,000 t relate to other species or fisheries (Kearney *et al*., in prep.). This catch of 16,000 t was divided among the inshore fish units exploited by recreational fishers. Estimates of historical recreational catches for each fish unit were then calculated using trends in population from the demographic statistics (Lowe *et al*., in prep.). The combined recreational and commercial catches were used when estimating the parameters of the Schaefer models for the individual fish units (Lowe *et al*., in prep.). Forward projections of recreational catch are also based on projected population growth and participation rates. In assessing total recreational catch, the total of the simulated recreational catches must be scaled upwards to include the portion of the recreational catch from the species and fisheries that were not modelled (Kearney *et al*., in prep.). Unfortunately, the reports fail to provide the detailed data necessary to comprehend fully the precise methods used to distribute the 30,000 t among the modelled fish units (and unmodelled units) and the basis for this distribution, and also fail to provide a precise description of the hindcasting or forecasting processes.

> Total recreational catch was scaled up to 30,000 t for graphical presentation by pro-rata distribution across the States of the unaccounted 14,000 t recreational catch using the distribution of the 16,000 t accounted in the 220 fish units modelled.

The initial estimates of *r* and *k* were adjusted subjectively to match model predictions with published estimate(s) of sustainable biomass, the observed time series of effort per unit of catch (EPUC) and/or expert opinion from fishery scientists familiar with the fishery. The use of EPUC is proposed by Lowe *et al.* (in prep.) as an alternative to catch per unit of effort (CPUE). However, their derivation results in the conclusion that EPUC is inversely proportional to the biomass, whereas CPUE is assumed conventionally to be directly proportional to the biomass, and thus the use of EPUC introduces an unnecessary complexity to the analysis. Furthermore, if time series of both catch and CPUE are available for a fishery, more appropriate methods of analysis are available to obtain statistically sound and objective estimates of the parameters of the Schaefer model.

The methods proposed by Lowe *et al.* (in prep.) to calculate estimates of the parameters of the Schefer model using the time series of catch data and an estimate of the longevity of the species are interesting and are likely to be useful for fisheries for which appropriate effort data are unavailable. Unfortunately, Lowe *et al.* (in prep.) provide no indication of the extent to which these estimates proved acceptable. Furthermore, neither the precise details of the published data nor the expert opinion used to subjectively modify each of the other sets of parameters are reported (but note that the current draft is very preliminary and the deficiency may be addressed in the final version of the document). Thus, it is not possible to assess the likely validity of the resulting parameter estimates, to determine the parameters used for each fish stock, or to assess whether the resulting "fit" is appropriate or whether the projected catches are likely to be reasonable. Furthermore, it is not possible to duplicate the methods described by Lowe *et al.* (in prep.) and determine identical parameter estimates.

The resultant model projection for each of the 220 stocks was assessed critically by the project team before the results were accepted (B. Kearney, pers. comm.). This assessment has been reported for several selected fish stocks in Section 5 of Kearney *et al.* (in prep), however more detail of the subjective method used to assess face validity of the results should be provided in this section (and the legends on the figures corrected). That is, it is not at all clear how "reality checking" was done. Was the model fitted as described earlier in the draft (*i.e.* with constraints on *r* and using only catch data) or was this a fit to relative abundance data as well (given its availability for all of these selected species)? If the latter, the "reality checking" is not really a test of the method used for the majority of species. It is not particularly surprising that the Schaefer model is capable of fitting most of the time series reasonably well. However, it would be useful if each set of parameters, model fit and model projections was to be reviewed by the fishery scientists within each of the fishery agencies who have responsibility for the stock assessment. Such a review would provide further assurance that the projections are likely to be valid.

> The size of the task of parameterising 220 fish units and time constraint of the project precluded a comprehensive comparison of the Schaefer model simulation with other estimates. This aspect has been recommended for further work involving appropriate State and Commonwealth agencies. Nevertheless, in addition to reproduction of available catch data throughout the historical period for individual fish units, further confidence is provided by the reproduction of nationally aggregated production.

The decision to use subjective methods to tune the parameter estimates such that model predictions match previously published estimates of parameters derived from the application of other models, often based on model structures that differ from those of the Schaefer model, or to match estimates of sustainable yield produced by those models, may have been necessary. However, if the objective estimates of the parameters *r* and *k* from the time series of catch data and longevity, which were calculated using the methods developed by Lowe *et al.* (in prep.), were adequate, it might have been better to accept these estimates and to compare the resulting estimates and predictions against the published values, thereby demonstrating that the new methods were able to produce estimates that are consistent with those produced by other methods.

While it is preferable to use objective methods for the calculation of parameter estimates, it is very likely that, for many of the 220 stocks considered within the project, the methods available may have been inadequate, especially for relatively short time series of catch data. The use of subjective methods to tune the parameter estimates is likely to produce projections that are consistent with published stock assessment and expert opinion. Thus, although the resulting representation of individual stocks may be less accurate, it is likely that, in aggregate, the projections are approximately consistent with "reality", as reflected in published stock assessments and expert opinion, and are useful in identifying issues that may confront fishery managers. However, the point is made on page 33 of Kearney *et al.* (in prep.) that, while the results are very uncertain, there is no reason to believe that they are biased. The latter point is not clear (again, this may relate to the currently inadequate description of the methods used). For example, if the lowest *k* consistent with the time series of catches is used in the study, a bias will inevitably be introduced as larger values of *k* are also possible.

> Best-estimates of *k* were based on extensive but informal judgement, and constrained by lower and upper bounds of respectively the minimum *k* (for which the fish unit crashes under historical catch data) and twice this value. More scrutiny was placed on economically and volumetrically important fish units.

It would be inappropriate to criticise the very early draft of Lowe *et al.* (in prep.), however the report would benefit by the citation of appropriate papers rather than the use of unsupported statements such as "it is generally agreed that …". Where adequate methods exist in the traditional fisheries literature, it would be better to use these rather than developing new theory (e.g. EPUC).

### *Scenarios*

All scenarios considered by Kearney *et al.* (in prep.) assume "perfect information" for management controls. While this is probably inevitable given the scope of the current study, the point should be noted and discussed (and modified in future work).

An error in the text on page 15 of Kearney *et al*. (in prep.) was identified by the project team in discussions at Canberra in early December, 2002. The text should have read "… catches are set to decrease stocks to approximately 72% of virgin biomass (at which stock size, the equilibrium yield is approximately 80% of the theoretical maximum sustainable yield)". I would prefer to avoid the use of the term "catch rate" when "catch" is intended, as "catch rate" is often considered to be a synonym for CPUE.

> Appropriate changes have been made.

The project considers three "management scenarios". The nomenclature of these scenarios is rather misleading. For example, the "cautious" scenario is a "status quo constant catch policy with an adjustment to the catch if the biomass falls below 20% of the virgin biomass" and could perhaps have been labeled as "status quo catch with adjustment".

1. In the "cautious" scenario, it is assumed that the fishery will continue to take the average catch that has been taken over the last decade. However, if this catch causes the stock to decline, the fishery will be closed (by management action) when the stock falls below 20% of the virgin biomass and will re-open when the fishery has recovered to 20% of the virgin biomass. Kearney *et al*. (in prep.) state that "*Fishing then re-commences at levels where yearly growth and yearly production are more or less balanced*". However, it appears probable that they intended to state that subsequent catches are then maintained at the level of surplus production, thus maintaining the fish unit at 20% of the virgin biomass. This scenario may avert recruitment failure by maintaining the stock at levels above a limit reference point which might be considered appropriate where the data are of high quality and both research and management are of a high standard. However, for data-poor fisheries, or fisheries for which research and management controls are less adequate, alternative more precautionary reference points such as 30-40% of the virgin biomass should be considered (see Mace, 2002). The statement on page 23 of Kearney *et al.* (in prep.) that the cautious strategy seeks to take MSY seems incorrect, as the strategy seeks to maintain the catch at the current level but, if this is not possible, to maintain it at a level such that, in the long term, the biomass will remain above 20% of the virgin biomass.

   > Descriptions have been adjusted accordingly.

2. For the "optimum long term" scenario, catches are set at 80% of the MSY if the biomass is greater than or equal to 72% of the virgin biomass, otherwise catches are set to 80% of the estimated annual production, thus allowing the stocks to recover to 72% of the virgin biomass. This strategy, which for the Schaefer model results in a level of fishing mortality that is approximately 0.55 of the natural mortality, is more conservative than the current stock assessment view that, for sustainability, the target fishing mortality must be approximately 0.75-0.8 of the level of natural mortality. Such a level of fishing mortality is, however, considered appropriate by some fisheries scientists (Carl Walters, pers. comm.).
3. The "continuous fishing" scenario attempts to maintain annual catches at the average level for the period 1991 to 2000. That is, this strategy attempts to maintain the status quo for catches, and managers take no additional action if the biomass declines to less than 20% of the virgin biomass, where recruitment might be at greater risk of failure.

The models are run for each of these management scenarios under two scenarios. In the base scenario, the impact of seal predation is ignored, while in the alternative scenario, consumption by seals is assumed to increase as the seal and sea lion populations grow to approximately three times their current biomass by 2035. The base case scenario assumes implicitly that, even though seal and sea lion populations may increase, the impact of their increased predation has already been factored into the parameter estimates of the Schaefer models of the various fish units.

Figures 8 to 12 presented in Section 5 of Kearney *et al*. (in prep.) represent the historical catches without adjustment for the consumption by seals, while Figure 13 represents the combined impact of historical catches and seal consumption. However, in none of these figures does the caption identify that the projections, which are shown in these figures, are based on the "optimum long term" fisheries management scenario (B. Kearney, pers. comm.).

Several aspects of Figure 14 of Kearney *et al.* (in prep.) require further consideration and explanation. Why is the trajectory for the "optimum long term" projection bumpy? With the averaging resulting from the combination of a large number of fisheries and the use of deterministic projections, a smoother projection might have been expected. It is also surprising that, while Figure 14 reveals that the "optimum long term scenario drops production sharply in 2002" (statement on p.21), the decrease is only of the same magnitude as that produced under the "cautious" management strategy. It would have been expected that a further reduction in catch beyond that resulting from the "cautious" strategy might have been required under the "optimum long term" management scenario.

> The resulting planned catch rate oscillates about a trend due to the use of a one-year time step in the fish unit modelling. This is not sufficiently short for those fish units that have shorter life cycles of several months. This minor artefact could be addressed in future by nesting more refined models within the framework.
>
> The immediate reductions in catch at the beginning of both the precautious and optimum scenarios are of the same magnitude because they both reflect the temporary cessation of fishing for those fish units that are below 20% of virgin biomass at the end of the history period. The catch for the optimum scenario is marginally greater than for the precautious scenario because some recovery of short lifecycle fisheries below 50% of virgin biomass has occurred immediately under the pro-active management for the optimal scenario.

Sections 7.1 to 7.4 of Kearney *et al.* (in prep.) are nearly independent of the modelling results previously discussed (but interesting none the less). For example, projected fish imports are set to increase dramatically even if current production was to be maintained. Conversely, the projections for stock outcomes are more or less independent of "demand". This suggests that the first sentence of Section 7.2 is incorrect.

The last paragraph of Section 7.3 of Kearney *et al.* (in prep.), which discusses how uncertainty is dealt with, seems way off the mark. Having multiple scenarios does NOT "acknowledge the uncertainties in the projections". In fact, there is almost no attempt to deal with sensitivity to uncertainties in assumptions, data or methods in the whole document.

Section 7.5 of Kearney *et al.* (in prep.) does a reasonable job of acknowledging the assumptions and limitations of the study. This could usefully be synthesized into a short section on "where to from here" (future research). This study has made some "brave assumptions" in dealing with data uncertainty on catches and biomass trends, but then balks at dealing with other issues like habitat degradation because of "lack of data".

### *Fur seal and sea lion interactions*

Details of how the predation by fur seals and sea lions were included in the simulation model for the seal scenario are not yet provided in the draft document produced by Lowe *et al.* (in prep.), however Kearney *et al.* (in prep., p.16) provide a brief description of the approach that was used. Data for the seals and sea lions were derived from Goldsworthy *et al.* (in prep.). Their estimates of seal and sea lion biomass were combined with their estimates of annual consumption rates, diet composition and spatial distribution to produce estimates of the consumption of each of the fish species in the fish units of southern Australia lying within the 2000 range of the seal species. Trends in the abundance of the seal populations (Goldsworthy *et al*., in prep.) appear then to have been used to estimate historical consumption and predict future consumption (Kearney *et al*., in prep., p.19). After determining the current consumption by seals and estimating the historical levels of consumption, parameter estimates for the Schaefer model were then determined, treating the predation by seals as the "catch" by an additional "external harvester" in an identical manner to the approach used for recreational fishing (Kearney *et al*., in prep., p.27; B. Kearney, pers. comm.).

The current consumption of the species modelled in the project is estimated to be 300,000 t (Kearney *et al*., in prep., p.27) of the total consumption of 432,024 t (Goldsworthy *et al*., in prep., p.16). The increase in the abundance of seals and sea lions, which is likely to treble (Goldsworthy *et al*., in prep.), will lead to an annual prey consumption of commercial fish species in excess of 1 million tonnes by 2035 (Kearney *et al*., in prep., p.27).

The biomass dynamics models that have been used in the fish futures project do not allow consideration of the trophic interactions that have been described by Goldsworthy *et al.* (in prep.), who calculated that, while increasing seal biomass appeared to have relatively little effect on the available biomass for commercial fishers, the biomass of ling, redfish, whiting and jackass morwong increased while dories, warehou and flathead declined. Goldsworthy *et al.* (in prep.) concluded that the species composition was likely to be affected but the overall biomass available to commercial fishers was likely to remain relatively constant. Thus, it is possible that the 30,000 t impact of seal predation on commercial catches that has been predicted by Kearney *et al*. (in prep., p.28) may be an overestimate.

Kearney *et al*. (in prep., p. 27) express concern that the exponential growth of the seal populations and increase in consumption to over a million tonnes per annum may have a greater impact on the ecosystem than simply a change in species composition. The magnitude of this change goes well beyond a slight extrapolation and the impact of the increased predation is likely to extend beyond the range in which predictions from the simple production-accumulation-catch-predation-loss model, which is used in Ecopath/Ecosim, remain adequate. For example, recruitment may be affected as spawning biomass is reduced. When calculating the impact of increases in seal abundance on prey consumption, Goldsworthy *et al.* (in prep.) input a specified quantity of biomass accumulation into the Ecosim model, which thus determines the changes in biomass of the other species groups. Thus, the increase in seal biomass was assumed and was not constrained by density-dependent processes.

Both Goldsworthy *et al.* (in prep.) and Kearney *et al.* (in prep.) have identified that other predators such as cetaceans, dolphins and sea birds have an impact on fish populations. Such impacts have not yet been included in the fish futures model. However, considering seals as a proxy for these other species, the model has demonstrated that the predators' impact on fish catches and, likewise, the impact of those catches on the predator populations are likely to be important. Clearly, the impact of the increasing populations of marine mammals needs to be considered by fishery managers.

### *Minor issues*

1. The graphs in Kearney *et al*. (in prep.) should reach the year 2000, at least for human population (Fig. 1).
2. The "Effort efficiency" component that is shown on Figure 7 of Kearney *et al.* (in prep.) should become an input to "Required boat stock" rather than "Evolving fish stock", to match more appropriately the structure of the model.
3. The number of fish units modelled is specified in Lowe *et al.* (in prep.) as 158 and does not include the minor fish units included by Kearney *et al* (in prep.) who report that 220 fish units were considered. The reports should be consistent.

   Following the analysis for the report (Lowe et al) a further 62 fish units were included in the analysis, with only marginal change in aggregate figures.

4. It is not clear if, or how, discarding is dealt with in catch data. Discarding rates of target species are quite high in some fisheries (e.g. SET).
5. Reference to fishing stopping at low biomass is made on p. 29 of Kearney *et al.* (in prep.). How low? Although the methods describe the cessation of fishing when the biomass falls below 20% of the virgin biomass under the cautious management scenario, there is no indication that fishing would cease under either of the other two management strategies.
6. It is not feasible to constrain consumption to domestic supply (Kearney *et al*., in prep., p. 32).
7. The references to "catch rate" in the caption of Table 1 should be to "catch".
8. Which of the future scenarios is represented by the catches for the recreational fisheries that are shown in Figure 17? Additional details of the methods used to determine and project the recreational catches would assist.

### *References*


Goldsworthy, S. D., Bulman, C., He, X., Larcombe, J. and Littnan, C. (in prep.) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. Draft chapter for book "*Trophic Interactions between Fisheries and Marine Mammals*".

Kearney, B., Foran, B., Poldy, F. and Lowe, D. (in prep.) Modelling Australia's fisheries to 2050: policy and management implications. Draft report to Fisheries Research and Development Corporation. Version: 20 November, 2002.

Kearney, R. E. (2002). Allocating fisheries resources: Who deserves what. Conference paper presented to 3rd World Recreational Fisheries Conference, Darwin, May 2002.

Lowe, D., Foran, B., Kearney, B. and Poldy, F. (in prep.) Australian Fisheries Futures: 2020 and beyond. Draft report to Fisheries Research and Development Corporation.

Mace, P. M. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries*, **2**: 2-32.

## *Review Appendix 1. Seal and sea lion predation*

This appendix provides a brief review of the draft chapter written by Goldsworthy *et al.* (in prep.), which describes an analysis of the impact of seal and sea lion predation on commercial fisheries.

Goldsworthy *et al.* (in prep., p. 6) noted that populations of southern Australian fur seals are recovering from the exploitation that occurred prior to 1830 (should probably have been 1930) and are likely to exceed pre-exploitation numbers by *ca* 2020. Population estimates of the Australian fur seals (AFS) *Arctocephalus pusillus doriferus*, New Zealand fur seals (NZFS) *A. forsteri* and of the Australian sea lions (ASL) *Neophoca cinerea* were calculated by Goldsworthy *et al.* (in prep., p.8) from the estimates of pup production for each of the breeding colonies, which were determined from censuses taken at various times during approximately the last decade. This extrapolation, from pup to population numbers, used estimates of the age-specific survival and frequency of breeding for the AFS, NZFS and ASL. Goldsworthy *et al.* (in prep.) reported that fur seals are known to breed annually, while ASL breed about every 17.6 months. However, no data on the age-specific survival of each of the three species were available. Accordingly, Goldsworthy *et al*. (in prep.) fitted a third-order polynomial equation to life table data for female Antarctic *A. gazella*, South American *A. australis* and northern *Callorhinus ursinus* fur seals and used this for female AFS and NZFS. They then scaled the ages of the life table data by the ratio of the male to female longevities (i.e. 18 and 21 years, respectively) and refitted the polynomial equation to provide estimates of the age-specific survival of the male fur seals. These age-specific survival relationships were adjusted for the assumed longevities of male and female ASL of 30.5 and 27 years. The total population size of AFS was estimated to be 67,694, of which 80% are located in the colonies off Victoria. While the current population size of NZFS, 57,443, was of similar magnitude to that of AFS, the species was more widely distributed with 77% of the population located in South Australian waters. The population of ASL was estimated to comprise only 11,231 individuals, with 75% of pup production occurring in South Australia.

Using biomass estimates for each species, which were calculated from the population estimates using mass-age relationships (i.e., growth equations), Goldsworthy *et al*. (in prep.) estimated the annual energy requirements for each species. These estimates were then used to calculate the total annual prey biomass currently consumed by each species, which amounted to 240,317, 143,906 and 47,801 t for AFS, NZFS and ASL, respectively, a total annual consumption of 432,024 t. The distribution of foraging by each colony was assumed to have no directional component and the probability of foraging occurring at different distances from each colony was assumed by Goldworthy *et al*. (in prep.) to be described by a normal probability distribution, where the standard deviations of these distributions were estimated from (limited) satellite tracking data. Using the resultant probability distributions, Goldsworthy *et al.* (in prep.) derived estimates of the spatial distribution of annual prey consumption associated with each colony and compared these estimates with the spatial distribution of commercial catches. Goldsworthy *et al.* (in prep.) observed that the total commercial catch from the states in which seals do not breed or forage amounts to 152,234 t, or 35% of the annual consumption by seals. In the region encompassing the waters off Victoria and Tasmania, and the adjacent Commonwealth waters, Goldsworthy *et al.* (in prep., p.18) reported that seals consume 225,874 t·year$^{-1}$ compared with the commercial catch of 45,413 t. and in the Eastern Bass Strait Ecosystem (EBSE), they consume 39,222 t·year$^{-1}$ whereas commercial fishers have an annual catch (including discards) of 9,599 t and annual landings of 6,515 t. According to Goldsworthy *et al.* (in prep.), 51% of the biomass consumed by the seals in the EBSE consists of species that are fished commercially.

To investigate further the implications of the interactions between the fur seals and sea lions and the fish species caught by commercial fishers, Goldworthy *et al.* (in prep.) developed an EcoSim model for the Eastern Bass Strait shelf ecosystem. This model used, as inputs, details of the diet composition, catch (both retained and discarded), assimilation, migration and biomass accumulation of the different functional groups within the ecosystem. Goldsworthy *et al.* (in prep., p.15) noted that the "Ecosim simulations were not intended to be quantitative, but qualitative in terms of direction and magnitude of biomass change". Perhaps this explains the difference between the values that they have estimated for the consumption within the ESBE by seals of 39,222 t in their Table 6 (p. 59) and 87,748 t in their Table 7 (p.60). A similar discrepancy exists between the estimates of annual commercial catch (including discards) of 9,599 t in Table 6 and 21,883 t in Table 7.

When Goldsworthy *et al.* (in prep.) simulated an increase in fishing effort, seal biomass was found to increase slightly, while a decrease in fishing effort resulted in a slight decrease in the seal biomass. They attributed this result to the fact that fishing effort has little effect on those species that comprise the major portion of the seals' diet, while the large fish targeted by fishers compete with seals for their prey. If exploitation of the small pelagic fish, which are an important component of the seals prey, was to be increased, Goldsworthy *et al.* (in prep.) found that the seal biomass would be reduced.

Growth of the seal populations in the EBSE over the next 30 years to either their estimated pre-exploitation biomass or to in excess of their pre-exploitation biomass was also considered by Goldsworthy *et al.* (in prep.), by entering biomass accumulation terms into the Ecopath/Ecosim model. While increasing seal biomass appeared to have relatively little effect on the available biomass for commercial fishers, the biomass of ling, redfish, whiting and jackass morwong increased while dories, warehou and flathead declined. Thus, species composition was likely to be affected, but overall biomass available to commercial fishers was likely to remain relatively constant. Although the seal populations are thought to be recovering, Goldworthy *et al*. (in prep., p.28) were unable to provide estimates of the rate or extent of such recovery. However, they noted that experience in populations of other species of fur seals suggested that the fur seal populations might recover to or beyond their pre-exploitation levels.

The ecosystem model that was developed for the EBSE currently excludes birds, cetaceans and dolphins, but Goldsworthy *et al*. (in prep.) note that, when data become available, it could be extended to include these groups. It is clear from this study, however, that, if the populations of fur seals and sea lions recover to the extent that appears likely, their consumption of fish is likely to treble. While the overall impact on catches may not be greatly affected, the impact for different species and fish stocks in particular regions may well be very significant.

# Appendix B - Schaefer parameters

The two parameters, k (virgin biomass) and r, used in the Schaefer model to determine the fish unit stock levels are given in Table B.1. The process to estimate the parameters was described in Chapter Three - using the data documented in Chapter Four - .

**Table B.1** Schaefer parameters for all 220 fish unts

| Fishery | CAAB | Family Common name | Virgin biomass (tonnes) | r (year$^{-1}$) |
|---|---|---|---|---|
| BSCZSF | 23270000 | scallop | 3,414 | 0.49 |
| ETBF | 37441000 | Mackerels_and_tunas | 6,500,000 | 0.88 |
| ETBF | 37442000 | broadbill_swordfishes | 12,000 | 0.33 |
| GABTF | 37255000 | roughies_and_sawbellies | 39,000 | 0.03 |
| GABTF | 37258000 | Redfishes_nannygais_and_alfonsin | 11,000 | 0.11 |
| GABTF | 37296000 | Flatheads | 13,638 | 0.22 |
| GABTF | 37345000 | Redbait | 179,323 | 0.33 |
| GABTF | 99999000 | Other_Unknown | 4,418 | 0.31 |
| NPF | 28711000 | penaeid_prawns | 37,280 | 1.00 |
| SBTF | 37441000 | Mackerels_and_tunas | 625,181 | 0.24 |
| SEF | 28714000 | penaeid_prawns_2 | 722 | 2.47 |
| SEF | 37227000 | hakes_and_southern_hakes | 72,000 | 0.20 |
| SEF | 37228000 | aphyonids_live-bearing_brotulas | 14,661 | 0.50 |
| SEF | 37255000 | roughies_and_sawbellies | 209,597 | 0.08 |
| SEF | 37258000 | Redfishes_nannygais_and_alfonsin | 28,774 | 0.24 |
| SEF | 37264000 | Dories | 5,548 | 0.60 |
| SEF | 37287000 | scorpionfishes | 4,293 | 0.16 |
| SEF | 37296000 | Flatheads | 22,924 | 0.60 |
| SEF | 37330000 | whitings | 6,901 | 1.20 |
| SEF | 37337000 | Trevallies_and_jacks | 12,060 | 0.20 |
| SEF | 37345000 | Redbait | 179,323 | 0.33 |
| SEF | 37377000 | Morwongs | 12,734 | 0.40 |
| SEF | 37439000 | black_mackerels_snake_mackerels | 36,518 | 0.40 |
| SEF | 37445000 | trevallas | 39,830 | 0.40 |
| SEF | 99999000 | Other_Unknown | 40,636 | 0.31 |
| SSF | 37017000 | hound_sharks | 44,219 | 0.24 |
| SSF | 37999000 | Other_Teleosts | 5,041 | 0.31 |
| SSJF | 23615000 | squid_&_calamary | 4,254 | 4.88 |
| TSOF | 37441000 | Mackerels_and_tunas | 842 | 0.35 |
| TSPF | 28711000 | penaeid_prawns | 4,400 | 2.40 |
| TSRLF | 28820000 | spiny_lobsters | 1,050 | 0.88 |
| Estuarine | 23359000 | pipis | 1,650 | 1.65 |
| Estuarine | 23615000 | squid_&_calamary | 220 | 4.88 |
| Estuarine | 28711000 | penaeid_prawns | 1,700 | 2.40 |
| Estuarine | 37085000 | Herrings_sardines_pichards_and_s | 1,800 | 0.51 |
| Estuarine | 37337000 | Trevallies_and_jacks | 4,100 | 0.15 |
| Estuarine | 37344000 | Australian_salmons | 4,400 | 0.19 |
| Estuarine | 37353000 | breams | 4,800 | 0.40 |
| Estuarine | 37361000 | drummers_and_sweeps | 8,500 | 0.34 |

| Fishery | CAAB | Family Common name | Virgin biomass (tonnes) | r ($year^{-1}$) |
|---|---|---|---|---|
| Estuarine | 37381000 | Mullets | 40,000 | 0.33 |
| Estuary_Prawn_Trawl | 28711000 | penaeid_prawns | 1,600 | 2.40 |
| Fish_Trawl | 23607000 | Cuttlefish | 166 | 2.47 |
| Fish_Trawl | 23615000 | squid_&_calamary | 865 | 4.88 |
| Fish_Trawl | 37330000 | whitings | 2,743 | 0.41 |
| Fish_Trawl | 37337000 | Trevallies_and_jacks | 14,641 | 0.11 |
| Fish_Trawl | 37345000 | Redbait | 78,782 | 0.33 |
| Fish_Trawl | 37353000 | breams | 2,289 | 0.40 |
| Ocean_Hauling | 37085000 | Herrings_sardines_pichards_and_s | 1,000 | 0.73 |
| Ocean_Hauling | 37337000 | Trevallies_and_jacks | 2,100 | 0.15 |
| Ocean_Hauling | 37344000 | Australian_salmons | 6,200 | 0.19 |
| Ocean_Hauling | 37361000 | drummers_and_sweeps | 1,783 | 0.34 |
| Ocean_Hauling | 37381000 | Mullets | 15,000 | 0.33 |
| Ocean_Hauling | 37441000 | Mackerels_and_tunas | 2,700 | 0.35 |
| Ocean_Prawn_Trawl | 23607000 | Cuttlefish | 398 | 2.47 |
| Ocean_Prawn_Trawl | 23615000 | squid_&_calamary | 240 | 4.88 |
| Ocean_Prawn_Trawl | 23659000 | octopuses | 871 | 3.30 |
| Ocean_Prawn_Trawl | 28711000 | penaeid_prawns | 2,400 | 1.76 |
| Ocean_Prawn_Trawl | 37330000 | whitings | 5,600 | 0.73 |
| Ocean_Trapline | 37337000 | Trevallies_and_jacks | 3,500 | 0.15 |
| Ocean_Trapline | 37353000 | breams | 10,612 | 0.14 |
| Other_NSW | 23359000 | pipis | 280 | 1.65 |
| Other_NSW | 23607000 | Cuttlefish | 153 | 2.47 |
| Other_NSW | 23615000 | squid_&_calamary | 260 | 4.88 |
| Other_NSW | 23659000 | octopuses | 262 | 3.30 |
| Other_NSW | 28711000 | penaeid_prawns | 1,800 | 2.40 |
| Other_NSW | 37085000 | Herrings_sardines_pichards_and_s | 2,400 | 0.51 |
| Other_NSW | 37330000 | whitings | 3,070 | 0.41 |
| Other_NSW | 37337000 | Trevallies_and_jacks | 17,000 | 0.11 |
| Other_NSW | 37344000 | Australian_salmons | 5,600 | 0.19 |
| Other_NSW | 37353000 | breams | 8,000 | 0.23 |
| Other_NSW | 37381000 | Mullets | 11,000 | 0.33 |
| Other_NSW | 37441000 | Mackerels_and_tunas | 1,750 | 0.35 |
| Abalone_Vic | 24038000 | abalones | 19,951 | 0.30 |
| Bays_and_Inlets | 23220000 | mussels | 2,496 | 0.20 |
| Bays_and_Inlets | 23615000 | squid_&_calamary | 146 | 4.88 |
| Bays_and_Inlets | 37085000 | Herrings_sardines_pichards_and_s | 6,682 | 0.73 |
| Bays_and_Inlets | 37086000 | anchovies | 4,500 | 0.82 |
| Bays_and_Inlets | 37165000 | Carp_barbs_and_goldfish | 15,613 | 0.44 |
| Bays_and_Inlets | 37234000 | Garfishes | 850 | 0.73 |
| Bays_and_Inlets | 37296000 | Flatheads | 4,944 | 0.30 |
| Bays_and_Inlets | 37330000 | whitings | 3,739 | 0.34 |
| Bays_and_Inlets | 37344000 | Australian_salmons | 8,454 | 0.19 |
| Bays_and_Inlets | 37353000 | breams | 11,116 | 0.23 |
| Bays_and_Inlets | 37361000 | drummers_and_sweeps | 481 | 0.34 |
| Bays_and_Inlets | 37381000 | Mullets | 4,248 | 0.33 |
| Danish_Seine | 37296000 | Flatheads | 7,760 | 0.30 |
| Danish_Seine | 37330000 | whitings | 4,333 | 0.41 |

| Fishery | CAAB | Family Common name | Virgin biomass (tonnes) | r (year$^{-1}$) |
|---|---|---|---|---|
| Danish_Seine | 37345000 | Redbait | 78,782 | 0.33 |
| Freshwater | 37056000 | Freshwater_eels | 8,803 | 0.11 |
| Freshwater | 37165000 | Carp_barbs_and_goldfish | 12,211 | 0.44 |
| Ocean_Fishery | 23615000 | squid_&_calamary | 1,630 | 4.88 |
| Ocean_Fishery | 37017000 | hound_sharks | 2,000 | 0.22 |
| Ocean_Fishery | 37085000 | Herrings_sardines_pichards_and_s | 6,795 | 0.73 |
| Ocean_Fishery | 37086000 | anchovies | 1,263 | 0.82 |
| Ocean_Fishery | 37228000 | aphyonids_live-bearing_brotulas | 441 | 0.16 |
| Ocean_Fishery | 37344000 | Australian_salmons | 5,700 | 0.19 |
| Ocean_Fishery | 37441000 | Mackerels_and_tunas | 1,477 | 0.35 |
| Ocean_Fishery | 37445000 | trevallas | 5,346 | 0.21 |
| Otter_Trawl | 23615000 | squid_&_calamary | 225 | 4.88 |
| Otter_Trawl | 37227000 | hakes_and_southern_hakes | 3,700 | 0.20 |
| Otter_Trawl | 37296000 | Flatheads | 3,175 | 0.44 |
| Otter_Trawl | 37345000 | Redbait | 78,782 | 0.33 |
| Otter_Trawl | 37377000 | Morwongs | 7,000 | 0.11 |
| Otter_Trawl | 37439000 | black_mackerels_snake_mackerels | 4,263 | 0.34 |
| Otter_Trawl | 37445000 | trevallas | 1,330 | 0.21 |
| Otter_Trawl | 99999000 | Other_Unknown | 505 | 0.31 |
| Rock_Lobster_Vic | 28820000 | spiny_lobsters | 5,083 | 0.40 |
| Rock_Lobster_Vic | 28925000 | eriphiid_crabs | 520 | 0.33 |
| Scallop | 23220000 | mussels | 9,035 | 0.20 |
| Scallop | 23270000 | scallop | 56,878 | 0.49 |
| Shark | 37017000 | hound_sharks | 16,000 | 0.22 |
| Shark | 37023000 | Sawsharks | 2,146 | 0.33 |
| Shark | 37445000 | trevallas | 3,121 | 0.21 |
| LINE | 37311000 | Freshwater_perches_temperate_bas | 12,500 | 0.23 |
| LINE | 37351000 | emperors_and_sea_breams | 4,900 | 0.25 |
| LINE | 37353000 | breams | 5,004 | 0.23 |
| LINE | 37441000 | Mackerels_and_tunas | 4,900 | 0.44 |
| MIXED | 28711000 | penaeid_prawns | 319 | 2.40 |
| MIXED | 28865000 | spanner_crabs | 5,312 | 0.55 |
| MIXED | 28911000 | swimming_crabs | 1,643 | 1.65 |
| MIXED | 37310000 | snooks_and_barramundi_and_glass f | 5,854 | 0.30 |
| MIXED | 37311000 | Freshwater_perches_temperate_bas | 11,182 | 0.23 |
| MIXED | 37330000 | whitings | 5,185 | 0.41 |
| MIXED | 37351000 | emperors_and_sea_breams | 3,820 | 0.25 |
| MIXED | 37353000 | breams | 5,325 | 0.29 |
| MIXED | 37381000 | Mullets | 22,794 | 0.33 |
| MIXED | 37441000 | Mackerels_and_tunas | 6,000 | 0.44 |
| NET/CRAB | 28865000 | spanner_crabs | 15,358 | 0.55 |
| NET/CRAB | 28911000 | swimming_crabs | 2,500 | 1.65 |
| NET/CRAB | 37310000 | snooks_and_barramundi_and_glass f | 6,100 | 0.22 |
| NET/CRAB | 37330000 | whitings | 4,738 | 0.41 |
| NET/CRAB | 37381000 | Mullets | 14,000 | 0.33 |
| NET/CRAB | 37441000 | Mackerels_and_tunas | 2,469 | 0.44 |
| SPANNER | 28865000 | spanner_crabs | 13,364 | 0.55 |

| Fishery | CAAB | Family Common name | Virgin biomass (tonnes) | r ($year^{-1}$) |
|---|---|---|---|---|
| TRAWL | 23270000 | scallop | 21,297 | 1.22 |
| TRAWL | 28711000 | penaeid_prawns | 15,400 | 2.40 |
| TRAWL | 28821000 | shovel-nosed/slipper_lobsters | 3,349 | 0.66 |
| TRAWL | 28911000 | swimming_crabs | 589 | 1.65 |
| TRAWL | 37330000 | whitings | 12,491 | 0.41 |
| Abalone_SA | 24038000 | abalones | 12,868 | 0.30 |
| Inland_waters | 23359000 | pipis | 1,900 | 1.65 |
| Inland_waters | 37085000 | Herrings_sardines_pichards_and_s | 8,102 | 0.44 |
| Inland_waters | 37165000 | Carp_barbs_and_goldfish | 27,476 | 0.44 |
| Inland_waters | 37311000 | Freshwater_perches_temperate_bas | 10,682 | 0.10 |
| Inland_waters | 37329000 | freshwater_perches | 390 | 0.33 |
| Inland_waters | 37381000 | Mullets | 3,129 | 0.33 |
| Marine_Scale | 23359000 | pipis | 1,400 | 1.65 |
| Marine_Scale | 23615000 | squid_&_calamary | 1,308 | 4.88 |
| Marine_Scale | 28911000 | swimming_crabs | 3,067 | 1.65 |
| Marine_Scale | 37029000 | eastern_shovelnose_ray | 20,000 | 0.22 |
| Marine_Scale | 37085000 | Herrings_sardines_pichards_and_s | 30,184 | 0.73 |
| Marine_Scale | 37234000 | Garfishes | 6,128 | 0.73 |
| Marine_Scale | 37330000 | whitings | 20,678 | 0.37 |
| Marine_Scale | 37344000 | Australian_salmons | 13,412 | 0.55 |
| Marine_Scale | 37345000 | Redbait | 125,469 | 0.33 |
| Marine_Scale | 37353000 | breams | 10,039 | 0.14 |
| Marine_Scale | 37381000 | Mullets | 2,035 | 0.33 |
| Marine_Scale | 37382000 | Pikes | 1,315 | 0.33 |
| Marine_Scale | 37465000 | Triggerfishes_and_leatherjackets | 4,959 | 0.55 |
| Marine_Scale | 99999000 | Other_Unknown | 1,780 | 0.31 |
| Miscellaneous | 23659000 | octopuses | 702 | 3.30 |
| Miscellaneous | 24999000 | Other_Molluscs | 2,210 | 0.31 |
| Prawn | 28711000 | penaeid_prawns | 10,500 | 1.22 |
| Rock_Lobster_SA | 28820000 | spiny_lobsters | 25,385 | 0.40 |
| WA | 23270000 | scallop | 34,487 | 1.22 |
| WA | 23615000 | squid_&_calamary | 1,088 | 4.88 |
| WA | 23659000 | octopuses | 229 | 3.30 |
| WA | 24038000 | abalones | 5,400 | 0.25 |
| WA | 25415000 | Beche-de-mer | 960 | 0.82 |
| WA | 28711000 | penaeid_prawns | 15,000 | 1.46 |
| WA | 28795000 | Yabbies | 957 | 0.82 |
| WA | 28820000 | spiny_lobsters | 129,412 | 0.40 |
| WA | 28911000 | swimming_crabs | 3,244 | 1.65 |
| WA | 37013000 | Blind/nurse/longtail_carpet/cat/ | 613 | 0.33 |
| WA | 37017000 | hound_sharks | 8,000 | 0.29 |
| WA | 37018000 | whaler_sharks_and_weasel_sharks | 10,000 | 0.15 |
| WA | 37029000 | eastern_shovelnose_ray | 26,000 | 0.22 |
| WA | 37085000 | Herrings_sardines_pichards_and_s | 48,094 | 0.73 |
| WA | 37188000 | Forktailed_Catfishes | 1,062 | 0.33 |
| WA | 37192000 | eel-tailed_catfishes | 1,824 | 0.38 |
| WA | 37287000 | scorpionfishes | 492 | 0.16 |
| WA | 37311000 | Freshwater_perches_temperate_bas | 1,760 | 0.23 |

| Fishery | CAAB | Family Common name | Virgin biomass (tonnes) | r (year$^{-1}$) |
|---|---|---|---|---|
| WA | 37320000 | pearl_perches | 2,169 | 0.33 |
| WA | 37330000 | whitings | 9,507 | 0.41 |
| WA | 37337000 | Trevallies_and_jacks | 7,698 | 0.29 |
| WA | 37344000 | Australian_salmons | 29,000 | 0.55 |
| WA | 37346000 | fusiliers_sea_perches_and_snappe | 4,192 | 0.27 |
| WA | 37347000 | threadfin_breams_monocle_breams | 1,404 | 0.33 |
| WA | 37350000 | grunter_breams | 671 | 0.33 |
| WA | 37351000 | emperors_and_sea_breams | 12,000 | 0.22 |
| WA | 37353000 | breams | 21,000 | 0.18 |
| WA | 37377000 | Morwongs | 928 | 0.21 |
| WA | 37381000 | Mullets | 13,283 | 0.33 |
| WA | 37383000 | threadfin_salmons | 934 | 0.25 |
| WA | 37384000 | Wrasses | 836 | 0.25 |
| WA | 37441000 | Mackerels_and_tunas | 5,251 | 0.35 |
| WA | 37465000 | Triggerfishes_and_leatherjackets | 414 | 0.55 |
| WA | 37999000 | Other_Teleosts | 5,766 | 0.31 |
| Abalone_Tas | 24038000 | abalones | 36,289 | 0.30 |
| Rock_Lobster_Tas | 28820000 | spiny_lobsters | 16,934 | 0.40 |
| Scalefish | 37234000 | Garfishes | 392 | 0.73 |
| Scalefish | 37296000 | Flatheads | 7,641 | 0.30 |
| Scalefish | 37330000 | whitings | 654 | 0.41 |
| Scalefish | 37337000 | Trevallies_and_jacks | 97,451 | 0.29 |
| Scalefish | 37344000 | Australian_salmons | 13,000 | 0.19 |
| Scalefish | 37377000 | Morwongs | 2,400 | 0.18 |
| Scalefish | 37378000 | trumpeters | 968 | 0.33 |
| Scalefish | 37384000 | Wrasses | 877 | 0.25 |
| Scalefish | 37439000 | black_mackerels_snake_mackerels | 2,400 | 0.49 |
| Scalefish | 37445000 | trevallas | 2,431 | 0.29 |
| Scalefish | 37999000 | Other_Teleosts | 100,156 | 0.31 |
| NT | 28911000 | swimming_crabs | 1,463 | 1.65 |
| NT | 37029000 | eastern_shovelnose_ray | 6,300 | 0.33 |
| NT | 37310000 | snooks_and_barramundi_and_glass f | 8,167 | 0.30 |
| NT | 37346000 | fusiliers_sea_perches_and_snappe | 3,676 | 0.27 |
| NT | 37351000 | emperors_and_sea_breams | 588 | 0.25 |
| NT | 37353000 | breams | 6,500 | 0.23 |
| NT | 37383000 | threadfin_salmons | 6,200 | 0.25 |
| NT | 37441000 | Mackerels_and_tunas | 5,100 | 0.35 |
| NT | 37999000 | Other_Teleosts | 2,524 | 0.31 |

# Appendix C - Resilience of fish units

An index indicating the exploitation status has been established for each fish unit. This relates how well the fish unit can absorb losses due to wild capture fishing. Underlying this construct is the assumption that a fish unit at very low levels of biomass is susceptible to collapse i.e., unrecoverable reduction in the biomass, from anthropogenic or other causes. Natural variations in a species biomass will occur for a variety of reasons such as disease or environmental changes. Depending on the details of the species such variations have the potential to directly cause the species to collapse. Additionally, natural fluctuations in biomass may mean that a previously 'safe' level of fishing is subsequently so high as to collapse the fishery.

The exploitation status has been constructed from the combination of two components. One recognises the importance of the relative level of the fish unit stock or biomass. Based on judicious choice of biomass proportion (relative to virgin biomass), this measure of "stock resilience" was ascribed as: under-utilised; fully-utilised; over-utilised; and critical. The ratio of biomass to virgin biomass that has been ascribed to each of these categories is shown in the left columns of Table C.1.

The second component measures the effect of catch rate. This "catch resilience" is determined by comparing the actual annual catch with the growth rate of the fish unit. If the catch is greater than the growth rate then the biomass is clearly reduced in that time period. The category labels of catch resilience are the same as for stock resilience. The ratio of catch to growth rate for each category is shown in the upper rows of Table C.1. Note that the catch resilience is a function of the biomass since the growth rate changes with the level of biomass (as depicted by the logistic curve of the Schaefer model—growth rates are lowest at minimal biomass, increasing to a maximum at half the virgin biomass, and then decreasing as the biomass asymptotically approaches the virgin biomass).

The two resilience components were determined for each fish unit, and over time for each of the three scenarios that described the alternative management regimes. Each component category was given an arbitrary index, from 0 to 3, with the higher index indicating greater levels of exploitation. The two components were then combined (simply summed) into the one combined indicator as described in Table C.1. It is suggested that an integrative index such as this be further developed in the next phase of the work, particularly directed at the policy requirements of ministerial advisors, fisheries agencies executives and environmental NGOs.

**Table C.1** Indices and categories of resilience

| | | | Catch to Growth ratio | | | |
|---|---|---|---|---|---|---|
| | | Relative Range | 0.0-0.5 | 0.5-1.0 | 1.0-1.5 | >1.5 |
| | | Description | Under-utilised | Fully-utilised | Over-utilised | Critical |
| | | Index | 0 | 1 | 2 | 3 |
| Biomass to virgin biomass ratio: Relative Range | Description | Index | **Combined Indicator** | | | |
| 0.8-1.0 | Under-utilised | 0 | **0** | **1** | **2** | **3** |
| 0.5-0.8 | Fully-utilised | 1 | **1** | **2** | **3** | **4** |
| 0.2-0.5 | Over-utilised | 2 | **2** | **3** | **4** | **5** |
| 0.0-0.2 | Critical | 3 | **3** | **4** | **5** | **6** |

Since the combined index now extends from 0 to 6, two additional categories (namely severe and super-critical) were introduced as shown in Table C.2 to highlight those species that were critical in *both* stock and catch resilience. (Using this structure, it was also possible to track over the scenario period (including a short period preceding the scenarios) the direction of change of resilience status for each fish unit.)

**Table C.2** Combined indicator and corresponding categories

| Combined Indicator | Category label |
|---|---|
| 0 | Under-utilised |
| 1 | Under-utilised |
| 2 | Fully-utilised |
| 3 | Over-utilised |
| 4 | Severe |
| 5 | Critical |
| 6 | Super-critical |

The following table (Table C.3) shows the combined indicator (of exploitation status) for each of the 220 fish units. The combination of 'Fishery' and CAAB fields uniquely identifies each of the fish units. The indicator for 2001 is the same for the three scenarios. The indicator for each scenario is shown for 2051.

Summary graphs following this table illustrate how the overall status of Australian fisheries changes over time for each of the scenarios.

**Table C.3** Combined indicator status for all fish units under the three scenarios in 2051, and for 2001.

| | Fishery | CAAB | Family Common name | 2001 | continuous | precautionary | optimistic |
|---|---|---|---|---|---|---|---|
| 1 | BSCZSF | 23270000 | scallop | 1 | 6 | 4 | 2 |
| 2 | ETBF | 37441000 | Mackerels_and_tunas | 2 | 3 | 3 | 2 |
| 3 | ETBF | 37442000 | broadbill_swordfishes | 4 | 2 | 2 | 2 |
| 4 | GABTF | 37255000 | roughies_and_sawbellies | 6 | 6 | 4 | 3 |
| 5 | GABTF | 37258000 | Redfishes_nannygais_and_alfonsin | 4 | 3 | 3 | 3 |
| 6 | GABTF | 37296000 | Flatheads | 3 | 6 | 4 | 2 |
| 7 | GABTF | 37345000 | Redbait | 3 | 3 | 3 | 3 |
| 8 | GABTF | 99999000 | Other_Unknown | 6 | 6 | 4 | 3 |
| 9 | NPF | 28711000 | penaeid_prawns | 2 | 2 | 2 | 2 |
| 10 | SBTF | 37441000 | Mackerels_and_tunas | 6 | 6 | 4 | 4 |
| 11 | SEF | 28714000 | penaeid_prawns_2 | 2 | 2 | 2 | 2 |
| 12 | SEF | 37227000 | hakes_and_southern_hakes | 4 | 6 | 4 | 2 |
| 13 | SEF | 37228000 | aphyonids_live-bearing_brotulas | 3 | 3 | 3 | 2 |
| 14 | SEF | 37255000 | roughies_and_sawbellies | 6 | 6 | 4 | 4 |
| 15 | SEF | 37258000 | Redfishes_nannygais_and_alfonsin | 3 | 6 | 4 | 2 |
| 16 | SEF | 37264000 | Dories | 1 | 2 | 2 | 2 |
| 17 | SEF | 37287000 | scorpionfishes | 6 | 6 | 4 | 4 |
| 18 | SEF | 37296000 | Flatheads | 3 | 2 | 2 | 2 |
| 19 | SEF | 37330000 | whitings | 2 | 2 | 2 | 2 |
| 20 | SEF | 37337000 | Trevallies_and_jacks | 2 | 3 | 3 | 2 |
| 21 | SEF | 37345000 | Redbait | 3 | 3 | 3 | 3 |
| 22 | SEF | 37377000 | Morwongs | 2 | 2 | 2 | 2 |
| 23 | SEF | 37439000 | black_mackerels_snake_mackerels | 2 | 1 | 1 | 2 |
| 24 | SEF | 37445000 | trevallas | 2 | 4 | 4 | 2 |

| | Fishery | CAAB | Family Common name | 2001 | continuous | precautionary | optimistic |
|---|---|---|---|---|---|---|---|
| 25 | SEF | 99999000 | Other_Unknown | 6 | 6 | 4 | 4 |
| 26 | SSF | 37017000 | hound_sharks | 2 | 2 | 2 | 2 |
| 27 | SSF | 37999000 | Other_Teleosts | 6 | 6 | 4 | 4 |
| 28 | SSJF | 23615000 | squid_&_calamary | 0 | 0 | 0 | 3 |
| 29 | TSOF | 37441000 | Mackerels_and_tunas | 6 | 6 | 4 | 3 |
| 30 | TSPF | 28711000 | penaeid_prawns | 2 | 2 | 2 | 2 |
| 31 | TSRLF | 28820000 | spiny_lobsters | 3 | 2 | 2 | 2 |
| 32 | Estuarine | 23359000 | pipis | 3 | 2 | 2 | 2 |
| 33 | Estuarine | 23615000 | squid_&_calamary | 0 | 0 | 0 | 0 |
| 34 | Estuarine | 28711000 | penaeid_prawns | 1 | 2 | 2 | 2 |
| 35 | Estuarine | 37085000 | Herrings_sardines_pichards_and_s | 1 | 2 | 2 | 3 |
| 36 | Estuarine | 37337000 | Trevallies_and_jacks | 1 | 2 | 2 | 2 |
| 37 | Estuarine | 37344000 | Australian_salmons | 0 | 1 | 1 | 3 |
| 38 | Estuarine | 37353000 | breams | 3 | 6 | 4 | 2 |
| 39 | Estuarine | 37361000 | drummers_and_sweeps | 2 | 3 | 3 | 3 |
| 40 | Estuarine | 37381000 | Mullets | 1 | 2 | 2 | 3 |
| 41 | Estuary_Prawn_Trawl | 28711000 | penaeid_prawns | 1 | 1 | 1 | 2 |
| 42 | Fish_Trawl | 23607000 | Cuttlefish | 1 | 2 | 2 | 2 |
| 43 | Fish_Trawl | 23615000 | squid_&_calamary | 0 | 0 | 0 | 3 |
| 44 | Fish_Trawl | 37330000 | whitings | 2 | 6 | 4 | 2 |
| 45 | Fish_Trawl | 37337000 | Trevallies_and_jacks | 1 | 2 | 2 | 2 |
| 46 | Fish_Trawl | 37345000 | Redbait | 3 | 3 | 3 | 3 |
| 47 | Fish_Trawl | 37353000 | breams | 2 | 3 | 3 | 3 |
| 48 | Ocean_Hauling | 37085000 | Herrings_sardines_pichards_and_s | 2 | 2 | 2 | 2 |
| 49 | Ocean_Hauling | 37337000 | Trevallies_and_jacks | 1 | 6 | 4 | 2 |
| 50 | Ocean_Hauling | 37344000 | Australian_salmons | 2 | 6 | 4 | 2 |
| 51 | Ocean_Hauling | 37361000 | drummers_and_sweeps | 2 | 6 | 6 | 2 |
| 52 | Ocean_Hauling | 37381000 | Mullets | 2 | 6 | 4 | 2 |
| 53 | Ocean_Hauling | 37441000 | Mackerels_and_tunas | 3 | 6 | 4 | 2 |
| 54 | Ocean_Prawn_Trawl | 23607000 | Cuttlefish | 2 | 2 | 2 | 2 |
| 55 | Ocean_Prawn_Trawl | 23615000 | squid_&_calamary | 0 | 0 | 0 | 3 |
| 56 | Ocean_Prawn_Trawl | 23659000 | octopuses | 4 | 4 | 4 | 2 |
| 57 | Ocean_Prawn_Trawl | 28711000 | penaeid_prawns | 3 | 3 | 3 | 2 |
| 58 | Ocean_Prawn_Trawl | 37330000 | whitings | 3 | 3 | 3 | 2 |
| 59 | Ocean_Trapline | 37337000 | Trevallies_and_jacks | 4 | 4 | 4 | 2 |
| 60 | Ocean_Trapline | 37353000 | breams | 3 | 2 | 2 | 2 |
| 61 | Other_NSW | 23359000 | pipis | 3 | 3 | 3 | 3 |
| 62 | Other_NSW | 23607000 | Cuttlefish | 3 | 2 | 2 | 2 |
| 63 | Other_NSW | 23615000 | squid_&_calamary | 0 | 0 | 0 | 3 |
| 64 | Other_NSW | 23659000 | octopuses | 4 | 4 | 4 | 2 |
| 65 | Other_NSW | 28711000 | penaeid_prawns | 1 | 0 | 0 | 2 |
| 66 | Other_NSW | 37085000 | Herrings_sardines_pichards_and_s | 3 | 2 | 2 | 2 |
| 67 | Other_NSW | 37330000 | whitings | 4 | 6 | 3 | 2 |
| 68 | Other_NSW | 37337000 | Trevallies_and_jacks | 3 | 6 | 4 | 2 |
| 69 | Other_NSW | 37344000 | Australian_salmons | 3 | 6 | 4 | 2 |
| 70 | Other_NSW | 37353000 | breams | 2 | 4 | 4 | 2 |
| 71 | Other_NSW | 37381000 | Mullets | 3 | 6 | 4 | 2 |
| 72 | Other_NSW | 37441000 | Mackerels_and_tunas | 3 | 3 | 3 | 3 |

| | Fishery | CAAB | Family Common name | 2001 | continuous | precautionary | optimistic |
|---|---|---|---|---|---|---|---|
| 73 | Abalone_Vic | 24038000 | abalones | 2 | 2 | 2 | 2 |
| 74 | Bays_and_Inlets | 23220000 | mussels | 3 | 6 | 4 | 3 |
| 75 | Bays_and_Inlets | 23615000 | squid_&_calamary | 0 | 4 | 4 | 4 |
| 76 | Bays_and_Inlets | 37085000 | Herrings_sardines_pichards_and_s | 1 | 2 | 2 | 2 |
| 77 | Bays_and_Inlets | 37086000 | anchovies | 1 | 2 | 2 | 3 |
| 78 | Bays_and_Inlets | 37165000 | Carp_barbs_and_goldfish | 2 | 1 | 1 | 3 |
| 79 | Bays_and_Inlets | 37234000 | Garfishes | 1 | 2 | 2 | 2 |
| 80 | Bays_and_Inlets | 37296000 | Flatheads | 2 | 4 | 4 | 2 |
| 81 | Bays_and_Inlets | 37330000 | whitings | 3 | 3 | 3 | 2 |
| 82 | Bays_and_Inlets | 37344000 | Australian_salmons | 2 | 1 | 1 | 2 |
| 83 | Bays_and_Inlets | 37353000 | breams | 4 | 6 | 4 | 2 |
| 84 | Bays_and_Inlets | 37361000 | drummers_and_sweeps | 6 | 6 | 4 | 3 |
| 85 | Bays_and_Inlets | 37381000 | Mullets | 2 | 2 | 2 | 2 |
| 86 | Danish_Seine | 37296000 | Flatheads | 2 | 2 | 2 | 2 |
| 87 | Danish_Seine | 37330000 | whitings | 1 | 1 | 1 | 2 |
| 88 | Danish_Seine | 37345000 | Redbait | 3 | 3 | 3 | 3 |
| 89 | Freshwater | 37056000 | Freshwater_eels | 2 | 4 | 4 | 2 |
| 90 | Freshwater | 37165000 | Carp_barbs_and_goldfish | 2 | 1 | 1 | 3 |
| 91 | Ocean_Fishery | 23615000 | squid_&_calamary | 3 | 0 | 0 | 1 |
| 92 | Ocean_Fishery | 37017000 | hound_sharks | 1 | 2 | 2 | 2 |
| 93 | Ocean_Fishery | 37085000 | Herrings_sardines_pichards_and_s | 1 | 1 | 1 | 3 |
| 94 | Ocean_Fishery | 37086000 | anchovies | 1 | 2 | 2 | 2 |
| 95 | Ocean_Fishery | 37228000 | aphyonids_live-bearing_brotulas | 3 | 6 | 4 | 4 |
| 96 | Ocean_Fishery | 37344000 | Australian_salmons | 5 | 6 | 4 | 2 |
| 97 | Ocean_Fishery | 37441000 | Mackerels_and_tunas | 1 | 2 | 2 | 2 |
| 98 | Ocean_Fishery | 37445000 | trevallas | 1 | 2 | 2 | 2 |
| 99 | Otter_Trawl | 23615000 | squid_&_calamary | 0 | 0 | 0 | 3 |
| 100 | Otter_Trawl | 37227000 | hakes_and_southern_hakes | 0 | 1 | 1 | 3 |
| 101 | Otter_Trawl | 37296000 | Flatheads | 2 | 2 | 2 | 2 |
| 102 | Otter_Trawl | 37345000 | Redbait | 3 | 3 | 3 | 3 |
| 103 | Otter_Trawl | 37377000 | Morwongs | 1 | 1 | 1 | 2 |
| 104 | Otter_Trawl | 37439000 | black_mackerels_snake_mackerels | 0 | 1 | 1 | 3 |
| 105 | Otter_Trawl | 37445000 | trevallas | 1 | 2 | 2 | 2 |
| 106 | Otter_Trawl | 99999000 | Other_Unknown | 3 | 6 | 4 | 2 |
| 107 | Rock_Lobster_Vic | 28820000 | spiny_lobsters | 4 | 6 | 5 | 2 |
| 108 | Rock_Lobster_Vic | 28925000 | eriphiid_crabs | 6 | 6 | 4 | 4 |
| 109 | Scallop | 23220000 | mussels | 1 | 1 | 1 | 2 |
| 110 | Scallop | 23270000 | scallop | 0 | 2 | 2 | 3 |
| 111 | Shark | 37017000 | hound_sharks | 1 | 2 | 2 | 2 |
| 112 | Shark | 37023000 | Sawsharks | 3 | 6 | 4 | 3 |
| 113 | Shark | 37445000 | trevallas | 1 | 2 | 2 | 2 |
| 114 | LINE | 37311000 | Freshwater_perches_temperate_bas | 6 | 6 | 4 | 3 |
| 115 | LINE | 37351000 | emperors_and_sea_breams | 5 | 6 | 4 | 2 |
| 116 | LINE | 37353000 | breams | 3 | 6 | 6 | 4 |
| 117 | LINE | 37441000 | Mackerels_and_tunas | 5 | 6 | 5 | 2 |
| 118 | MIXED | 28711000 | penaeid_prawns | 2 | 2 | 2 | 2 |
| 119 | MIXED | 28865000 | spanner_crabs | 6 | 6 | 3 | 2 |
| 120 | MIXED | 28911000 | swimming_crabs | 3 | 3 | 3 | 3 |

| | Fishery | CAAB | Family Common name | 2001 | continuous | precautionary | optimistic |
|---|---|---|---|---|---|---|---|
| 121 | MIXED | 37310000 | snooks_and_barramundi_and_glassf | 4 | 6 | 4 | 2 |
| 122 | MIXED | 37311000 | Freshwater_perches_temperate_bas | 6 | 6 | 6 | 6 |
| 123 | MIXED | 37330000 | whitings | 3 | 6 | 6 | 2 |
| 124 | MIXED | 37351000 | emperors_and_sea_breams | 6 | 6 | 4 | 4 |
| 125 | MIXED | 37353000 | breams | 2 | 3 | 3 | 3 |
| 126 | MIXED | 37381000 | Mullets | 6 | 6 | 4 | 3 |
| 127 | MIXED | 37441000 | Mackerels_and_tunas | 2 | 2 | 2 | 2 |
| 128 | NET/CRAB | 28865000 | spanner_crabs | 6 | 6 | 5 | 2 |
| 129 | NET/CRAB | 28911000 | swimming_crabs | 2 | 3 | 3 | 2 |
| 130 | NET/CRAB | 37310000 | snooks_and_barramundi_and_glassf | 5 | 6 | 4 | 2 |
| 131 | NET/CRAB | 37330000 | whitings | 3 | 6 | 6 | 2 |
| 132 | NET/CRAB | 37381000 | Mullets | 4 | 6 | 3 | 2 |
| 133 | NET/CRAB | 37441000 | Mackerels_and_tunas | 6 | 6 | 4 | 3 |
| 134 | SPANNER | 28865000 | spanner_crabs | 6 | 6 | 3 | 2 |
| 135 | TRAWL | 23270000 | scallop | 2 | 2 | 2 | 2 |
| 136 | TRAWL | 28711000 | penaeid_prawns | 3 | 3 | 3 | 2 |
| 137 | TRAWL | 28821000 | shovel-nosed/slipper_lobsters | 6 | 6 | 6 | 2 |
| 138 | TRAWL | 28911000 | swimming_crabs | 4 | 3 | 3 | 2 |
| 139 | TRAWL | 37330000 | whitings | 6 | 6 | 6 | 6 |
| 140 | Abalone_SA | 24038000 | abalones | 2 | 2 | 2 | 2 |
| 141 | Inland_waters | 23359000 | pipis | 3 | 2 | 2 | 2 |
| 142 | Inland_waters | 37085000 | Herrings_sardines_pichards_and_s | 2 | 2 | 2 | 2 |
| 143 | Inland_waters | 37165000 | Carp_barbs_and_goldfish | 1 | 1 | 1 | 3 |
| 144 | Inland_waters | 37311000 | Freshwater_perches_temperate_bas | 3 | 6 | 4 | 2 |
| 145 | Inland_waters | 37329000 | freshwater_perches | 2 | 4 | 4 | 2 |
| 146 | Inland_waters | 37381000 | Mullets | 2 | 2 | 2 | 2 |
| 147 | Marine_Scale | 23359000 | pipis | 3 | 2 | 2 | 3 |
| 148 | Marine_Scale | 23615000 | squid_&_calamary | 0 | 4 | 4 | 4 |
| 149 | Marine_Scale | 28911000 | swimming_crabs | 3 | 2 | 2 | 2 |
| 150 | Marine_Scale | 37029000 | eastern_shovelnose_ray | 2 | 6 | 4 | 2 |
| 151 | Marine_Scale | 37085000 | Herrings_sardines_pichards_and_s | 3 | 2 | 2 | 2 |
| 152 | Marine_Scale | 37234000 | Garfishes | 3 | 2 | 2 | 2 |
| 153 | Marine_Scale | 37330000 | whitings | 2 | 2 | 2 | 2 |
| 154 | Marine_Scale | 37344000 | Australian_salmons | 3 | 2 | 2 | 2 |
| 155 | Marine_Scale | 37345000 | Redbait | 3 | 3 | 3 | 3 |
| 156 | Marine_Scale | 37353000 | breams | 5 | 6 | 4 | 3 |
| 157 | Marine_Scale | 37381000 | Mullets | 2 | 2 | 2 | 2 |
| 158 | Marine_Scale | 37382000 | Pikes | 6 | 6 | 4 | 3 |
| 159 | Marine_Scale | 37465000 | Triggerfishes_and_leatherjackets | 2 | 2 | 2 | 2 |
| 160 | Marine_Scale | 99999000 | Other_Unknown | 6 | 6 | 4 | 3 |
| 161 | Miscellaneous | 23659000 | octopuses | 4 | 4 | 4 | 3 |
| 162 | Miscellaneous | 24999000 | Other_Molluscs | 6 | 6 | 4 | 3 |
| 163 | Prawn | 28711000 | penaeid_prawns | 3 | 2 | 2 | 2 |
| 164 | Rock_Lobster_SA | 28820000 | spiny_lobsters | 4 | 6 | 4 | 2 |
| 165 | WA | 23270000 | scallop | 2 | 2 | 2 | 2 |
| 166 | WA | 23615000 | squid_&_calamary | 3 | 4 | 4 | 0 |
| 167 | WA | 23659000 | octopuses | 2 | 2 | 2 | 3 |
| 168 | WA | 24038000 | abalones | 4 | 6 | 4 | 2 |

| | Fishery | CAAB | Family Common name | 2001 | continuous | precautionary | optimistic |
|---|---|---|---|---|---|---|---|
| 169 | WA | 25415000 | Beche-de-mer | 6 | 5 | 2 | 2 |
| 170 | WA | 28711000 | penaeid_prawns | 3 | 3 | 3 | 2 |
| 171 | WA | 28795000 | Yabbies | 6 | 5 | 5 | 2 |
| 172 | WA | 28820000 | spiny_lobsters | 3 | 3 | 3 | 2 |
| 173 | WA | 28911000 | swimming_crabs | 3 | 4 | 4 | 2 |
| 174 | WA | 37013000 | Blind/nurse/longtail_carpet/cat/ | 6 | 6 | 4 | 3 |
| 175 | WA | 37017000 | hound_sharks | 2 | 2 | 2 | 2 |
| 176 | WA | 37018000 | whaler_sharks_and_weasel_sharks | 3 | 6 | 6 | 2 |
| 177 | WA | 37029000 | eastern_shovelnose_ray | 3 | 6 | 4 | 2 |
| 178 | WA | 37085000 | Herrings_sardines_pichards_and_s | 1 | 3 | 3 | 2 |
| 179 | WA | 37188000 | Forktailed_Catfishes | 6 | 6 | 4 | 3 |
| 180 | WA | 37192000 | eel-tailed_catfishes | 1 | 1 | 1 | 2 |
| 181 | WA | 37287000 | scorpionfishes | 1 | 6 | 4 | 2 |
| 182 | WA | 37311000 | Freshwater_perches_temperate_bas | 6 | 6 | 4 | 3 |
| 183 | WA | 37320000 | pearl_perches | 6 | 6 | 4 | 3 |
| 184 | WA | 37330000 | whitings | 3 | 6 | 6 | 3 |
| 185 | WA | 37337000 | Trevallies_and_jacks | 3 | 6 | 6 | 2 |
| 186 | WA | 37344000 | Australian_salmons | 2 | 3 | 3 | 2 |
| 187 | WA | 37346000 | fusiliers_sea_perches_and_snappe | 6 | 6 | 4 | 4 |
| 188 | WA | 37347000 | threadfin_breams_monocle_breams | 6 | 6 | 4 | 3 |
| 189 | WA | 37350000 | grunter_breams | 6 | 6 | 4 | 4 |
| 190 | WA | 37351000 | emperors_and_sea_breams | 5 | 6 | 4 | 2 |
| 191 | WA | 37353000 | breams | 3 | 6 | 4 | 2 |
| 192 | WA | 37377000 | Morwongs | 6 | 6 | 4 | 4 |
| 193 | WA | 37381000 | Mullets | 2 | 3 | 3 | 2 |
| 194 | WA | 37383000 | threadfin_salmons | 6 | 6 | 4 | 4 |
| 195 | WA | 37384000 | Wrasses | 6 | 6 | 4 | 4 |
| 196 | WA | 37441000 | Mackerels_and_tunas | 3 | 6 | 4 | 2 |
| 197 | WA | 37465000 | Triggerfishes_and_leatherjackets | 6 | 6 | 5 | 2 |
| 198 | WA | 37999000 | Other_Teleosts | 6 | 6 | 4 | 3 |
| 199 | Abalone_Tas | 24038000 | abalones | 2 | 2 | 2 | 2 |
| 200 | Rock_Lobster_Tas | 28820000 | spiny_lobsters | 3 | 6 | 4 | 2 |
| 201 | Scalefish | 37234000 | Garfishes | 6 | 5 | 5 | 2 |
| 202 | Scalefish | 37296000 | Flatheads | 3 | 4 | 4 | 2 |
| 203 | Scalefish | 37330000 | whitings | 1 | 2 | 2 | 2 |
| 204 | Scalefish | 37337000 | Trevallies_and_jacks | 1 | 1 | 1 | 3 |
| 205 | Scalefish | 37344000 | Australian_salmons | 2 | 6 | 4 | 2 |
| 206 | Scalefish | 37377000 | Morwongs | 2 | 6 | 6 | 2 |
| 207 | Scalefish | 37378000 | trumpeters | 6 | 6 | 4 | 3 |
| 208 | Scalefish | 37384000 | Wrasses | 6 | 6 | 4 | 4 |
| 209 | Scalefish | 37439000 | black_mackerels_snake_mackerels | 1 | 2 | 2 | 3 |
| 210 | Scalefish | 37445000 | trevallas | 3 | 6 | 4 | 2 |
| 211 | Scalefish | 37999000 | Other_Teleosts | 1 | 1 | 1 | 2 |
| 212 | NT | 28911000 | swimming_crabs | 4 | 3 | 3 | 2 |
| 213 | NT | 37029000 | eastern_shovelnose_ray | 3 | 6 | 4 | 2 |
| 214 | NT | 37310000 | snooks_and_barramundi_and_glassf | 5 | 6 | 4 | 2 |
| 215 | NT | 37346000 | fusiliers_sea_perches_and_snappe | 6 | 6 | 4 | 4 |
| 216 | NT | 37351000 | emperors_and_sea_breams | 6 | 6 | 4 | 4 |

| | Fishery | CAAB | Family Common name | 2001 | continuous | precautionary | optimistic |
|---|---|---|---|---|---|---|---|
| 217 | NT | 37353000 | breams | 2 | 6 | 4 | 2 |
| 218 | NT | 37383000 | threadfin_salmons | 3 | 2 | 2 | 3 |
| 219 | NT | 37441000 | Mackerels_and_tunas | 3 | 4 | 4 | 2 |
| 220 | NT | 37999000 | Other_Teleosts | 6 | 6 | 4 | 4 |

The summary graphs (Fig's C.1-3) show the proportion of fish units within each category of exploitation status as a function of time. These graphs are similar in construction to that produced by the FAO for world fisheries 'development' shown in Figure 1.5.

Comparison of these figures shows some key differences. Under the continuous fishing scenario, the super-critical category expands appreciably (and the critical and severe only vary by relatively small amounts). Evidently fish units from the under-utilised and over-utilised categories have become severe, critical or super-critical over time. This change is simulated to be somewhat more rapid over the next couple of decades.

In the precautionary fishing scenario, much of the super-critical category is held within the severe category, but there is a very fine line between these categories. To be classed as severe, the fish unit will either be critical in terms of biomass or catch-to-growth ratio and fully-utilised in the other (i.e., in terms of component indices summing to the combined index, 3 + 1 = 4), or the fish unit will be over-utilised in both biomass and catch rate components (2 + 2 = 4).

In substantial contrast with the continuous and precautionary fishing scenarios, the optimum long-term scenario sees a cascading reduction of the problem categories and a large expansion of the fully-utilised category. This emphasises the long-term sustainable nature of the optimum scenario. By 2050 the majority of fish units are being fully-utilised, and there is the suggestion that this proportion would continue to increase.

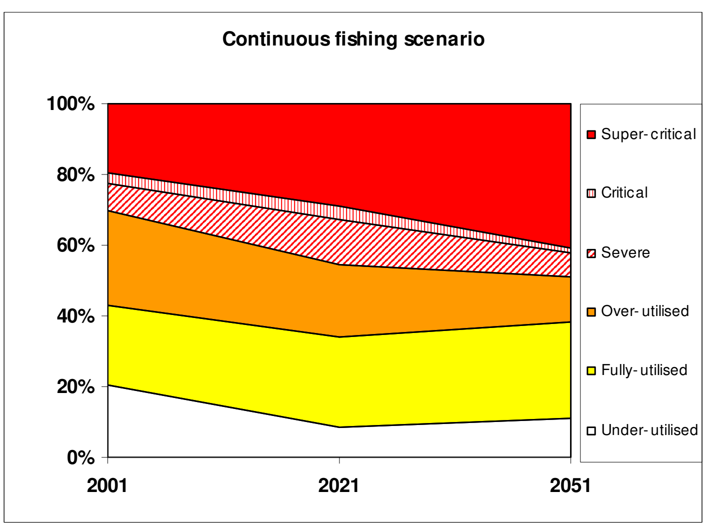


**Figure C.1** Proportion of all fish units in each combined indicator category, under the continuous fishing scenario.

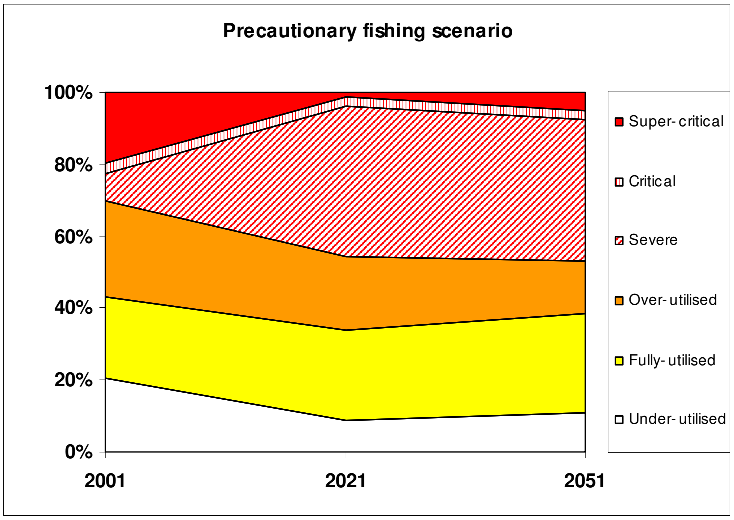


**Figure C.2** Proportion of all fish units in each combined indicator category, under the precautionary fishing scenario.

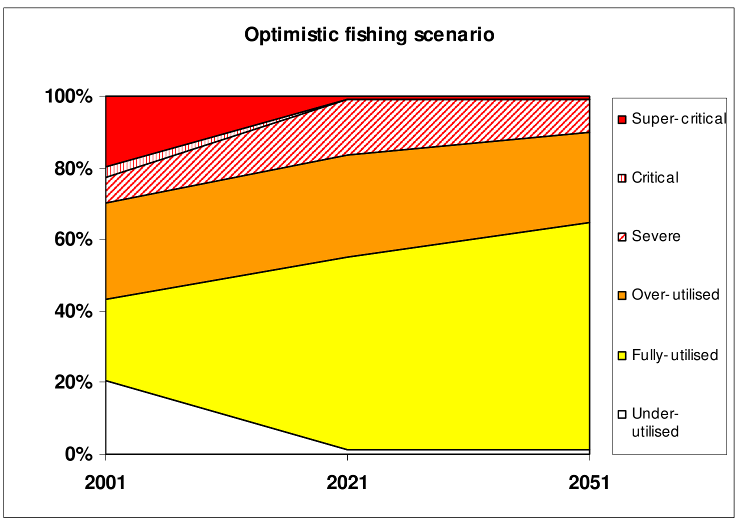


**Figure C.3** Proportion of all fish units in each combined indicator category, under the optimum fishing scenario.

# Appendix D - Effort-benefit matrix for recommendations

Matrix of cost-benefit analysis for recommendations. Issues with costs and benefits to the right are preferable to those on the left. Costs and benefits judged subjectively, and in a relative sense.

**Table D.1** Cost-benefit (or effort-importance) for recommendations

| Issue | Effort / cost | | | Importance / benefit | | |
|---|---|---|---|---|---|---|
| | High | Med | Low | Low | Med | High |
| ***Scenario development & analysis*** | | | | | | |
| Market demand | | More detailed population profiles (e.g., coastal, affluence, lifestyle) | Different populations; seafood preference | | Understanding of factors in & beyond control to inform further market research | |
| Input requirements | | | Analyse labour & capital requirements | | Inform e.g., rate of aquaculture development | |
| Wild capture productivity | | Utilise "wastes" in feed | Easier to implement with framework development (see aquaculture) | | Explore implications of increased aquaculture | |
| World context – trade | | More detailed examination of world production futures & markets | | | | Provide realistic constraints on import volume & export demand (couple with economics?) |
| – energy | | | Oil and natural gas production | | | Implications for fleet size; further driver of aquaculture |
| Ecological constraints | | | Explore uncertainty of climate change & pollutants effects | | Better understanding of the possible implications for production | |
| | | Expert input & modelling of environmental impacts | | | | Wider exposure of environmental issues as relevant to sustainable fisheries industry |
| Economic coupling / analysis | Develop an economic 'shell' around the physical analysis | Couple through data transfer as early analysis (& proof of concept) | | | (Data transfer ->) Awareness of economic levers; proof of concept | Understand the potential and limitations of policy based on economic levers |
| Footprint analysis | Spatially analyse production data | | | | Allocation of demand from domestic consumption and exports to key locations | |
| ***Framework development*** | | | | | | |
| Aquaculture | | Wastes utilised | By-catch and | Make these | | See above for |

| Issue | Effort / cost | | | Importance / benefit | | |
|---|---|---|---|---|---|---|
| | High | Med | Low | Low | Med | High |
| | | by aquaculture and other protein use | waste factors (limited data) | losses explicit, but impact limited if not linked to utilisation | | wild capture productivity |
| Fish ecosystems | Fairly extensive modelling effort or coupling with extant models | | | | | Increased credibility & confidence. Ability to explicitly study environment impacts; expansion of wild capture; food-chain effects. |
| Wild capture expansion | Considerable data collection and analysis (but limited framework development?) | | | | | Better 'whole of system' analysis including migratory fish |
| ***Data refinement*** | | | | | | |
| Missing data | | | Acquire ABS data and extrapolate | | Little impact on scenarios, but increase credibility | |
| FAO discrepancy | | Find product-live weight conversion factors from FAO | (possibly less effort if data is readily available) | Increases confidence in national aggregate picture for history | | |
| Improved Schaefer parameters | | Liaising with ABARE, etc and experts; model comparisons | | | | Further buy-in and confidence of stakeholders |

# Appendix E - Further scenario development

The following outlines possible scenarios that could be described as "richer" and consistent with story-line development. They use the primary scenarios described in Chapters 5 and 6 as a basis.

## *Scenarios in brief*

As discussed in previous sections, the investigation considers three main levers, each with two possible projections. In totality, this amounts to eight possible variations to consider (Table E.1).

**Table E.1** Matrix of possible scenarios

| No. | Wild prodn | Farm prodn | Consum. | Scenario Label | Supply/demand description | Title |
|---|---|---|---|---|---|---|
| 1 | L | L | L | A | moderate demand / low supply | Baseline |
| 2 | L | L | H | | | |
| 3 | L | H | L | | | |
| 4 | L | H | H | | | |
| 5 | H | L | L | B | moderate demand / moderate supply | Conservative Development |
| 6 | H | L | H | | | |
| 7 | H | H | L | | | Export focussed |
| 8 | H | H | H | C | high demand / high supply | Seafood is a hit! |
| | | | | | | |
| 1* | L | L | L | A* | moderate demand / very low supply | Pessimistic |

In this investigation, three particular combinations, representing the range of possibilities are considered. In brief:

- Scenario A
  - This is the *Baseline* scenario of moderate demand with low supply. Essentially it considers the possibility of attempting to continually and consistently obtain at least the same yields as in the recent past (the average of the past ten years) from wild capture fisheries. If any particular fishery is already "overfished", or goes into serious decline, it is assumed that countervailing pressures (management, economics, behaviour) stabile the fishery at twenty percent of virgin biomass. In a sub-scenario (A*), the fisheries are allowed to decline to zero. Both aquaculture and consumption is projected to follow historical trends, levelling off at conservative levels.
- Scenario B
  - This is considered a *Conservative Development* scenario with moderate demand and moderate supply. In this scenario it considers the impact of fishing practices that take the maximum long-term sustainable yields from fisheries whilst ensuring the biomass remains at a resilient level. Aquaculture and consumption remain the same as in Scenario A.
- Scenario C
  - This is titled "Seafood is a hit!" with high demand and high supply. It is so titled, since it is considered to occur only if there is a significant raising of awareness of domestic consumers of the benefits of seafood that they eventually double their annual intake. In order to assist in supplying a rapidly growing domestic market, as well as a burgeoning export market, aquaculture production is considered to grow faster and to higher levels than in the previous scenarios.

These scenarios are described in more detail in the next section.

## *Scenarios in detail*

- Scenario A
  - A* "Pessimistic outcomes" "Low supply, Low demand"
  - A "Baseline" "Low supply, Low demand"
  - Main Levers
    - A*Wild fish units allowed to collapse completely (low branch)
    - A Wild fish units drop to fraction of virgin (10-20%) (low branch)
    - Consumption per capita is trended upwards conservatively to limit of 23kg. (low branch)
    - Aquaculture projected to double in 20-30 years. (low branch)
  - Minor Levers
    - Exports trends as in history
    - Rec fishers participation rate constant with yr2000
  - Setup
    - From a physical point of view, it is attempted to obtain the same yields as in the recent past.
    - This scenario essentially looks at whether it is possible to supply the same composition of species from the same fisheries of the recent past into the future. This is codified simply as the average of the last few years (typically 10).
    - Obviously, the outcome from the scenario depends somewhat on the span of years chosen. However, we shouldn't get to hung up about it as it is only an indicator of the expected overall outcome, and the exact span chosen will only affect fisheries at the margins.
    -
  - Consequences
    - Reduced domestic production => reduced total domestic supply may lead to:
      - reduction in recreational fishing.
      - More imports
      - Less exports
      - reduced consumption?
  - Storyline
    - It is artificial since if some fisheries are collapsing, we would expect more pressure on other fisheries not so pressured. However, we use it as a baseline to start exploration.
    - Reasons for this future scenario could be varied:
      - Current pressures (debt, tragedy of the commons) cause people to attempt to supply the same amount as recent past. Increasing domestic consumption applies continual pressure to fisheries.
      - And/or environmental degradation (climate change, local disturbance) cause stocks to decline? (not really as I keep *k* constant)
    - This predictably leads to lower domestic production. This impacts all other drivers.
  - The difference between A* and A will be interesting from a yield per annum and cumulative perspectives.
- Scenario B
  - "Conservative development" "moderate Supply, low Demand"
  - Main Levers
    - Wild fish units harvested in sustainable manner and allowing a recovery of biomass to a (theoretically) biologically robust level (Catch =80% growth or 80% MSY; long-term level is 72% virgin biomass).
    - Consumption per capita is trended upwards conservatively to a limit of 23kg.
    - Aquaculture projected to double in 20-30 years
  - Minor Levers
    - Exports trends as in history
    - Rec fishers participation rate constant with yr2000
  - Setup
    - From a physical point of view, it is attempted to maximise wild yields over long-term (i.e. sustainably).
    - This depends on the correct identification of MSY (and thus *k* and *r*).
    - It glosses over ecological effects.
  - Consequences
    - Moderate growth in production.

- Storyline
  - This implies adaptive fishing practices (management and exploitation) appropriate to the biological productivity of individual fish units and ecological sustainability of supporting ecosystems.
  - It assumes only a moderate increase in aquaculture, possibly due to government regulation, public concerns, health concerns, environmental concerns, economic limitations to business growth, lack of suitable sites, lack of suitable technology.
  - This is (perhaps) a conservative expectation. We have assumed that adaptive fisheries practices are adopted to ensure biological and ecological sustainability. This assumes the science is well developed and used.
  - With aquaculture growing only moderately (perhaps for a multitude of reasons), total production should grow moderately.

- Scenario C
  - "Rapid development" "High Supply, High Demand"
  - Setup
    - Wild capture is as efficient as possible, while fish stocks remain relatively .robust to disturbance. Aquaculture is allowed to develop extensively with few barriers. Marketing causes local population to favour seafood for lifestyle and health reasons.
  - Consequences
    - Income must be fairly high relative to rest of the world for Australians to be able to afford product. Alternatively, aquaculture worldwide is made cheap, efficient, sustainable and environmentally friendly.
  - Wild fish units harvested in sustainable manner and allowing a recovery of biomass to a (theoretically) biologically robust level.
  - Aquaculture projected to quadruple in total volume
  - Consumption per capita is trended upwards conservatively to a limit of 23kg.
  -