National Pollutant Inventory

Emission Estimation Technique Manual

for

Aggregated Emissions from Temperate Water Finfish Aquaculture

26 June 2001 - Version 1.0

Environment Australia

First Published (Version 1.0) 26 June 2001
Version 1.0 – 26 June 2001

ISBN: 06 4254 6967

www.npi.ea.gov.au

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The manual was prepared in conjunction with Australian States and Territories according to the National Environment Protection (National Pollutant Inventory) Measure.

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Acknowledgments

This manual was prepared by Colin Shepherd, Gwen Fenton and Graham Woods from the Marine Environment Section of the Tasmanian Department of Primary Industries, Water and Environment. The assistance of officers of State Fisheries Departments, researchers and various industry representatives in South Australia, Victoria, New South Wales and Tasmania is gratefully acknowledged. The editors especially wish to thank the following people for assistance and advice during preparation of the handbook and for organising and providing site visits to finfish farms around southern Australia.

In South Australia:

Brian Jeffries and Kirsten Rough, South Australian Tuna Boat Owners Association; Steven Clarke, South Australian Research and Development Institute; Fiona vom Berg, Coast and Marine Section, Environment Protection Agency, South Australia; Hagen Stehr and Trenton Hardie, Stehr Group; Colin Freeman, Australian Bight Seafood Pty Ltd; Dr Peter Petrusevics and Jean Cannon. We are particularly indebted to Don Workman and the crew of *Bella Isha* from the Stehr Group and David Stanhope and the staff of Robarra Farm for allowing access to their farms.

In Victoria:

Brendan Larken and Brett Ingram, Aquaculture Program, Marine and Freshwater Resources Institute, Snobs Creek; Karen Campbell, Regional Aquaculture Development; Margaret Brett, Fisheries Victoria and Hugh Meggitt, Goulburn River Trout Pty Ltd. We are particularly indebted to Mark Fergurson and Paul Cox from Eildon Trout farm and the Meggitt family for allowing access to their farms.

In New South Wales:

Jeff Allen, Stewart Fielder and Mark Booth, Port Stephens Research Centre; Peter Nicholson and Nick Arena, Tailor Made Fish Farms; Dan Liszka, Pisces Marine Aquaculture Pty Ltd; Lindsey Fraser and Frank and Madge Bowden, Native Fish Growers Co-Operative Ltd; Anthony O'Donohue and Luke Dutney, O'Donohue Filter Sands. We are particularly indebted to Bruce Davies and the crew of *Tanu,* Frank and Madge Bowden, Linda Trudgeon, Dorothy and Ray Harris, Peter Nicholson and Anothony O'Donohue for allowing access to their farms.

In Western Australia

Brett Glencross, Fisheries Western Australia.

In Tasmania:

The staff of the Marine Farming and Marine Environment Branch, Department of Primary Industries, Water and Environment. Professor Nigel Forteath, John Hayes and Rachelle Hawkins, Beauty Point Seahorses; Wayne Donovan and John Ranicar, Eels Australis; Dr Peter Davies, Freshwater Systems and Harry King, Saltas hatchery. We are particularly indebted to Beauty Point Seahorses and Saltas for allowing access to their facilities and to a number of salmon and ocean trout farms from around Tasmania, especially Tassal, Nortas, Aquatas and Huon Aquaculture. We thank the numerous farm hands and managers from these farms for their valuable input and time and for providing guidance around these facilities.

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For
Finfish Aquaculture

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1 Introduction

The National Pollutant Inventory (NPI) is an internet-based database designed to provide the community, industry and government with information on the types and amounts of certain substances being emitted to the air, land and water. The main objectives of the NPI are to:

- provide information to industry and government to assist in environmental planning and management;
- satisfy community demand for accessible information on emissions to the environment; and
- promote cleaner waste minimisation, cleaner production, and energy and resource savings (Source: National Pollutant Inventory Guide 1998).

The purpose of this Emission Estimation Technique (EET) Manual is to assist the Australian Aquaculture industry and State authorities in estimating emissions of listed substances to the National Pollutant inventory. It provides a general overview of the more common temperate water finfish aquaculture methods and describes the procedures and recommended methods for estimating emissions of Category 3 NPI listed substances, specifically total nitrogen (TN) and total phosphorus (TP). These emission estimates must be reported to Environment Australia (EA) by relevant State authorities if annual emissions of N and P exceed 15 tonnes and 3 tonnes respectively.

However, individual Aquaculture facilities are exempt from reporting emission data to the NPI. Estimation of all *aggregated* emission data associated with aquaculture will be undertaken by State and Territory environment authorities using NPI handbooks and reported on regional basis.

The species covered by this manual are:

- Atlantic salmon (*Salmo salar*)
- Trout (*Oncorhynchus mykiss* and *Salmo trutta*)
- Tuna (*Thunnus maccoyii*)
- Silver perch (*Bidyanus bidyanus*)
- Eel (*Anguilla australis*)
- Barramundi (*Lates calcarifer*)
- Seahorse (*Hippocampus abdominalis*)
- Ornamental Fish
- Other Native Fish

These species have been chosen since they represent the majority of the temperate finfish species currently cultured in southern Australia (Brown *et al 1997*). The methods described in this Manual are based on the farming methods currently employed for the listed species and may be used as a guide for estimating emissions from other species which use similar farming techniques (See Appendix 1).

This Manual was drafted by the Marine Environment Section of the Tasmanian Department of Primary Industries, Water and Environment on behalf of the Commonwealth Government. It has been developed through an extensive process of national consultation involving State environmental authorities and key industry stakeholders.

2 Overview of Australian Aquaculture

Although Australian aquaculture is small by world standards its importance in Australia's fisheries sector has risen strongly in recent years. In 1998/1999 annual production in Australia was 32 000 tonnes, valued at $602 million (Source: Australian Fisheries Statistics ABARE report 1999).

2.1 Salmonids

The Australian salmonid industry encompasses commercial farming, hatcheries, tourism and recreational fishing. Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) are the dominant species, with small quantities of brown trout (*S. trutta*) and brook trout (*Salvelinus fontinalis*) also farmed (Brown *et al 1997*). Trout also form the basis of extensive recreational fisheries in many rivers and lakes in southern Australia and are bred and released into waters by government hatcheries in some States.

2.1.1 Altantic salmon

Farmed Atlantic salmon is currently the only type of salmon commercially produced in Australia. Farming is largely carried out in southern Tasmania and in Macquarie Harbour, on Tasmania's west coast, although salmon farming is being attempted in other States. For example two licences have recently been issued in South Australia (Vom Berg, South Australian Environment Protection Agency, *per comm*.). The farming techniques used in Australia have generally been adapted from those successfully employed in Norway and Scotland for many years. The system involves hatching salmon fry in freshwater facilities where, after several months of growth, the par go silvery and become pigmented. Their diet is then modified to include a high salt content that prepares the juvenile salmon for transfer to the marine environment. This normally occurs after about sixteen months (Tasmania DPIWE, *per comm*.). The fish are then transferred to open sea-cages where they spend around twelve to fifteen months. During this period they grow from around 80 grams to a marketable size of 3.5 - 4.5 kilograms. Supply to both the domestic and export market is predominantly of whole fresh fish. Around two-thirds of farmed salmon production is sold as whole fresh fish which are gutted and gilled (Tasmanian Department of Primary Industry and Fisheries 1996). The remainder is sold frozen or as a range of value added products. There are currently 35 Atlantic salmon licences in Tasmania with the prospect of further expansion of the industry in the future.

2.1.2 Trout

The freshwater industry is based on the production of rainbow trout throughout the temperate regions of New South Wales, Victoria and to a lesser extent Tasmania, South Australia and Western Australia (Brown *et al 1997*). Rainbow trout (*Oncorynchus mykiss*) are farmed in both fresh and saline waters. The main trout producing area is Victoria, with trout being that State's largest and longest established aquaculture industry (Brown *et al 1997*). The Goulburn-Broken Catchment is the focus of this industry in Victoria, producing 2/3 of Australia's inland salmonid production (Proceedings of Marine and Freshwater Resources Institute, Fisheries Victoria 1998). There are essentially two categories of freshwater trout farming. The first consists of a small number of large farms supplying approximately 80% of the market. The second group consists of small farms producing small volumes, often for the tourist trade (Brown *et al 1997*). The freshwater farming techniques employed generally involve diverting water from a river or stream through the farm, using either gravity feeding methods or mechanical pumps, and then redirecting the water back to the river downstream. The majority of farms breed their own fish, although purchasing of fry and fingerlings does occur (Brown *et al 1997*). Trout are also farmed in sea-cages in Tasmania, predominantly in Macquarie Harbour using similar techniques as those employed for the salmon industry.

2.2 Non-salmonids

2.2.1 Tuna

Southern bluefin tuna farming involves capturing wild “maximum” size juveniles and placing them in sea-cages for ongrowing. Tuna farming relies on harvesting juveniles aged from 1 to 5 years (Trenton Hardie *per comm.*). The Australian southern bluefin tuna quota regulates the number of fish caught. The growout process can take between three and seven months depending on the size of juveniles caught and the desired size of marketable tuna. The industry aims at producing quality, high value tuna for the Japanese sashimi market. Compared with wild catch, tuna farming offers the benefit of control over end product quality, risk and seasonality. Presently tuna farming only occurs in South Australia and the entire tuna crop is farmed within 25 kilometres of Port Lincoln.

2.2.2 Silver Perch

This species has only recently attracted interest by growers since New South Wales Fisheries research identified it had great potential as a commercial freshwater aquaculture species (Austasia Aquaculture 1992). The industry is based on culture in static, aerated earthen ponds. Wastewater is often collected in an effleunt/settlement pond and then irrigated onto crops or pasture or reused for fish culture (Aquaculture in NSW 1999). Presently, this industry may be limited by several factors that include: the developing experience of growers, the cost of feed (40% of market price according to Allen & Rowland 1996), an average feed conversion ratio (FCR) of 2:1, and the lack of suitable harvesting techniques. However, research on silver perch diets in NSW in 2000 has resulted in a reduction of about 60% in feed ingredient costs. Silver perch diets may therefore now be the cheapest of any intensively cultured fish in Australia (Australian Aquaculture Yearbook 2000) and this suggests the industry will continue to grow significantly in the future. New research is also currently under way in Victoria to investigate the diversification of irrigation farming to include silver perch production. The approach being taken is to ongrow the fish in enclosures in irrigation channels for land-based crop and fruit growing (Brown *et al 1997*).

2.2.3 Eels

Shortfin eel (*Anguilla australis*) harvesting involves capturing wild stock from waterways or capturing eels from waterways that have been stocked and then ongrown to marketable size. Production of eels is based on stocking lakes and dams in Victoria and Tasmania with juvenile eels from Tasmania. After stocking there is little management or feeding. In Queensland however, grow-out of eels in commercial ponds is currently being investigated. These eels are being fed a diet composed of an imported "paste" and this new farming technique may be adopted in other States depending on the results of these trials (John Ranicar, *per comm.*). Presently, eels take about eight to nine years to reach commercial size. Most of the Australian eel catch is destined for export markets. In Tasmania, 12 commercial eel fishing licences have been issued in 2000 (Tasmanian Inland Fisheries Service, *per comm*). In addition, the Service also provides between 1-3 tonnes annually of juvenile eels for ongrowing in other areas. Presently, only the Inland Fisheries Service is permitted to harvest wild juvenile eel stock in Tasmania. The Service, under the "*Inland Fisheries Act 1995*", controls all licensing of eels in Tasmania.

2.2.4 Barramundi

Barramundi are slowly becoming an important inland aquaculture species for southern Australian states. The industry started in Queensland but barramundi farms have now been established in six States, with approximately 180 barramundi farming licences issued (Australian Aquaculture Yearbook 2000). The bulk of production is cultured in open tanks using recirculating systems. Many facilities employing recirculating systems are being developed indoors and as such can be established in most climates. Consequently, the number of indoor facilities is rapidly increasing and the supply of fish from such facilities now amounts to a modest proportion of the total farmed barramundi production (Australian Aquaculture Yearbook 2000). Barramundi farming is now the largest inland aquaculture sector in South Australia, with a significant proportion of this State's production cultivated in flow-through systems using geo-thermally heated bore water. The specialised hatchery phase of barramundi farming means the majority of farms opt to purchase their stock as larvae, or as juvenile fish. Once fingerlings are approximately 60-80mm they are transferred into the tanks for the grow-out phase of the production cycle. Most farmed barramundi are harvested as "plate sized" at around 450-600 grams and this size is usually attained after 6-9 months of grow-out.

2.2.5 Seahorses

A recent addition to the Tasmanian aquaculture industry is commercial farming of the "fat bellied" seahorse, *Hippocampus abdominalis.* The seahorses are currently destined for the aquarium trade in the United States of America (although the company also intends targeting the Chinese medicinal and curio markets in the future)(Nigel Forteath, *per comm.*). The seahorses have been grown from 600 brood stock that were originally collected from the wild under a permit. From this parental stock the company now produces approximately 150 000 seahorses annually. The seahorses are grown in tanks at a land-based facility in northern Tasmania and reach saleable size after approximately 8 months. The seahorses are grown on a diet of fresh feed that the company also cultures. Present monitoring of discharge water suggests it highly unlikely the farm currently produces category 3 emissions that would exceed the NPI thresholds.

2.2.6 Ornamental Fish

The Australian marine aquarium fish industry is based on the collection of fish from the wild, with most of the collecting occurring in tropical parts of Australia eg. the Great Barrier Reef (Brown *et al 1997*). The Australian freshwater aquarium industry appears based mainly around farmed fish either imported from overseas or locally in Australia. The industry comprises many small backyard or "cottage style" operators and most are not licensed. This means that data about this industry is very hard to compile. It seems unlikely that many of these operators work on a scale large enough to produce emissions that would exceed the NPI thresholds for category 3 substances.

2.2.7 Others

A range of other native 'warmwater' fish are being produced across southern Australia. These include the highly valued Murray cod (*Maccullochella peeli*), golden perch (*Macquaria ambigua*), native *catfish (Tandanus tandanus*), snapper (*Pagrus auratus*) and yellowtail kingfish (*Seriola lalandi*). Typical systems employed include the production of fingerlings utilising "green pond" methods for restocking purposes and controlled intensive farming. However, a number of the species are presently set to be grown in commercial quantities following extensive trials using cage culture or re-circulation tank systems. There is also an emerging sector with interest in using inland saline water for fish culture, and apparently experimentation is under way in several Australian states (Australian Aquaculture Yearbook 2000).

3 Licensing and Production

3.1 Industry Sectors

The Australian aquaculture industry consists of a number of industry sectors with numerous licence holders. The number of licence holders varies greatly between States but Appendix 2 presents a general view of the number of licence holders (where data is available) in all Australian States currently involved in temperate water finfish culture. The complex, multi-jurisdictional nature of aquaculture licensing results in considerable differences between States with regards to licensing requirements but the aquaculture industry is subject to a broad range of regulatory rules and regulations. This manual does not attempt to describe the individual licensing conditions for each of the States involved in temperate finfish culture. The relevant State fisheries and planning authorities should however be contacted in each State covered in this handbook if further information about these requirements is required. Appendix 3 shows the gross value of Australian aquaculture production in 1998-99 by each State presently involved in temperate water finfish culture.

4 Emission Sources and Control Technologies

Current finfish farming practices in temperate Australia can be broadly divided into three main groups:

(1) semi-open systems (usually floating cage culture)

(2) semi-closed systems (usually land based culture)

(3) closed systems (usually land based recirculation culture)

4.1 Overview of semi-open systems

Semi-open systems are generally used for finfish culture and are commonly typified by net-pen/water cage systems in which the fish are contained in a relatively uncontrolled environment. Movement and control of stock is possible but the control of water in, through and around the culture system is virtually impossible. In temperate Australia the main industries using semi-open systems include the salmonid industry in Tasmania and the tuna industry in south Australia. In a semi-open system, excess feed can fall through the cage and be deposited on the sea/estuary bottom under and near cages. Solid faecal material, depending on water movement, is either carried away from the site or also deposited on the sea floor beneath the cages. Currents carry away soluble N and P, in dissolved, maily excetory form. Fish cultured in semi-open systems are either captured in the wild and towed to the grow-out site (as in the case of tuna), or grown in a hatchery and transported by air or road to the culture site (as in the case of salmonids). Once fish are located at the farm site they are usually moved by towing the net-pens. Feed used in the culture of salmonids is generally processed feed. In comparison, tuna feed is usually fresh or frozen baitfish that is often imported (AQUAVETPLAN Enterprise Manual 1999).

4.2 Overview of semi-closed systems

Semi-closed aquaculture systems are those where species of finfish (crustacea or molluscs) are contained so that the animals, water and other associated materials are not in direct contact with natural waterways. Water is normally abstracted from an adjacent natural source and discharge water or effluent from the farming operations is released back into the same waterway. The release of effluent water back into natural watercourses may be continuous or intermittent, introduced directly or indirectly into the waterway. However, some farms will discharge effluent water into a settlement dam, effectively attempting to ensure that the water does not enter directly back into the natural waterway. These farms will then either reuse limited amounts of the surface water from the dam, once settlement of suspended solids occurs, or simply rely on evaporation to remove the wastewater produced. In NSW it is a condition of permits for intensive aquaculture of silver perch and eels that the effluent ponds must be twice (2X) the volume of the largest culture pond. In semi-controlled systems there is a degree of control over both stock movements and water flows. Semi-closed aquaculture systems have two main means of controlling impacts of waste outputs. The more traditional pollution control method is that of quality thresholds placed upon discharges from sites. The second approach, which appears to be gaining acceptance, takes a more “holistic” view of resource usage, and relies upon the control of inputs to the farming process to limit waste discharges. Regardless of the method employed to limit waste, the majority of semi-closed systems produce point source pollution, which in management terms, both at the farm and regulatory level, can be relatively simple to measure and control. The most common form of restriction on aquaculture operations from closed systems is regulation of discharging water quality (Kelly & Cripps 1999). The levels and limits of parameters are determined in accordance with environmental quality standards determined by the relevant authorities in each State.

4.3 Overview of closed systems

Closed systems are generally typified by a system where both the stock and the water are closely controlled, usually in tanks with attached filtration systems. These systems are often relatively small, the premises are readily quarantined, stock is easily confined and accessed and there is a low quantity of animals (gross weight) held within the system and hence individuals can be of high value (AQUAVETPLAN ENTERPRISE MANUAL 1999). There is minimal water exchange since these systems depend on advanced water treatment technologies, as exemplified by multi-stage biofilters, together with combined biochemical treatment units, including oxygen injection ozonation, UV-treatment, anaerobic denitrification (Mayer & McLean 1995), and the use of zeolites for ion exchange (Rosenthal & Black 1993). In many facilities the wastewater produced is either diverted to a settling pond or emptied into urban sewerage systems (AQUAVETPLAN ENTERPRISE MANUAL 1999). However, the total N and P volumes emitted in the effluent are usually considerably lower compared with semi-closed systems due to the smaller amounts of discharge water produced. It is likely that further advances in technology and design of recirculation systems will reduce the capital costs associated with these plants, such that they become economically viable for the cultivation of a greater variety of species in the future.

A significant new emerging technology that accompanies semi-closed and closed systems involves polyculture to utilise the effluent water. In Victoria an experiment in growing wasabe in the effluent of trout farms has now become a commercial enterprise. Water flow from the trout ponds is 300 litres a minute down each bed. Such beds can mature about 3000 wasabe plants for harvest in little more than a year (Fish Farming International April 2000). Similarly, a barramundi farm in New South Wales has been able to deal with the strict environmental requirements for wastewater in that state by using the nutrient rich waste as a resource for growing hydroponic lettuces.

5 Waste Production

Wastes from aquaculture include all materials used in the process, which are not removed from the system during harvesting. The quantity of the total waste produced and released into the environment, is closely correlated to the culture system used (Bergheim & Asgard 1996).

5.1 The origin of wastes

5.1.1 Feed-derived waste

The waste from aquaculture facilities is predominantly from feed (De Pauw & Joyce 1991: Pillay, T. 1992 and Handy & Poxton 1993), and includes uneaten feed (feed waste), undigested feed residues and excretion products (Cripps 1993). The main pollutants from an aquaculture source are organic matter, nitrogen and phosphorus (Cho and Bureau 1997). In marine fish farming the main excretory material is ammonium-N and urea which dissolve directly into the water. Approximately 70% of the nitrogen fed to cultivated fish is released into the marine environment as soluble ammonium (Gowen & Bradbury 1987). The waste output of dietary origin can be described using simple principles of nutrition (See Figure 1.). Ingested feedstuffs must be digested before utilisation by the fish. The digested proteins, lipids, and carbohydrates provide energy and nutrients for maintenance, growth and reproduction of the animal. The remainder of the unassimilated food is excreted in the faeces as solid waste (SW), and the by-products of metabolism (ammonia, urea, phosphate, etc.) are excreted as dissolved waste (DW) mostly by the gills and kidneys. The total aquaculture wastes (TW) associated with feeding and production is made up of SW and DW, together with feed waste (FW):

TW = SW + DW + FW (Source: Cho & Bureau

However, whilst faecal material (SW) and uneaten fish food (FW) represent a loss of nitrogen to the sediment, the amount, as a proportion of the total nitrogen fed to the fish, is small, being about 10% (Gowen *et al* 1991).

6 Estimating Category 3 Emissions

This manual attempts to outline the most relevant and effective methods to estimate aquaculture emissions of NPI category 3 substances from facilities employing the culture practices previously described. Advances in farm management practices combined with technological developments in feed and feeding systems may result in reductions of emissions from individual farms in the future.

As previously discussed, there is general consensus that diet related factors are the main causes of pollution to the environment in aquaculture (De Silva and Anderson 1995). The sources of pollution from feeds and associated feeding practices include:

- Feed loss - from dust
- Uneaten feed – inappropriate feed size or feeding methods
- Feacal matter – from undigested component of feed
- Waste metabolites – excreted from the fish

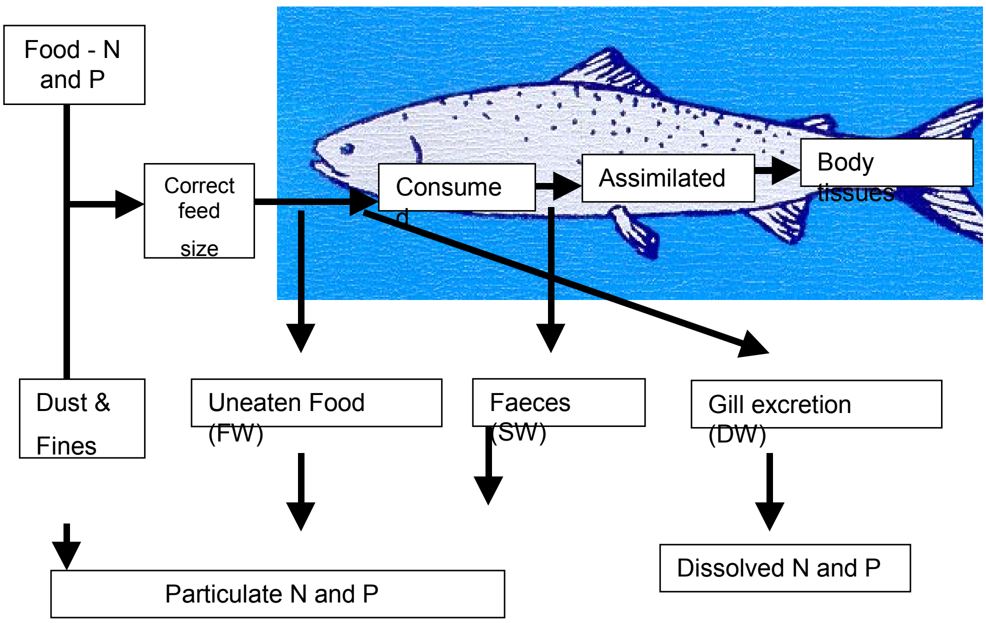

Figure 1 The fate of nitrogen and phosphorus in farm waters from dietary bioelements. (Source: Proceedings of Marine and Freshwater Resources Institute, Fisheries Victoria 1998).

Two Emission Estimation Techniques are proposed to determine the volumes of category 3 substances (nitrogen and phosphorus) emitted by temperate water finfish aquaculture facilities in Australia:

6.1 Direct Measurement

This method can be used on semi-closed and closed systems and is possibly the most accurate method for calculating emissions from finfish farming activities. It involves direct measurement of total N and P in the discharge water. This can be obtained by multiplying the annual water allocation to the farms within a catchment by the values collected from water quality analysis of the effluent water. However, it's clear some facilities will no longer use their previous water allocation due to a change in the farming activities employed and hence there is a need for some farms to have their allocations re-evaluated. For example, in Tasmania some hatcheries that previously used flow-through systems with large water needs have now upgraded to recirculating systems that only output small volumes of water daily. Adjustments in allocation volumes on such facilities needs to be taken into account when calculating emission estimates.

Equation 1. $T_{N+P} = E_{N/P}*F_A$

Where T_{N+P} = discharge of total N and P to water (t/year)

(NB – a conversion factor is missing in the above example)

Example 1 Trout farms in the Goulbourn-Broken Catchment

Net P concentrations (discharge concentration less upstream concentration) measured from trout farms in the Goulburn-Broken Catchment (GBC) between January 1990 and January 1995 (Metzeling *et at*. 1996) ranged from 0.06 – 0.25 mg/L (Median 0.16 mg/L). The water allocation to trout farms in the GBC in the 1993/94 season was approximately 450 ML/day (Proceedings of Marine and Freshwater Resources Institute, Fisheries Victoria 1998). Therefore, using the median net total P concentration;

Approximately 26.2 t/annum P was discharged in the 1990 – 1994

This type of calculation is only applicable to farms that have regulated water supplies and where water quality data is routinely collected. There will be a wide range of total N and P concentrations observed in the effluent waters of any finfish farms depending on time of year, stocking densities and other husbandry techniques. Water quality data would need to be measured over a reasonable time to account for these variations before accurate, reliable figures could be determined for input into the direct measure equation. On unregulated rivers the following calculation could be employed.

Equation 2. $T_{N+P} = E_{N+P} * F/10^6$

Where T_{N+P} = discharge of total N and P to discharge water (kg/year)

E_{N+P} = concentration of N and P in effluent (mg/L)

There is once again the problem of huge temporal variation in nutrient levels in discharge waters. Davies (*per comm.)* showed large diurnal variations in effluent water from a Tasmanian salmon hatchery due to feeding activity and flushing of the system. Davies (1995) demonstrated that the volumes of N and P in the discharge water would reflect the activities on that site within the last few hours. Therefore, a reliable monitoring system would need to be developed to assure these variations are accounted for when estimating approximate emissions of total N and P in the discharge water. It is envisaged that such a monitoring schedule would need to be developed that incorporated obtaining reliable data over a reasonable time period with sampling conducted over a full cycle of normal husbandry methods.

6.2 Mass Balance

The mass balance equation presented is suitable for use by both marine and freshwater land-based fish farming using semi-open systems. The definitions, values and any assumptions for the equation are described below.

Equation 3 $T_{N+P} = (F_{N+P} * FCR) – (A_{N+P})$

Where T_{N+P} = discharge of total N and P to water (kg/t/fish produced)

F_{N+P} = total N and P in feed (kg/t)

FCR = food conversion rate*

A_{N+P} = N and P converted to fish biomass (kg/t)

All variables presented are described as kg of total Phosphorus and Nitrogen per tonne of fish produced (kg/t). The proportion of P and N in the feed is obtained directly from the producers. Currently the majority of temperate water finfish farms in Australia use feed supplied from either Pivot Aquaculture Pty Ltd or Ridley Agriproducts Pty Ltd. The level of P and N in the feed will vary depending on the size of pellet being used and the size of the fish being grown. A table of FCR's for the main finfish species described in this manual is contained in Table 1.

Table 1 FCR estimates for various finfish species

Species	FCR	Source
Salmon	1.2:1	Trevor Dix (*per comm.*)
Trout (freshwater)	1.3:1	Brett Ingram (*per comm.*)
Tuna	11:1	Jeff Buchanan * (*per comm.*)
Silver perch	2:1	Brown *et al* 1997
Eels	2:1	John Ranicar (*per comm.*)
Barramundi	2:1	Stewart Fielder (*per comm.*)
Seahorse	N/A	
Ornamental fish	N/A	

*This FCR figure is based on a small sample size of fish off the experimental farm that SARDI manages for their research. It should be noted that the tuna are fed wet whole fish compared with dry formulated feeds that the majority of other species receive.

The proportion of N and P in the feed can be obtained directly from the feed suppliers. In 1999/2000 the Barastoc DF Trout Grower was used by the majority of trout farms in Victoria (Brett Ingram, Victorian Marine and Freshwater Institute *pers comm.*) and the Atlantic Salmon Grower by the majority of farms in Tasmania (Alasdair Bradley, Pivot Aquaculture *pers comm)*. These products contain between 6% and 7.3% N (median value of 6.9%) and 1.2% and 1.5% P (median value 1.4%)(Alasdair Bradley, Pivot Aquaculture and R. Bradford, Ridley Agriproducts Pty Ltd, *pers comm.*). The fish do not consume a proportion of feed entering the farm and this component represents both dust and uneaten pellets that either sink to the bottom of the ponds or under the cages. Approximately between 2% and 15% (median 6.5%) of feed added to trout and salmon farms (GBWQWG 1995 and Baird *et al* 1996) is not consumed by fish. The N and P content of whole fish is approximately 3.0% (Enell 1995) and 0.4 – 0.5% of fresh weight respectively (Lall 1991). After deducting N and P harvested with the fish and the proportion of feed not consumed by fish, the remaining N and P is excreted in particulate (faecal) and soluble form. Results from Enell (1987), Ackefors and Enell (1990) and Ackefors and Enell (1991a) have shown that about 78% of the discharged N is in dissolved form and the rest (22%) in particulate form. To determine the estimated TN and TP emissions for a farm or region for every tonne of fish production, firstly multiply the proportion of N or P in the feed by the FCR for the stock to give the total amount of N or P entering the system. By subtracting the N or P assimilated into the fish body tissue from the total N or P entering the system, the estimated emissions for each element per tonne of fish production can be calculated. A series of worked examples are provided below to demonstrate the use of the mass balance equation described.

Example 2 Semi-open salmon farm in marine environment (based on single cage).

$T_{N+P} = (F_{N+P} * FCR) – (A_{N+P})$

N discharge

1. Proportion of N in feed = 69.0 kg N/t (N content = 6.9%[1])

2. Using a FCR of 1.2 it is estimated that 1200 kg of feed containing 82.8 kg N/t is required to produce 1 tonne of fish

3. N content of fish = 3.0%[2] and therefore 30 kg N/t is removed from the system at harvest

4. Based on these figures, the model estimates that 52.8 kg N/t is discharged to the aquatic receiving environment each year for every tonne of fish produced

([1] median value provided by feed suppliers ie. Pivot Aquaculture / Ridley Agriproducts Pty Ltd;

[2] value obtained from Enell 1995)

Note. A proportion of the feed is unconsumed = 6.5%[3] (82.8*6.5/100) and therefore 5.4 kg N/t of fish produced was not eaten or represents dust. This material will sink to the bottom of the ponds or under cages but is often re-suspended at a later time and hence is included in the total emission value derived. No attempt has been made to quantify the amount of N volatised in this equation. ([3] median value from Baird *et al* 1995 and GBWQWG 1995)

The figure calculated from the equation (52.8 kg N/t) should then be multiplied by the farm's annual production (tonnes of fish) to calculate the total N emission for that year. For example, if the farm produced 267 tonnes of salmon then the annual emission output would be 14.1 t of N for that year.

$T_{N+P} = (F_{N+P} * FCR) – (A_{N+P})$

P discharge

1. Proportion of P in feed = 14.0 kg P/t (P content = 1.4%[1])

2. Using a FCR of 1.2 it is estimated that 1200 kg of feed containing 16.8 kg P/t is required to produce 1 tonne of fish

3. P content of fish = 0.45%[2] and therefore 4.5 kg P/t is removed from the system at harvest

4. Based on these figures, the model estimates that 12.3 kg P/t is discharged to the aquatic receiving environment each year for every tonne of fish produced

([1] median value provided by feed suppliers ie. Pivot Aquaculture / Ridley Agriproducts Pty Ltd; [2] value obtained from Lall 1991)

Note. A proportion of the feed is unconsumed = 6.5%[3] (16.8*6.5/100) and therefore 1.1 kg P/t was not eaten or represents dust. This material will sink to the bottom of the ponds or under cages but is often re-suspended at a later time and hence is included in the total emission value derived. No attempt has been made to quantify the amount of P volatised in this equation. ([3] median value from Baird *et al* 1995 and GBWQWG 1995)

The figure calculated from the equation (12.3 kg P/t) should then be multiplied by the farm's annual production (tonnes of fish) to calculate the total P emission for that year. For example, if the farm produced 267 tonnes of salmon then the annual emission output would be 3.3 t of P for that year.

Example 3. Trout farming using range of pellet sizes from different suppliers to feed fish.

Fish diets can be classified on the basis of type (starter, grower, finishing and broodstock) and these types represent a range of pellet sizes with different feed compositions. It is important that the mass balance equation figures reflect the feed history of each farm. In the example provided, the farm uses a range of pellet sizes to feed mainly adult fish and the feed comes from several different suppliers. Therefore it is necessary to determine the weighted mean of the N and P content in the feed.

$$T_{N+P} = (F_{N+P} * FCR) - (A_{N+P})$$

<u>N discharge</u>

1. Weighted mean N in feed

$$\frac{[59\ t\ (\text{Pivot } 45{:}22)*7.3\%^{1}]+[195\ t\ (\text{Ridley T17})*6\%^{1}]+[26\ t\ (\text{Aller})*6.9\%^{1}]}{(59+195+26)}$$

$$\frac{430.7+1170+179.4}{280}$$

= 6.36%

Therefore proportion of N in feed = 63.6 kg N/t

2. Using a FCR of 1.2 it is estimated that 1200 kg of feed containing 76.3 kg N/t is required to produce 1 tonne of fish

3. N content of fish = 3.0%[2] and therefore 30 kg N/t is removed from the system at harvest

4. Based on these figures, the model estimates that 46.3 kg N/t is discharged to the aquatic receiving environment each year for every tonne of fish produced

([1] values obtained from feed suppliers ie. Pivot Aquaculture; Ridley Agriproducts Pty Ltd & Aller Aqua Pty Ltd

[2] value obtained from Enell 1995)

Note. A proportion of the feed is unconsumed = 6.5%[3] (76.3*6.5/100) and therefore 4.9 kg N/t was not eaten or represents dust. This material will sink to the bottom of the ponds or under cages and is often re-suspended at a later time and is included in the total emission value derived. No attempt has been made to quantify the amount of N volatised in this equation. ([3] median value from Baird *et al* 1995 and GBWQWG 1995)

The figure calculated from the equation (46.3 kg N/t) should then be multiplied by the farm's annual production (tonnes of fish) to calculate the total N emission for that year. For example, if the farm produced 267 tonnes of salmon then the annual emission output would be 12.4 t of N for that year.

$T_{N+P} = (F_{N+P} * FCR) – (A_{N+P})$

P discharge

1. Weighted mean P in feed

$$\frac{[59\text{ t (Pivot 45:22)}*1.5\%^{1}]+[195\text{ t (Ridley T17)}*1.3\%^{1}]+[26\text{ t (Aller)}*1.2\%^{1}]}{(59+195+26)}$$

$$= \frac{88.5+253.5+31.2}{280}$$

= 1.33%

Therefore proportion of P in feed = 13.3 kg P/t

2. Using a FCR of 1.2 it is estimated that 1200 kg of feed containing 15.96 kg P/t is required to produce 1 tonne of fish

3. P content of fish = 0.45%[2] and therefore 4.5 kg P/t is removed from the system at harvest

4. Based on these figures, the model estimates that 11.46 kg P/t is discharged to the aquatic receiving environment each year for every tonne of fish produced

([1] values obtained from feed suppliers ie. Pivot Aquacultur; Ridley Agriproducts Pty Ltd & Aller Aqua Pty Ltd;

[2] value obtained from Lall 1991)

Note. A proportion of the feed is unconsumed = 6.5%[3] (15.5*6.5/100) and therefore 1.0 kg P/t was not eaten or represents dust. This material will sink to the bottom of the ponds or under cages and is often re-suspended at a later time and is included in the total emission value derived. No attempt has been made to quantify the amount of P volatised in this equation. ([3] median value from Baird *et al* 1995 and GBWQWG 1995)

The figure calculated from the equation (11.46 kg P/t) should then be multiplied by the farm's annual production (tonnes of fish) to calculate the total P emission for that year. For example, if the farm produced 267 tonnes of salmon then the annual emission output would be 2.9 t of P for that year.

The mass balance calculation can be applied to all finfish species presently being cultured in temperate Australian waters. It requires knowledge of the FCR's, the proportion of N and P in the diet and the proportion of N and P assimilated into the fish being grown. Whilst the majority of fish species being farmed feed predominantly on pelletised diets, the equation can be used on farms using wet feeds, like the tuna industry. Presently tuna are fed exclusively wet diets, mainly in the form of imported frozen pilchards although some experimental work on developing pelletised feed is being conducted (Alasdair Bradley, *per comm*). It is possible the use of frozen feeds may result in increased wastage, with uneaten food settling on the bottom. This is most likely due to the frozen feed having a high water content which can lead to an accelerated disintegration rate and decreased stability in water (Gowen and Bradbury 1987). The data from Braaten *et al* (1983) suggest wastage of wet diets is approximately 20% in marine environments. The tuna are currently being fed a large range of dietary items which includes 23 different pilchard species (Kirsten Rough *per comm*). Data on the N and P content of these pilchards is limited and considerable variation may exist depending on where they are sourced. However, some work has been done analysing the composition of the pilchards and is summarised in Table 2. Median values for the N and P content of the pilchards are 2.92% and 0.83% respectively (Brett

Glencross *per comm*). The N and P content of the tuna is very close to the median values used in the above equations on salmonid farming. The tuna values are N content approximately 3.9% and P content approximately 0.25% (Jeff Buchanan *per comm.*). **Note**: These figures are estimates based on only a very small number of samples which doesn't include bones, skin etc of the fish, so they probably under estimate the P content of whole tuna. The above example shows the values used in the mass balance equation should be species specific. However, to examine each individual species to this level was beyond the scope of this manual and for a number of experimental species, not all the data needed presently appears to exist.

The failure to include an Emission Estimation Technique (EET) in this manual for other NPI substances does not mean that estimations of aggregated emissions for that substance will not be required in the future. It is important to note that other estimation techniques, not outlined in this manual, may be applicable for certain aquaculture activities. Alternative methods can be suggested and used, but these would need to be acceptable to the relevant State Environmental Authorities

It must be emphasised that values derived from these equations must be treated as estimates only as a range of other factors can influence Phosphorus and Nitrogen levels in effluent waters have not been taken into account in the development of these equations. Whilst every care has been taken into the development of these calculations, users should be aware that they are intended as a guide only.

7 Other Potential Waste Produced from Aquaculture

7.1 Chemical Usage

In general, the use of chemicals to control diseases (bactericides, fungicides, parasiticides), aquatic vegetation (algae's) and other nuisance organisms (insecticides, piscicides) in aquaculture is required. Chemicals also include compounds to reduce handling trauma to species being cultured (anaesthetics) and to induce spawning or promote growth (hormones). There is also a range of compounds used to disinfect water, improve water quality and increase productivity (lime, fertilisers). Whilst a wide range of chemicals are used in aquaculture, there appears to be little data available on the quantities used (Beveridge *et al* 1991). The use and discharge of chemical treatments and veterinary products on fish farms in temperate Australia raise a number of environmental issues. The uncontrolled application of antifoulant products on farming equipment and antibiotic usage in feed have been identified as having the potential to cause environmental problems. However, in Australia, State and Federal legislative controls are currently in place to regulate and control the type and usage of antifouling and antibiotic treatments.

7.1.1 Chemotherapeutants

<u>*Antibiotics*</u>

The Norwegian State Pollution Control Agency anticipates that 75% of antibiotics used may be lost to the sediment (Gowen *et al* 1987). There is a growing concern about the effects of antibiotics used to control disease on fish farms, especially their effects on natural bacterial communities and wild fish outside the pens. This appears to be stimulating numerous studies, some of which are ongoing in Europe (Capone *et al* 1996, Kerry *et al* 1996 and Pursell *et al* 1996). Unfortunately, there is little information available on the effects of the various compounds on natural ecosystems in temperate Australian waters. At least, in Molluscs any uptake seems to be cleansed from their system after a relatively short time (Jones 1990). It appears from our current knowledge, that antibiotics have the potential to cause environmental problems but generally contain minor NPI substances.

<u>*Antifoulants*</u>

Copper-based antifoulants are widely used in marine mariculture, e.g. in Norway the total use of copper oxide in 1990 amounted to *c*. 0.7kg/t of salmon production (Braaten 1991). The sediments close to cages have occasionally been found to be enriched with copper (Braaten 1991). All aquaculture companies in temperate Australia intending to use copper-based antifoulants must register for a permit from the National Registration Authority. All antifoulants based on tributyltin (TBT) are presently banned. Large scale environmental effects, if any, of antifoulants in the sea are undoubtedly difficult to estimate, but certainly, the bulk of antifouling substances in use today are used on boats and structures other than fish farm cages (Heen *et al* 1993).

Disinfectants

Disinfectants are commonly used in fish hatcheries to wash fish tanks before use, and in the course of the general cleaning operations. Common disinfectants used are formalin, chlorine and chloramine, the latter often in conjunction with ammonia, which enhances its stability (Heen *et al* 1993). These substances are highly toxic, not only to the target microorganisms, but also to the fish. However, the quantities used are small and the flushing volumes large, so it is probably unlikely that the use of disinfectants by hatcheries would result in emissions of reportable levels of NPI substances on an annual basis.

7.2 Bloodwater

The current methods of harvesting and processing of farmed fish occasionally results in bloodwater being released back into the marine environment. This problem is normally restricted to farming operations where fish harvesting occurs at sea prior to the fish being processed at shore-based facilities. However, there are concerns that bloodwater discharged directly into waters around some farm sites during routine harvesting of fish may decrease water quality. Most states have controls on waste in place that imply products from harvesting or processing must be disposed of in a manner that does not affect the ecology of the marine* environment. The appropriate disposal of bloodwater is a problem the aquaculture industry acknowledges it is facing. The industry is being pro-active in examining options to assess best practice management of this problem. In Tasmania recent funding has been obtained to assess the most cost effective and environmentally sensitive method of bloodwater disposal from salmonid farming.

Figure 2 summarises possible pathways of a number of potential environmental impacts associated with fish farming.

* Some of the species discussed are fresh water. Should the term here include them?

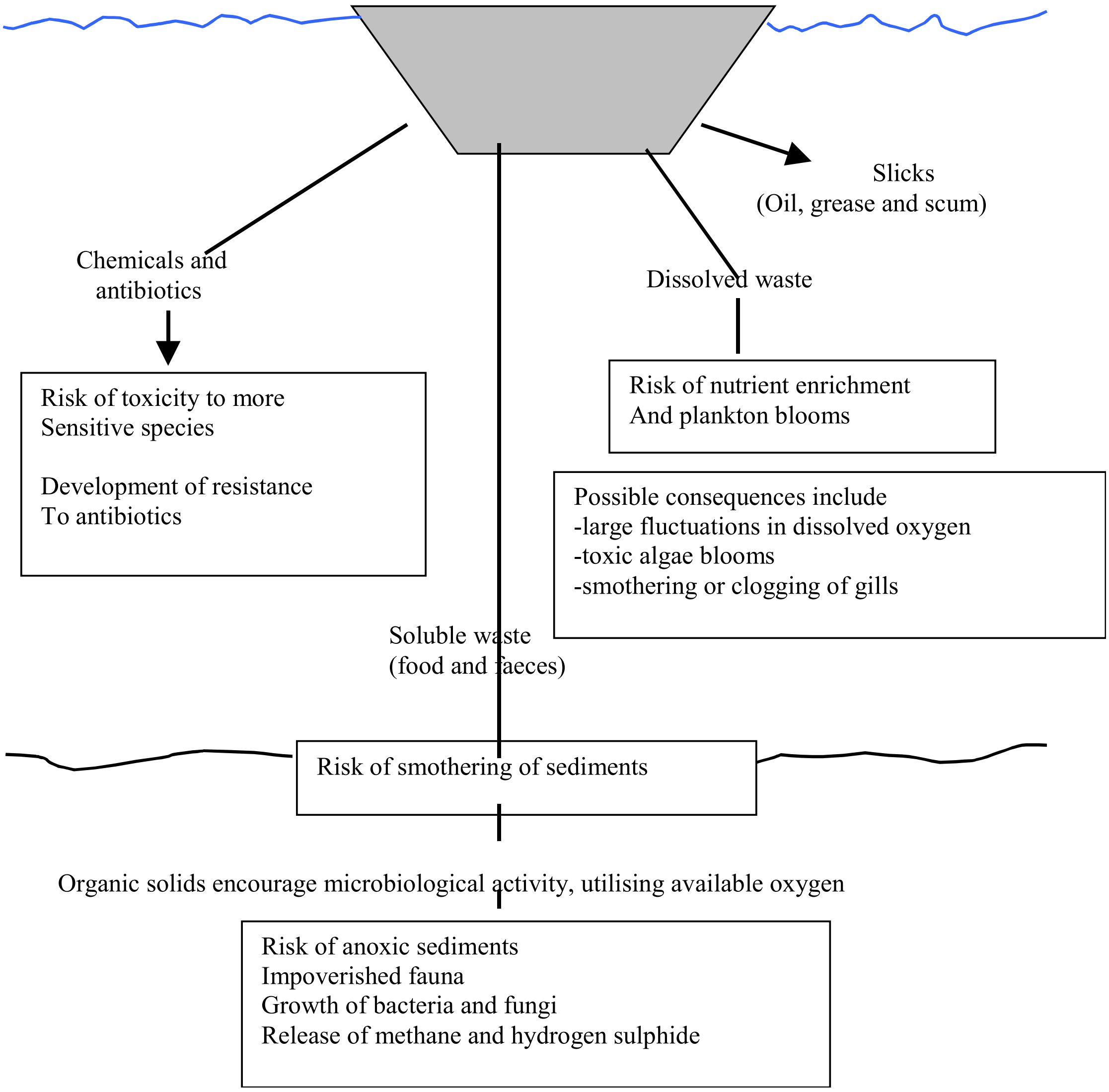

Figure 2 Pathways of potential environmental impacts associated with semi-closed fish farming (Smith & Haig 1991).

8 Discussion

"The environmental impact of aquaculture is an important issue now and in the future. The way we manage our natural resources represents one of the greatest challenges of the new millennium" (Hon Warren Truss, Federal Minister for Agriculture, Fisheries and Forestry).

Aquaculture operations in Australia continue to expand each year and with this expansion the risk to the environment from aquaculture wastes grows correspondingly (Cowey and Cho 1991). It may be argued that these risks are minor in comparison to risks rising from industrial or domestic pollution. Nevertheless, the concerns of environmental scientists have been powerfully argued and have lead to a growing public awareness of the dangers of environmental abuse. Consequently, it is in the aquaculture industry's interest to describe and quantify the problem and then to provide measures to limit or prevent it.

Whilst the nutrient load from single fish farms in certain coastal and inland water bodies can be significant, the assessment of the farm's impact must also involve consideration of impacts from other sources and must be examined in context of the receiving aquatic environment. The Nordic fish farming production in 1994 resulted in a load of about 13 750 tonnes of N and 1 200 tonnes of P, but these quantities are considered negligible in comparison with other pollution sources (Enell 1995). The quantities of N and P from the fish farming in that year were equal to 0.5% of the atmospheric deposition on the sea surface and 3% of the atmospheric P load (Enell 1995). A recent CSIRO study of the Huon estuary in southern Tasmania postulates a nutrient budget in the estuary showing finfish farms currently producing only small loads of dissolved inorganic nitrogen (DIN) compared with marine sources (CSIRO Huon Estuary report 2000). Many recent Finfish operations in Australia have evolved in accordance with acceptable discharge levels of N and P determined by the relevant State authorities. Any attempts to change these levels could seriously threaten important regional industries and warrant careful consideration. Some States (eg. NSW) already have specific licence requirements of zero discharge of effluent water for any land based aquaculture.

It appears that most finfish farmers in temperate Australia may be able to address many of the issues associated with their farms environmental effects on receiving waters through operational solutions. It also appears that feed manufactures are seeking to improve digestibility of pellets, and to tailor the macronutrient ratios both for the advantage of the farmed fish, and for the receiving environment (e.g. Talbot and Hole 1994, Hillestad *et al*. 1999). A pro-active response by the aquaculture industry to meet its environmental obligations is undoubtedly required, or the industry faces the risk that society, through increasingly tougher legislation, will limit the possibilities of further development of fish farming.

Table 2 Pilchard compositions 1998-2000 (Source: Brett Glencross per comm.)

Date	Crude Protein	Nitrogen	Moisture	Ash	Phosphor us	Fat
1998 mean	17.72	2.84	31.1			
1998 Shipment A	16.68	2.67	35.02			
1998 Shipment B	18.24	2.92	29.16			
1999 Mean	18.76	3.00	27.52			
2000 WA pilchards	19.89	3.18	28.00	4.68	0.83	2.05

9 Glossary of Terms

Term	Definition
ABARE	Australian Bureau of Agricultural and Resource Economics
DIN	Dissolved Inorganic Nitrogen
DPIWE	Department of Primary Industry, Water and the Environment
EA	Environment Australia
EET	Emission Estimation Technique
FCR	Food Conversion Ratio. Determined by dividing the total amount of feed (dry weight) consumed by the fish by the increase in weight of those fish (wet weight)
mg/L	Milligrams per litre, equivalent to ppm (parts per million)
ML	Megalitre
NPI	National Pollutant Inventory
N	Nitrogen
P	Phosphorus
SARDI	South Australian Research and Development Institute
TN	Total nitrogen
TP	Total phosphorus

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11 Appendices

Appendix A: Finfish species cultured in Australian temperate waters (Source: AQUAVETPLAN Enterprise Manual 1999)

Appendix B: Number of Finfish licence holders for each state.

Appendix C: Australian aquaculture production in 1998-99, by State as (Source: Australian Fisheries Statistics ABARE report 1999).

Appendix A: Finfish species cultured in Australian temperate waters (Source: AQUAVETPLAN Enterprise Manual 1999)

Table 3 Finfish species cultured in Australian temperate waters (Source: AQUAVETPLAN Enterprise Manual 1999)

Common Name	Scientific Name	Where Produced	Destination	Systems involved
Atlantic salmon	Salmo salar	Tas Vic SA	Domestic markets and export	Hatcheries Raceways Sea cages
Tuna	*Thunnus maccoyii*	SA	Domestic markets and export	Sea cages
Rainbow trout	*Oncorhynchus mykiss*	NSW Vic Tas SA	Domestic markets and export	Hatcheries Raceways Ponds Sea cages
Brown trout	*Salmo trutta*	Vic	Domestic waterways	Hatcheries Raceways Ponds
Silver perch	*Bidyanus bidyanus*	NSW SA	Domestic markets	Hatcheries Ponds
Mulloway	*Argyrosomus Hololepidotus*	NSW	Domestic markets	Hatcheries Net pens
Snapper	*Pagrus auratus*	SA NSW	Domestic markets	Hatcheries
Australian bass	*Macquaria novaemaculata*	NSW	Domestic waterways	Hatcheries
Golden perch	*Macquaria ambigua*	NSW	Domestic waterways	Hatcheries
Barramundi	*Lates calcarifer*	SA NSW	Domestic markets	Hatcheries Ponds Net pens
Goldfish	*Carassius auratus*	All states	Domestic markets	Ponds
Eels	*Anguilla australis*	Vic NSW	Export	Dams
Murray cod	*Maccullochella Peelii*	NSW	Domestic markets	Land based facility
Snapper	*Pagrus auratus*	NSW	Domestic markets	Net pens
Eastern cod	*Maccullochella Ikei*	NSW	Domestic markets	N/A
Yellowtail Kingfish	*Seriola lelandi*	NSW SA	Domestic markets	Sea cages
Seahorses	*Hippocampus abdominalis*	Tas	Export	Land based facility

Appendix B: Number of Finfish licence holders for each state.

Victoria (Source: Fisheries Victoria Aquaculture Production Information Bulletin 1998)

Sector	**Number of Licence holders**
Eels	12
Warmwater finfish (inland)	33
Salmonids	31
Ornamental fish	8

New South Wales (Source: Aquaculture in NSW 1999)

Sector	**Number of Licence holders**
Trout	5
Eels	N/A
Silver perch	134
Inland native fish	N/A
Ornamental fish	9[a]
Barramundi	1 [a]

Tasmania (Source: Brown *et al* 1997 and DPIWE & IFS *pers comm.*).

Sector	**Number of Licence holders**
Salmon	35
Eels	12
Trout	7

South Australia (Source: Brown *et al* 1997).

Sector	**Number of Licence holders**
Tuna	17
Barramundi	7[a]
Silver perch	3[a]
Ornamental fish	1[a]

Western Australia (Source: Brown *et al* 1997).

Sector	**Number of Licence holders**
Ornamental fish	35
Barramundi	2
Trout	10

a (Source: Brown *et al* 1997).

It should be noted that not all licenses are necessarily being used. For example, in 1997/98 there were 134 permits issued for silver perch farming in NSW but only 47 were in production. (Source: Aquaculture in NSW 1999).

Appendix C: Australian aquaculture production in 1998-99, by State as (Source: Australian Fisheries Statistics ABARE report 1999).

Table 4 Australian aquaculture production in 1998-99, by State as (Source: Australian Fisheries Statistics ABARE report 1999).

	NSW	Vic.	WA	SA	Tas	Aust.
Value	**$'000**	**$'000**	**$'000**	**$'000**	**$'000**	**$'000**
Fish						
Salmon	0	0	0	0	71 724	71 724
Trout	1 949	5 453 b	300	101	0	7 803
Tuna	0	0	0	166 700	0	166 700
Silver perch	1 557	0	0	0	0	1 814
Barramundi	0	0	0	3192	0	8 892
Other a	684	1 239	0	3 259	0	5 182
Total	4 190	6 692	300	173 252	71 724	262 115
Quantity	**t**	**t**	**t**	**t**	**t**	**t**
Fish						
Salmon	0	0	0	0	9 195	9 196
Trout	334	839	34	14	0	1 221
Tuna	0	0	0	6 365	0	6 393
Silver perch	164	0	0	0	0	191
Barramundi	0	0	0	249	0	762
Other a	87	89	0	412	0	588
Total	584	928	34	7 040	9 195	18 349

a Includes eels, aquarium fish and native fish
b Includes salmon production