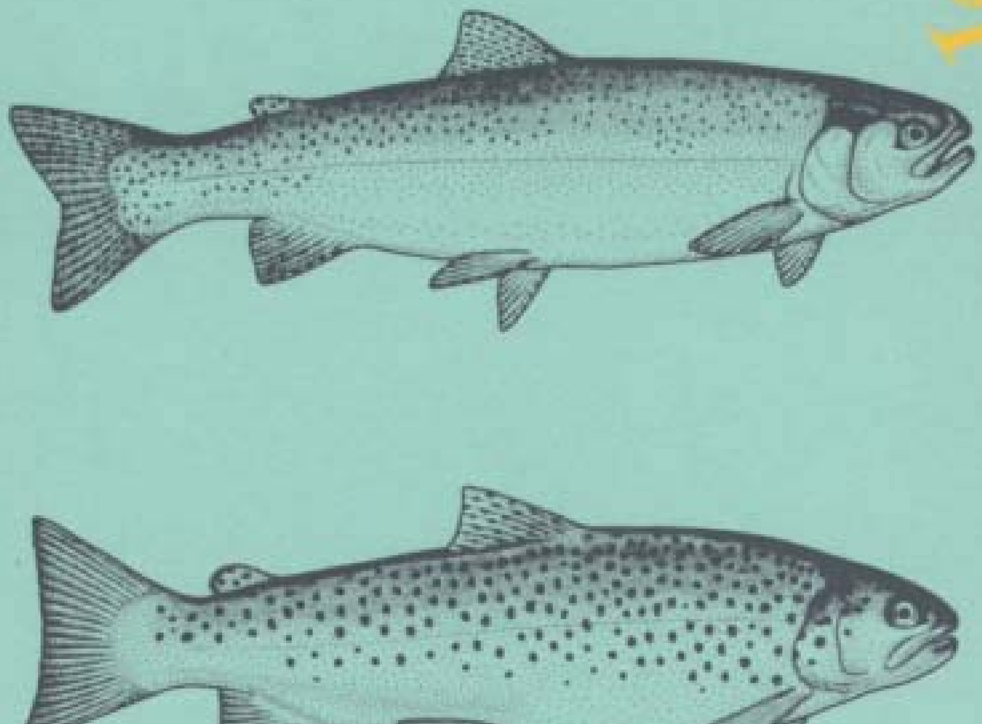
OVERVIEW OF THE IMPACTS OF INTRODUCED SALMONIDS ON AUSTRALIAN NATIVE FAUNA

invasive species program



Australian Nature Conservation Agency

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by

P. L. Cadwallader

prepared for the
Australian Nature Conservation Agency

1996

~~ AUSTRALIA,,)

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Australian Native Fauna
by P L Cadwallader

The views and opinions expressed in this report are those of the authors and do not necessarily reflect those of the Commonwealth Government, the Minister for the Environment or the Director of National Parks and Wildlife.

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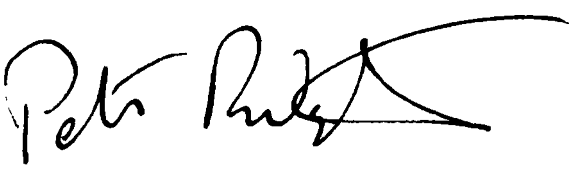
FOREWORD

This series of national overviews was commissioned by the Invasive Species Program to enable existing knowledge on the impact of introduced species on the natural environment to be collated and examined for key knowledge gaps. The impact of introduced animals on native species is an area that has been little studied in Australia. More often than not, the impact of introduced species is assumed rather than quantified.

Five species of salmonids were introduced into Australia in the late 1800's. Since that time salmonids, particularly trout, have become widely distributed in certain areas of Australia and form a significant component of recreational fishing. However, in some places, at some times, salmonids can constitute a threat to populations of native fish, like the endangered Barred galaxias.

This review on the impacts of introduced salmonids on Australian fauna is a comprehensive document providing excellent material for future research and planning for freshwater fisheries management. It is an invaluable contribution to the Australian Nature Conservation Agency's pursuit for information on the identified impacts of various introduced species and recommends a number of options to further investigate, clarify and contend with recognised impacts. I hope that it will be well utilised by all agencies and individuals concerned with biodiversity conservation.



Peter Bridgewater
Chief Executive Officer
Australian Nature Conservation Agency

SUMMARY

There have been few studies in Australia on the impacts of salmonids on fauna other than fish and those studies which have been done cover a relatively small part of the fish fauna. The most substantive evidence of impacts comes from an experimental introduction study and from observations made during the invasion of new areas. Much of the information on the distributions of salmonids and native fish is derived from surveys not specifically designed to investigate the effects of salmonids.

The numerous and widespread instances of fragmented galaxiid distribution patterns in the presence of trout, the more widespread distribution of galaxiids in the absence of trout, and the fragmentation of galaxiid distribution pattern as trout move upstream, provide a substantial body of evidence for an adverse impact of trout on stream-dwelling galaxiids.

The major impact of salmonids has been via predation. Salmonids have undoubtedly also had an impact via the spread of pathogens.

Studies on the effects of salmonids on the distributions of native fauna should be designed specifically to test the hypothesis that the occurrence of a particular species is affected by the presence of salmonids. Introduction experiments in the field provide the most convincing evidence of an impact.

Salmonids are implicated in the demise of ten of Australia's threatened fish species. Priority should be given to research on the threatened galaxiids, pygmy perches and Australian grayling. Reserves for all Tasmanian galaxiids should be established. The impact of trout on macroinvertebrates and aquatic vertebrates other than fish has been largely ignored and requires urgent assessment.

The value of salmonids as sport-fish and in aquaculture has overshadowed consideration of their effects on native fauna and, in general, legislation to safeguard native fauna from the effects of salmonids is lacking. The agencies responsible for the management of salmonid fisheries need to re-assess their attitudes and take a more pro-active approach to protecting native fauna.

Disclaimer

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1. INTRODUCTION

Habitat degradation is recognised as a major factor in the decline of Australia's native freshwater and estuarine fauna. In particular, the importance of sustaining fisheries by sustaining fish habitat is well recognised (Hancock 1992). However, even though habitat degradation has had a major impact on the range and abundance of many native freshwater fish species, introduced fish are also implicated in the demise of several species (Pollard and Burchmore 1986, Ingram *et al.* 1990, Jackson 1993, Jackson *et al.* 1993, Wager and Jackson 1993).

Earlier reviews of the effects of introduced fish on Australian native fauna by Butcher (1967), Weatherley and Lake (1967), Cadwallader (1978), Tilzey (1980), McKay (1984), Fletcher (1986), Morison (1988), Arthington (1989), Pollard (1990) and, specifically of the effects of salmonids, by Jackson (1981) and, more recently, Crowl *et al.* (1992) and Keam (1994), have highlighted the paucity of hard evidence in relation to the demonstration of an impact of introduced salmonids on Australian native fauna.

The purpose of this report is to:

- provide a summary of the introduction of salmonids into Australia, the species present, their distribution, utilisation and biology;
- review research findings on the impacts of salmonids on Australian native freshwater and estuarine fauna, together with relevant overseas work, particularly that done in New Zealand which shares several native taxa in common with Australia;
- review research methods and recommend practical methods and priorities for research in Australia to clarify the impact of salmonids on Australian native freshwater and estuarine fauna;
- identify specific localities and native species and populations where the impact of salmonids is regarded as greatest, and recommend management options;
- review policies and regulations relating to the introduction and stocking of salmonids from the perspective of impact on native fauna; and
- provide a comprehensive bibliography.

A priori it must be assumed that the introduction of any species will have an impact as far as the native fauna is concerned (Cadwallader 1978). As pointed out by Taylor *et al.* (1984), defining "impact" as any effect on a native population attributable to an introduced species deems its occurrence a foregone conclusion; that no effects should result from such perturbations strains ones's confidence in ecological principles. With few exceptions, research and comment on the impact of salmonids on the freshwater and estuarine fauna of Australia has been focused on the fish fauna. Jackson (1981) provided a list of the native fish (together with their maximum recorded lengths) which occur in trout waters in south-eastern Australia. Theoretically, members of the following fish families, all of which occur in waters in Australia in which salmonids have been introduced, could be affected at some stage of the their life cycle by salmonids: Petromyzontidae, Anguillidae, Galaxiidae, Retropinnidae, Prototroctidae, Aplochitonidae, Gadopsidae, Nannopercidae, Bovichthyidae, Teraponidae, Percichthyidae, Eleotridae and Gobiidae. Adding lists of the vertebrates other than fish and the macroinvertebrate families which occur in waters in which salmonids have been introduced makes quite a catalogue of Australian fauna which has been exposed to some interaction with these introduced fish.

At the outset it must be realised that the greatest impacts would have occurred in the years immediately following the introduction of salmonids into Australia. Consequently, the faunal assemblages in which many of the subsequent observations and research projects were carried out do not reflect "natural" conditions, but faunal assemblages which are likely to have been substantially modified from those which occurred before salmonids were introduced.

Observations that trout do not have an impact because they occur together with various macroinvertebrate and fish species are at best misleading. What the observations reflect is probably a much changed fauna, containing animals which, because of their particular life history characteristics, reproductive strategies or ability to withstand environmental extremes, are able to co-exist with salmonids. Those animals lacking appropriate predator -avoidance mechanisms or whose life history characteristics, behaviour or size make them particularly vulnerable to salmonids are likely to have already been eliminated or restricted to being a much less significant component of the fauna.

2. SPECIES OF SALMONIDAE IN AUSTRALIA

The family Salmonidae is relatively small, but contains some of the world's most popular angling species. Its members are characterised by an adipose fin, a lateral line, axillary processes on the pelvic fins, small scales and a dorsal fin high on the back and further forward than the pelvic fins (McDowall and Tilzey 1980) . The family is native to the cool and cold waters of the Northern Hemisphere (Berra 1981). Some species are restricted to fresh water, but others spend various parts of their lives in the sea. Salmonids have been introduced into many countries in the world, primarily to provide recreational fishing. There are five species of the family Salmonidae in Australia (Lake 1971, Merrick and Schmida 1984, Allen 1989).

2.1 Brown Trout *Salmo trutta* Linnaeus

Brown trout are native to Europe, from Iceland and Scandinavia southward to Spain and North Africa and eastward to the Black and Caspian Seas. They have been introduced into many countries and are present on all continents except Antarctica (Frost and Brown 1967, MacCrimmon and Marshall 1968, MacCrimmon *et al.* 1970).

Roughley (1966) described the introduction and spread of brown trout in Australia. They were introduced as fertilised eggs brought to Tasmania from the United Kingdom in 1864. Soon afterwards, stocks in Victoria were developed from eggs obtained from Tasmania, and in 1888 brown trout were introduced into New South Wales. Progeny from the resulting stocks were distributed widely throughout Tasmania, Victoria and New South Wales. Brown trout were first introduced into South Australia in 1901, but it was not until the 1930s that they became established in Western Australia. Despite repeated attempts, brown trout have not become established in Queensland.

Detailed early accounts of the introduction of brown trout are given by Wilson (1879) and Nicols (1882); later accounts include those of Fraser (1953), Arentz (1966), Lynch (1970), Gilmour (1973), Clements (1988), O'Brien (1988), Ritchie (1988) and Walker (1988). Self-sustaining brown trout stocks are now widespread in the cooler parts of Australia, and isolated populations of sea-run trout occur in Victoria and Tasmania (Kailola *et al.* 1993). Reasons for their success in the Australian environment are reviewed by Weatherley (1974) and Tilzey (1977). Probable key factors in their establishment and success were the physicochemical and biological similarities between many Australian trout habitats and those of the ancestral stocks, the minimal competition from native fauna, the abundance and availability of native food species and the virtual absence of parasites and disease (Tilzey 1977).

In addition to the existence of self-sustaining brown trout stocks, releases of hatchery-produced trout maintain fisheries in marginal habitats, in waters lacking suitable spawning conditions or where fishing pressure is thought to be too great for local populations to sustain (Nicholls 1962, Morrissy 1967, 1972, Cadwallader and Tilzey 1980, Cadwallader 1983, Baxter 1992, Cadwallader *et al.* 1992, Hall 1992).

A map outlining the distribution of brown trout in Australia is given by Kailola *et al.* (1993). More specific information on the occurrence of brown trout in the various States is given for Tasmania by Fulton (1990), for Victoria by Cadwallader and Backhouse (1983) and Tunbridge *et al.* (1991), for New South Wales by Lake (1957), Llewellyn (1983) and Faragher (1986), for South Australia by Morrissy (1967) and Scott *et al.* (1974), for Western Australia by Morrissy (1972), and for Queensland by Grant (1978).

McDowall and Tilzey (1980), Cadwallader and Backhouse (1983), Merrick and Schmida (1984) and Kailola *et al.* (1993) have reviewed the biology of brown trout in Australia.

Brown trout can reach over 1400 mm in length and over 20 kg in weight; in Australia, they have been recorded up to 14 kg in weight and up to 950-1000 mm long. Their optimum temperature range is 4-19 degrees Celsius and they typically occur in cool, well oxygenated waters, usually in streams with a gravel substrate and moderate to fast flow, but also in cool, clear lakes.

Spawning occurs in autumn and winter (April to July), often following a flood. Spawning fish typically migrate upstream into small tributaries with gravel beds. Pair formation occurs. The female excavates a depression in the stream bed, while the male chases away intruders. The male joins the female above the depression and their eggs and milt are released together, the fertilised eggs settling amongst the gravel. The female then covers the eggs by dislodging gravel upstream of the depression, and then excavates another. The spawning area, encompassing several depressions, is called a redd. Brown trout eggs are bright orange and 4-5 mm in diameter. Development within the egg takes several weeks, depending on temperature (about six weeks at 10 degrees Celsius).

Newly-hatched brown trout are 15-25 mm long and have a prominent yolk sac. At this stage they are called alevins. They remain in the gravel for several weeks, absorbing their yolk, before emerging to begin feeding. There is a general downstream movement after emergence. The young trout form small shoals in moderately fast water at the tails or margins of pools. At this stage, they have a series of bold, dark blotches along their sides and are called parr; the blotches are referred to as parr marks. -

Although initially gregarious, brown trout soon become solitary and territorial, becoming increasingly so as they get bigger. They feed on a wide range of animals, including aquatic insects, crustaceans, molluscs and small fish, as well as on terrestrial invertebrates which fall on the water surface.

The brown trout is an excellent angling species and is taken primarily on rod-andline using bait, lures or flies. It is considered as probably the most important introduced sport fish in Australia (McDowall and Tilzey 1980).

2.2 RainbowTrout *Oncorhynchus mykiss* (Walbaum)

Rainbow trout are native to the Pacific coast of North America, from Alaska to Mexico. Like brown trout, they have been introduced into many countries and are now present on all continents except Antarctica (MacCrimmon 1971).

Roughley (1966) and Clements (1988) have detailed the introduction and spread of rainbow trout in Australia. They were introduced in 1894 as fertilised eggs brought to New South-Wales from New Zealand, where the species had become established after introduction from the USA in 1883. Populations soon became established in New South Wales and the progeny from these stocks were subsequently distributed to Victoria, Tasmania and South Australia. Unlike brown trout, rainbow trout appear to have been successfully introduced into a few waters in southern Queensland. As with brown- trout,- rainbow trout did not become established in the south-west of Western Australia until the 1930s (Fraser 1953).,,

As with brown trout, self-sustaining rainbow trout stocks are-now widespread in the cooler parts of Australia, and releases of hatchery-produced fish are made in order to maintain fisheries in-marginal habitats, in waters lacking suitable spawning conditions or where fishing pressure is thought to be too . great for local trout populations to sustain.

The reasons for the success of rainbow trout in Australia are as described for the brown trout. A map outlining their distribution in Australia is given by Kailola *et al.* (1993). More specific information on their occurrence in the various States is given in the references cited for the State distributions of - brown trout. -

McDowall and Tilzey (1980), Cadwallader and Backhouse (1983), Merrick and Schmida (1984) and Kailola *et al.* (1993) have reviewed the biology of rainbow trout in Australia.

Rainbow trout are known to reach 1120 mm long and more than 18 kg in weight; in Australia, they have been recorded to 9.3 kg. Their optimum temperature range is 10-22 degrees Celsius. Essentially, their life history and environmental requirements are the same as those of brown trout, but they tend to be more successful in lakes than in rivers and streams. Spawning occurs a little later than that of brown trout, in winter and early spring (August-early November). In other respects, their breeding biology is similar except that their eggs are smaller than those of brown trout and they develop more quickly.

Young rainbow trout feed on zooplankton; adults feed on a wide range of aquatic organisms, including crustaceans, insects, molluscs and fish, as well as on terrestrial invertebrates which fall onto the water surface.

The rainbow trout is regarded as an excellent angling species. It is more easily hooked than brown trout and a better fighter once hooked. The rainbow trout is the only species of trout cultured commercially for direct human consumption in Australia, although brown trout are produced in hatcheries to provide fish for stocking for recreational fishing purposes. Trout farms in New South Wales, Victoria, Tasmania, South Australia and Western Australia mostly produce pan-sized (250-300 g) rainbow trout. In recent years, sea-cage farming of rainbow trout has developed in Tasmania; young trout are reared in freshwater hatcheries until they weigh 70-100 g before they are gradually acclimatised to sea water and transferred to floating sea cages in coastal bays for ongrowing (Kailola *et* at. 1993).

2.3 Brook Trout *Salvelinus fontinalis* (Ivlitchill)

Brook trout are native to north-eastern North America (Scott and Crossman 1973), and have been introduced into many countries throughout the world because of their appeal as a sport fish (MacCrimmon and Campbell 1969). In Australia, they have a restricted distribution in Tasmania and New South Wales (McDowall and Tilzey 1980, Merrick and Schmida 1984).

They were first introduced to Tasmania in 1883, but did not become established. Further introductions were made from Canada as recently as 1962. Self-sustaining populations now occur in a few waters, and hatchery releases maintain populations for recreational angling in several other waters (Fulton 1990). Brook trout have also been released since the 1970s in streams on the mountain tablelands of New South Wales. However, there are no records of the establishment of self-sustaining populations, although hatchery releases are made into several waters for recreational angling (Llewellyn 1983, Faragher 1986).

Attempts to introduce brook trout into South Australia in the early 1970s were unsuccessful (J. Williams, South Australian Fly Fishers' Association - pers. comm.).

McDowall and Tilzey (1980), Merrick and Schmida (1984) and Fulton (1990) have reviewed the biology of brook trout in Australia. They are known to reach a length of 850 mm and a weight of 6.5 kg; in New South Wales they have been recorded to 2 kg, and in Tasmania to 4 kg. They are a coldwater fish, occurring both in streams and cool lakes. Brook trout in streams tend to move upstream into small tributaries. The species does not usually coexist well with other salmonids, which could explain why its success in Australia is limited.

The breeding biology of the brook trout resembles that of the brown trout, with spawning occurring in late autumn. Their food typically consists of aquatic crustaceans, insects, molluscs and small fish, as well as terrestrial invertebrates.

The sporting qualities of brook trout are less well known than those of other salmonids. They are said to be readily caught, like rainbow trout, but do not fight as well (McDowall and Tilzey 1980).

2.4 Atlantic Salmon *Salmo salar* Linnaeus

Atlantic salmon occur naturally in cool and cold waters which flow into the North Atlantic Ocean, from northern Spain through eastern Europe to Iceland, Greenland, and along the north-east coast of North America (Jones 1959, Scott and Crossman 1973, Mills 1980). In Australia, they have a restricted distribution in Tasmania and New South Wales (Kailola *et* al. 1993).

Atlantic salmon were first introduced to Australia as fertilised eggs brought from the United Kingdom in 1864. Young salmon were subsequently released in Tasmania, Victoria and New South Wales with the aim of trying to establish sea-runs of Atlantic salmon similar to those in the United Kingdom. Detailed accounts of these early efforts are given by Boccius (1854), Allport (1864), Johnston (1888) , Saville-Kent (1888), Wilson (1879), Nicols (1882) and Seager (1888). Although the young salmon did well in the fresh waters of Tasmania, they did not return to these waters, after migration to the sea and the attempt to establish the species was a failure.

Atlantic salmon were subsequently reintroduced to Australia as eggs brought to New South Wales from Canada in the 1960s (Francois 1965, Arentz 1966, Roughley 1966, Clements 1988), and have recently been reintroduced to Tasmania as part of commercial aquaculture operations (Kailola *et al.* 1993).

There are no records of self-sustaining stocks of Atlantic salmon in New South Wales; releases of hatchery-produced fish maintain recreational fisheries in a few impounded waters in the high country (Llewellyn 1983, Faragher 1986). Atlantic salmon are occasionally reported in the lower River Murray in South Australia (B. Pierce, South Australian Research and Development Institute - pers. comm.); presumably these are escapees from impoundment stockings in New South Wales or from commercial fish farms in Victoria and New South Wales. In Tasmania, Atlantic salmon are now established in hatcheries supplying several sea-cage farms and have also been released into Great Lake. Escapees from sea-cages are present in several bays and estuaries in southern Tasmania (Fulton 1990).

Little is known of the natural history of Atlantic salmon in Australia. In its natural habitat, it is a migratory species, with adults moving into rivers in winter to spawn. These fish may reach almost 40 kg in weight. Wild sea-run populations have not become established in Australia, but escapees from sea-cages in Tasmania have been caught up to 10 kg in weight. Atlantic salmon in landlocked populations seldom exceed 2-3 kg (Fulton 1990). Like other trout and salmon, Atlantic salmon require cool or cold waters. Their diet is similar to that of trout (McDowall and Tilzey 1980, Merrick and Schmida 1984). The Atlantic salmon is regarded as a great sporting fish in its natural range, particularly in Europe, where it is often referred to as "the king of fish" (Jones 1959, Mills 1980). Because of its restricted distribution it is of little significance as a sport fish in Australia. However, the commercial culture of Atlantic salmon in sea-cages in Tasmania has recently become a major part of the aquaculture industry (Kailola *et al.* 1993). Atlantic salmon are also farmed commercially in fish farms in mainland south= eastern Australia, primarily in New South Wales and Victoria.

2.5 Chinook Salmon ***Oncorhynchus tshawytscha*** **(Walbaum)**

The chinook salmon is native to the west coast of North America from southern California to Alaska, and north-eastern Asia from northern Japan to Kamchatka. It has been introduced into several countries, but only in the South Island of New Zealand have self-sustaining populations become established (Davidson and Hutchinson 1938, Scott and Crossman 1973).

Chinook salmon were introduced to Australia as fertilised eggs brought to Victoria from California via New Zealand in 1877. Fry from this consignment were distributed widely in Victorian coastal rivers, but did not establish sea-run populations. From 1936 onwards, fertilised eggs were imported on a regular basis from either New Zealand or the USA and the progeny from these eggs were released into several lakes, but only in two deep, crater lakes, Lakes Purrumbete and Bullen Merri, did flourishing fisheries develop. Subsequently, a landlocked hatchery stock was developed from fish obtained from the USA in the 1960s. This stock is the source of releases into Lakes Purrumbete and Bullen Merri, the only two waters in Australia in which chinook salmon are currently released (Butcher 1947, Barnham 1977, Cadwallader and Backhouse 1983, Clements 1988).

Sea-run chinook salmon reach a large size, to 1470 mm in length and 57 kg in weight. In Victoria, landlocked chinook salmon have been recorded to 890 mm long and 11.4 kg in weight. They thrive in the two deep, cold lakes in which they are stocked and although they become ripe they do not breed because of a lack of suitable streams for spawning. They feed on a wide range of aquatic animals, including fish, insects, crustaceans and molluscs (Cadwallader and Backhouse 1983).

2.6 Summary of Present Status of. Salmon ids in Australia

Of the five salmonid species introduced into Australia, the brown trout and rainbow trout have the widest distributions and have formed self-sustaining populations throughout most of their ranges. In addition, releases of hatchery-produced fish maintain stocks for recreational fishing purposes in marginal habitats and in waters in which there are no suitable spawning areas. Brook trout have formed self-sustaining populations in a few localities, but there is no evidence that Atlantic salmon or chinook salmon have formed self-sustaining populations; all three of these species have restricted distributions in Australia.

3. REVIEW OF STUDIES ON THE IMPACTS OF SALMONIDS

For ease of presentation, the studies and observations on the ecological impacts of salmonids are considered in the following categories:

- studies which provide distributional information, including observed distributions recorded during fish surveys, before and after observations, comparisons of the distributions of particular species in the presence or absence of salmonids, and statistical analyses of distributional data sets for salmonids and native fauna (section 3.1);
- studies undertaken during the invasion of new areas by salmonids (section 3.2);
- experimental introduction studies, e.g. introducing salmonids into a delineated stretch of stream and monitoring the effects in comparison to a control stretch of stream without salmonids (section 3.3);
- feeding studies, including analysis of dietary overlap and competition, and predation (section 3.4);
- behavioural studies, including those on competition for space, either in natural systems or in artificial streams (section 3.5) ; and
- studies on the disease impacts of salmonids (section 3.6).

3.1 Studies on or Relating to Distributions of Salmonids and Native Fauna

Gray (1929)

In Popes Creek in southern New South Wales, Grey (1929) reported that Galaxias *coxii (= G.* brevipinnis) was plentiful, and could be found in pools practically on the brink of a waterfall, but that he failed to find any galaxiids in the stream below the waterfall. The only other fish he could find in the area were rainbow trout.

Whitley (1935)

Whitley (1935) reported the observation of E. O. G. Scott, who had made extensive collections of fish in Tasmania, that in Tasmanian streams, as elsewhere, galaxiids had been wholly or largely displaced by introduced salmonids, particularly in the western districts.

Williams (1964)

Williams (1964) reported that brown trout were the only fish taken during a survey of Lake Tarli Karng, a small, high-altitude lake in the Gippsland region of Victoria. Galaxias coxii (= G. brevippinis) was not taken either in the lake or in the inflowing creek although it had previously been recorded during 1892. Williams remarked that although it was not possible to state definitely that the introduction of trout, which took place over 40 years previously, had led to the extinction of the galaxiid, this seemed a hypothesis for which there was some circumstantial evidence.

Fish (1966)

Fish (1966) reported substantial changes in the fauna of Lake Waingata, a small, sand dune lake north of Auckland, New Zealand, following annual releases of rainbow trout fingerlings between 1960 and 1964. Earlier releases of trout fry between 1954 and 1959 had not been successful. Up until 1962, " numbers" of Galaxias gracilis were found in the lake. The species was scarce in 1963 and could not be found at all during surveys in 1964 and 1965. Similarly, McDowall et al. (1975) reported that the introduction of trout into Lake Taharoa was also followed by the virtual extinction of G. gracilis.

A substantial population of the freshwater crab Hymenosoma lacustris was found in Lake Waingata during earlier surveys, but none were found during the study. Occasional specimens of freshwater crayfish *Paranephrops* planifrons were trawled before 1962, but none were recorded during the study. The population of frogs, which was extremely vociferous up to 1962, was scarcely heard at all during subsequent surveys until the summer of 1965.

Frankenberg (1966, 1969)

In the headwaters of the Kiewa River on the Bogong High Plains in north-eastern Victoria, Frankenberg (1966, 1969) reported that Galaxias olidus and brown trout displayed an essentially complementary distribution pattern, with their ranges overlapping on only one occasion. Trout occupied the main body of the stream, while the galaxiids were usually found only in situations apparently inaccessible to trout, such as above waterfalls or in small tarns adjacent to the main stream. Assuming that the galaxiids were once continually distributed, Frankenberg concluded that the trout appeared to have fragmented their range into a number of small isolated populations.

Renowden (1968)

Renowden (1968) undertook a survey (primarily using a seine net and an electroshocker) of the freshwater fish fauna in the Otway region of Victoria and found that trout, mainly brown trout, had become established in virtually all the streams in the area. He stressed the difficulty in determining exactly what effects the introduction of trout had had on the indigenous fish fauna because of the lack of observations comparing the faunas of waters before and after the introduction of trout. A comparison of the faunas of similar streams, some of which contained trout and some of which did not, was not possible because of the presence of trout in virtually all of the local streams. However, it was possible to compare a section of stream containing trout with another section that did not contain trout.

There were several streams in the area in which trout could be found up to, but not above, obstructions such as a waterfall. One such stream, which was also reasonably accessible, was Hendersons Creek, a tributary of the St Georges River. The obstruction on this water was a pile of large boulders which had fallen across the creek, virtually forcing it underground for about 30 m. The creek ran through a succession of steep-walled valleys and for most of its length was surrounded by dense native vegetation of eucalypts and tree ferns. It consisted of a series of pools separated by long- stretches of shallow water. Because of the prevailing dry conditions at the time, water flowin the creek ceased during the course of the study. However, this was thought not to have had a serious impact on the results because even when the creek was running the fish were confined mainly to the pools.

The numbers and types of fish in each pool were recorded during December-January 1967-68 (Table 1). Of the pools below the rockfall, the one immediately below the rockfall contained a large number of galaxiids and a single trout; some pools contained several trout and virtually no galaxiids; other pools contained only one or two trout, and galaxiids were relatively more common; and one pool which contained no trout held several galaxiids. All three of the pools above the rockfall contained no trout, and held large numbers of G, *brevipinnis.*

Renowden commented that although numbers were small, it certainly appeared that the introduction of trout into the section of Hendersons Creek below the rockfall had brought about a fairly substantial decrease in the size of the galaxiid populations.

Further, Renowden cited a personal communication from a local, who reported that it was possible to catch as many as fifty " mountain trout" (i.e. Galaxias truttaceus and Galaxias *brevipinnis)* in any of the larger pools in the river before trout were introduced. At the time of the study, Renowden reported that it was virtually impossible to find these galaxiids in the main stream of the St Georges River.

Table 1. Numbers of fish taken in pools in Hendersons Creek, Otway region, Victoria, during the summer of 1967-68. P, pool number; D, approximate distance upstream (m) from the confluence with the St Georges River; T, trout; GM, *Galaxias maculatus;* GT, *Galaxias truttaceus;* GB, Galaxias *brevipinnis;* E, eels. Pools 1-9 were located downstream of a rockfall barrier; pools 1012 were located upstream of the barrier. Modified after Renowden (1968).

P	*D*		*GM*	*GT*	*GB*	*E*
1	50	4	4	0	0	0
2	80	4	0	0	0	0
3	500	1	1	0	0	1
4	600	1	1	1	1	1
5	680	2	2	3	0	2
6	800	6	0	1	0	7
7	1100	0	0	6	3	3
8	120	1	0	3	0	2
9	1250	1	0	0	34	5
10	1300	0	0	0	16	2
11	1350	0	0	0	13	1
12	1800	0	0	0	17	3

Andrews (1976)

During the collection of specimens for a taxonomic review of the Galaxiidae in Tasmania, Andrews (1976) found that Galaxias brevipinnis was one of the most widely distributed members of the family. He found that the species was fairly evenly distributed throughout the central and coastal regions and in many areas, because of its climbing ability, it was able to invade waters which were inaccessible to other species. However, in many areas its distribution appeared to have been fragmented by introduced salmonids. It was found to be abundant in areas which have never been stocked with trout and also in areas which were protected from invasion by physical barriers, e.g. waterfalls along the Hugel River were considered to provide a barrier which prevented trout from moving upstream from Lake St Clair into Shallow Lake where large shoals of G. brevipinnis occurred.

Knott et al. (1978)

In a study of Hartz Lake in southern Tasmania, Knott et al. (1978) found that the littoral rock fauna was dominated by crustaceans, particularly Anaspides tasmaniae, in contrast to the insect-dominated rock faunas reported for other Tasmanian lakes. Although attempts had been made in the past to introduce trout into Hartz Lake they did not appear to have survived, and Knott *et* al. found no evidence of the presence of trout in the lake. The authors argue that if trout had become established in the lake it is likely that A. tasmaniae would no longer be a component of the fauna, but that other species, judging from their occurrence in other lakes, would survive. The authors suggest that their findings support the contention of Knott (1973) and Lake and Knott (1973) that trout are responsible for the discontinuities in the distribution of A. tasmaniae on the basis of the observed distributions of A. tasmaniae and trout in Tasmania.

Cadwallader (1979)

The distribution of fish within the Seven Creeks River system, a tributary of the Goulburn River in the Murray-Darling basin, was determined by a survey carried out during the summer of 1975-76 (Cadwallader 1979). Nine native species and five introduced species were recorded during the survey, but the only evidence of a substantial effect of an introduced species on a native species was the apparent fragmentation of the range of Galaxias olidus by brown trout, whose numbers in the system had been augmented until the mid 1970s by releases of hatchery-reared fish, the first release of trout in the system occurring in 1886.

Galaxias olidus was widespread in the upper reaches of the system and was recorded at 22 of the 60 sampling sites, in 1st-order (11 sites), 2nd-order (9 sites), 3rd-order (1 site) and 4th-order (1 site) streams. (Stream order is an indication of the hierarchical status of a stream in relation to its tributaries; 1st-order streams have no tributaries, 2nd-order streams are formed by the confluence of two 1st-order streams, 3rd-order streams are formed by the confluence of two 2nd-order streams, and so on.) The presence of G. olidus in 3rd-order and 4th-order streams indicates that it is not confined to the upper limits of catchments. Brown trout were recorded at 19 sites, also in 1st-order (1 site), 2nd-order (4 sites), 3rd-order (5 sites) and 4th-order (9 sites) streams. However, the distribution of trout and galaxiids overlapped at only three sites, all of which were marginal trout habitats. Typically, trout occupied the main channel and the lower reaches of highland tributaries, whereas the galaxiids were found in the upper reaches of tributaries, in situations inaccessible to trout, such as above waterfalls.

Brown trout spawned in some of the upper tributaries of the Seven Creeks system, but their numbers in the system had been maintained primarily by regular releases of hatchery-reared fish. Many of these fish were released into marginal trout habitats from which they disappeared when stocking of the waters ended. For example, two of the three sites where galaxiids and trout were recorded together during the summer 1975-76 survey were revisited one year later during February 1977. At one of these sites the river blackfish Gadopsis marmoratus had also been recorded. During the second visit, no trout were recorded, but galaxiids and blackfish were taken in numbers comparable to those taken during 1975-76. At the time of the second visit, the streams at each site were reduced to a series of small pools (up to 0.5 m deep) with only a trickle of water in the interconnecting channels.

A few juvenile G. olidus were found in the upper reaches of the main channel after the 1975-76 survey, but not during the survey (even though the area was extensively fished). This downstream movement of juveniles from an upper tributary indicates the mechanism by which G. *olidus* could recolonise the main channel in the absence of trout.

Jackson and Williams (1980)

Jackson and Williams (1980) found eight species of native fish and two introduced fish during an investigation of the distribution of fish in streams in three areas of southern Victoria, viz. the upper part of the Yarra River catchment, in the Otway Ranges and on Wilsons Promontory. Brown trout did not occur on Wilsons Promontory,- but did occur in the other two areas; this provided an opportunity to compare the distributions of native fish in areas with and without trout.

In the upper Yarra River catchment, brown trout dominated the fish fauna, being found at 39 of the 49 sampling sites,- in 1st-order to 6th-order streams. Galaxias olidus occurred at only three sites, in a 1st-order, 2nd-order and 3rd-order stream, and was the only native species which did not occur with trout. The extent of association of brown trout and some of the native fish in the system was tested using a chi-square contingency table and indicated a highly significant negative relationship between brown trout and G. olidus.

In streams in the Otway ranges, brown trout were again the most frequently recorded fish, being taken at eight of the eleven sampling sites, in 3rd, 4th and 5th-order streams. Galaxias brevipinnis was found at the only three sites from which brown trout were absent, in 3rd and 4th-order streams. Unlike in the upper Yarra River catchment, Jackson and Williams found that brown trout were not abundant (1.2-2.8 individuals per 100 square metres) in 4th-order streams, and in these streams Galaxias maculatus and Galaxias truttaceus were abundant (3.9-13.9 individuals per 100 square metres).

On Wilsons Promontory, no trout were recorded and galaxiids were abundant at all of the seven sampling sites; G. breuipinnis occurred at two sites, G. truttaceus at four sites and G. maculatus at five sites.

Jackson and Williams concluded that their data provided circumstantial evidence that brown trout had deleteriously affected the distributions of G. olidus and possibly G. breuipinnis.

Jackson and Davies (1983)

Jackson and Davies (1983) recorded seven native and six introduced species of fish at 115 sampling sites in a survey in the Glenelg, Wannon and Wimmera River catchments in the Grampians region of Victoria during October-December 1979. They pointed out that the effects of the introduced- species on the native species were unclear, but that circumstantial evidence suggested that brown trout had fragmented the range of Galaxias olidus.

Galaxias olidus was the most widespread native species, occurring at 40 sites in all three catchments, in 1st-order to 5th-order streams. Brown trout were recorded at ten sites, in 1st-order to 4th-order streams in the Wannon and Wimmera River catchments. Typically, both Galaxias olidus and brown trout were recorded at sites with steep gradients at higher altitudes, and mainly in streams flowing through undisturbed catchments well shaded by overhanging vegetation.

Galaxias olidus dominated the headwater tributaries of all three river systems with the exception of those areas where brown trout occurred. There were many sites on the headwater tributaries of the Glenelg River, containing G. olidus, which appeared suitable for brown trout, but the low-lying swampy areas of the Glenelg River probably form an effective barrier to invasion by trout, particularly in summer when temperatures are high and oxygen levels low.

Koehn (1986a)

Koehn (1986a) recorded nine native and four introduced fish species at seven sites during a survey in Badger Creek in the upper Yarra River catchment in southern Victoria between May 1984 and March 1985. Brown trout were taken at four sites, being most abundant at the two most upstream sites. Galaxias olidus was recorded at two sites in the middle and lower reaches of the creek, where numbers of brown trout were low, but was absent from the two uppermost stream sites (where habitat conditions appeared suitable) where brown trout numbers were high. One specimen of Galaxias truttaceus and three specimens of Galaxias brevipinnis were also taken during the survey. The absence of G. olidus and the small numbers of G. brevipinnis in the upper reaches of the system, where they would normally be expected to be more abundant, led Koehn to suggest that their numbers may have been affected by the presence of trout.

Jones et al. (1990)

Jones et al. (1990) recorded Galaxias olidus and introduced brown trout and rainbow trout in a survey carried out at 22 sampling sites in the Naas-Gudgenby River catchment in the Australian Capital Territory during summer 1986-87. The galaxiids had a widespread but fragmented distribution, occurring at 17 of the 22 sites, in 2nd to 6thorder streams, and were most abundant in the smaller headwater streams and minor tributaries. Brown trout occurred at eight sites, principally in the main river channels, in 4th to 6th-order streams. Rainbow trout were more widely distributed than brown trout, extending further upstream into the smaller tributaries, and were found at eleven sites, in 3rd to 6th-order streams.
The authors found an inverse relationship between trout biomass and galaxiid biomass. They considered that at those higher-order stream sites where both trout and galaxiids occurred together, the increase in habitat diversity provided more refuges for galaxiids. In some stream sections containing trout, galaxiids were found at the edges among debris and overhanging vegetation. At other sites, galaxiids were abundant in sluggish backwaters and trout occurred in flowing water in the main channel. In the smaller streams, with much less cover, only trout were present. On the other hand, galaxiids were abundant in the Naas River and, especially, the Naas Creek where trout were absent. This catchment was considered to be unsuitable for trout, particularly in summer, because of its low discharge and abundant aquatic vegetation which choked the channel.

Lintermans and Rutzou (1990)

Lintermans and Rutzou (1990) recorded two native species (Galaxias olidus and the two-spined blackfish Gadopsis bispinosis) and rainbow trout in surveys carried out at 28 sampling sites in the upper Cotter River catchment in the Australian Capital Territory during 1988 and 1989. The rainbow trout was the most widely distributed species, being recorded at 20 sites, in 2nd to 5thorder streams, whereas G. olidus had the most restricted distribution, being recorded at only six sites, usually in the smaller, headwater, 1st to 3rd-order streams.
Galaxiids occurred with trout at only one site, where a single individual of each species was recorded above a 2.5 m waterfall, while below the waterfall numerous trout and no galaxiids were found. An inspection of the site about one year previously had indicated that only galaxiids were present above the waterfall. In the period between the initial inspection and the survey it is thought that a period of high flow enabled trout to move upstream above the waterfall. Four of the six sites where galaxiids were recorded were above waterfalls or barriers to trout access. It is unknown whether barriers exist below the other two sites. The authors considered that the fragmented distribution of G. olidus and its absence from sites occupied by rainbow trout provides evidence of the adverse impact of trout on this species.

Minns (1990)

Using the New Zealand Freshwater Fish Survey data base which contained almost 6, 500 entries by November 1985, Minns (1990) analysed presence-absence data for the New Zealand freshwater fish fauna for evidence of species interactions and of links with land use and geological patterns. Native and introduced species had overlapping geographical distributions but tended to be segregated at the site level. The number of freshwater fish species found in catchments and lakes increased with catchment and lake area respectively. Species-area curves were developed for lotic and lentic sites and explained a small portion of the variation. Regressions involving land use and geological variables accounted for more variation. Analysis of co-occurrence patterns, where distributions overlapped, indicated relatively more negative associations between native and introduced species than amongst native fish themselves or amongst introduced fish themselves. The presence-absence patterns of several native species were related to land use and geological factors. Minns concluded that both changes in land use and introduced fish, particularly brown trout and rainbow trout, had caused changes in the distribution of native fish species.

Sanger and Fulton (1991) .

In a paper on the conservation of endangered freshwater fish in Tasmania, Sanger and Fulton (1991) summarised information which suggests an impact of introduced trout on Galaxias *fontanus,* Galaxias johnstoni and Galaxias tanycephalus.

Populations of *G. fontanus* occurred in small tributaries of the Macquarie River and in the Swan River above Hardings Falls. Other streams in the area which contained no wholly freshwater fish (some contained eels) were very small and dried up in summer. Most of the permanent streams in the area contained self-sustaining populations of brown trout. The streams containing G. *fontanus* all had self-sustaining populations of trout downstream of the galaxiid populations. All the *G. fontanus* populations were considered to be under threat from brown trout. Their continued existence was thought to be dependent on natural barriers preventing brown trout moving upstream. These barriers ranged from shallow marshes to substantial waterfalls. Predation on G. *fontanus* by trout was reported to have been observed following penetration of the less substantial barriers by small numbers of trout. A recent introduction of brown trout above Hardings Falls on the Swan River was reported to have resulted in the galaxiids being almost completely eliminated from a major part of their former range in this stream within three years. Earlier, Fulton (1978) had pointed out that the downstream limit of the G. fontanus population in the Swan River coincided with a natural barrier to trout invasion, and postulated that the trout were responsible for the absence of galaxiids further downstream.

Populations of Galaxias johnstoni were restricted to isolated sections of the Clarence River system, the species being absent from all sections of the system where brown trout were established, including the type locality of *G. johnstoni.* Natural barriers limited the upstream invasion of brown trout. For example, in the Clarence River system below Clarence Lagoon there was a steep cascading stretch of stream which prevented upstream invasion by trout. Brown trout were the only fish present below the cascade, but immediately above the cascade, and even in some of the pools within the cascade, G. johnstoni and brook trout occurred. Interestingly, G. johnstoni and brook trout were also found together in Clarence Lagoon. Brook trout were reported to be unable to coexist with brown trout in Tasmanian rivers and lakes.

Populations of Galaxias tanycephalus were restricted to two lakes, viz. Arthurs and Woods Lakes, and a few associated streams. Sanger and Fulton reported that predation by brown trout was recognised as a major source of mortality in the Woods Lake population, although the galaxiids appeared to be "coping adequately with this pressure". However, the galaxiid population in Arthurs Lake was much smaller than in Woods Lake and it was suspected that predation by brown trout was at least partly responsible for this, although the authors reported that the two species have coexisted for about 100 years.

Sloane and French (1991)

Sloane and French (1991) reported that the relationship between observed galaxiid abundance and trout population density in the western lakes of the central plateau of Tasmania was not clear. Conceding that , neither parameter could be readily measured in these remote waters, their observations suggested that in some lakes (e.g. Lake Ingrid) both trout and galaxiids were particularly abundant, whereas in other waters (e.g. Lake Malbena) the abundance of both introduced and native fish seemed to be quite low. In lakes where trout were absent or in low numbers, galaxiids were observed to be more conspicuous in the open surface waters. When trout were abundant, the galaxiids appeared to be more confined to the lake margins, the rocky shorelines and the shallow bays dominated by emergent reeds.

Shirley (1991)

Following a study of the distribution and ecology of the endangered *Galaxias fuscus* in the Goulburn River system in central Victoria, Shirley (1991) concluded that trout (brown and rainbow trout) were influencing the distribution of the galaxiid. Analysis of the species composition at sites in areas where G. *fuscus* had previously been found indicated a negative effect of the presence of trout.

Of the 14 sites where *G. fuscus* had previously been recorded, it was still the only species present at seven of the sites, trout were the only species present at four of the sites, and at the remaining three sites (all within a 350 m stretch of the Taggerty River) both rainbow trout and G. fuscus were present, but the density of galaxiids (number of fish per square metre) was depressed compared to sites in trout-free areas.

The extant populations of G. fuscus in the upper reaches of the Keppel Hut Creek catchment were found to be separated from rainbow trout by a single large cascade, the trout having successfully circumvented several smaller cascades lower down stream.

Townsend and Crowl (1991)

Townsend and Crowl (1991) conducted an electrofishing survey of the fish at 198 sites in eight catchments in the Taieri River basin of the South Island of New Zealand and found a strong negative association between the distribution of introduced brown trout and Galaxias vulgaris, a native freshwater fish similar in many respects to Galaxias olidus which occurs in Australia (McDowall 1980, 1990a).

The survey included tributary catchments encompassing homogeneous examples of the four major land uses of the region, viz. native bush, native tussock grassland, plantations of introduced pines and agricultural pasture. Catchments were chosen according to the availability of background data with the intention of producing a balanced study design. Each land use type was represented by two catchments and, within each catchment, the main channel and at least three tributaries were selected. At the individual site level, three pool/riffle sequences within each stream channel were selected, incorporating as much of the stream as possible, so that the top site was located near the headwaters and the bottom site was near the confluence with the main channel.

Catchment-level variables, e.g. altitude and gradient, were derived from existing maps. Stream channel characteristics, e.g. physical features such as waterfalls and surrounding vegetation, were recorded, as were in-stream physical variables, such as velocity and substrate type, and chemical characteristics.

Statistical analyses were performed in two stages. Firstly, each sampling site was placed in two different classifications, one based on land use, the other based on the presence of *G. vulgaris* and trout. The fish classification included sites with no fish, sites with G. vulgaris only, sites with trout only, and sites with both G. vulgaris and trout. For each classification (land use and fish) separate multiple discriminant function analyses were performed on all variables to determine which were important in discriminating amongst the classes. Comparison of the variables included in the two models permitted Townsend and Crowl to determine whether or not land use could account for the observed fish distributions. Secondly, multiple regression analyses were used to determine which variables best explained the observed densities of G. vulgaris.

Of the 198 sites surveyed, 54 contained no fish, 69 had brown trout only, 63 had G. vulgaris only, and 9 had both brown trout and G. vulgaris. The most important variables in discriminating fish species assemblage classes were the number of waterfalls with a height of 3 m downstream of the site, the proportion of cobble in the substrate, and the elevation of the site.

Although habitat degradation as a result of agricultural and forestry practices was associated with lower densities of fish, these reductions were found in all fish species and did not help to explain the trout/galaxiid pattern. The statistical analyses incorporating the various physical, chemical

and biological variables indicated that presence and abundance of galaxiids were best predicted by the absence of trout. In most cases, G. vulgaris was found only above waterfalls which were large enough to prevent the upstream invasion of trout.
In support of their conclusion that brown trout were responsible for a negative effect on galaxiid abundance and distribution, Townsend and Crowl cited historical records which suggested that G. vulgaris was once widespread in the Taieri River basin. Trout were introduced in the 1870s and their distribution and abundance gradually increased. Although there were no quantitative historical records concerning G. vulgaris, it was clear that its distribution and abundance had decreased throughout the catchment. Four of the eight study catchments were in native tussock and bush habitats and had received minimal human disturbance, so that historical galaxiid distributions might be expected to have remained intact if land degradation was the responsible factor. However, these sites showed the same scale of population fragmentation as the most heavily modified catchments, consistent with the hypothesis that brown trout and not land use determined the observed distribution of G. vulgaris.

Hamr (1992)

Galaxias *pedderensis* and Galaxias parvus occurred in the original Lake Pedder and its feeder streams. In 1972, a new enlarged Lake Pedder was created as the result of the construction of a large hydroelectric scheme. Following the creation of the new lake, there was a large population explosion of galaxiids, with large schools being observed until the late 1970s. In the early 1980s, the number of galaxiids in the lake declined dramatically. Surveys indicated that although numbers of G. parvus remained high in the Pedder region, the number of G. pedderensis had undergone a dramatic decline in the lake and its surrounding streams. The species was found to be absent from the lake and occurred in low numbers in only two feeder streams. The causes of the demise of G. *pedderensis* were not clear, but it was considered that the introduction of brown trout may have been at least partly responsible. However, the situation was complicated because the lake and adjoining streams had also been invaded by Galaxias brevipinnis, another potential competitor and predator.

Ault and White (1994)

Ault and White (1994) examined the effect of brown trout on Galaxias truttaceus in several streams in south-eastern Tasmania by using population abundance models to compare habitat use by the galaxiids in streams with and without trout. The study sites included 35 sites in five streams lacking trout and 14 sites in four streams' containing trout. Habitat use by G. *truttaceus* was investigated with respect to four principal components extracted from eight habitat variables, viz. mean depth (1), mean water velocity (2), mean substrate size' (3) and proportions of detritus (4), vegetation (5), silt and algae (6), overhead cover (7) and instream cover (8). Fish were sampled by electrofishing.
Different size-classes of G. truttaceus displayed varying non-random patterns of . habitat use, shifting from shallow, open sections of stream to deep sections with plenty of cover as they increased in size. All size-classes preferred slow-flowing sections of stream to fast-flowing sections. Population abundance models were constructed for three size-classes of G. truttaceus, viz. less than 85 mm long, 85-125 mm long and longer than 125 mm. Given the hydrologically variable nature of the study streams, all the models were found to be reasonably successful in explaining the observed variation. The application of the models to streams containing brown trout indicated that the presence of trout was more important than habitat characteristics in determining the abundance of G. *truttaceus*. In streams containing trout, the density of each size-class of galaxiids was substantially less than that expected on the basis of habitat characteristics alone.
The authors concluded that their study provides evidence that brown trout adversely affect G. truttaceus because differences due to habitat characteristics were accounted for when streams with and without trout were compared.

McIntosh et a/. (1994)

McIntosh et al. (1994) investigated the impact of small (less-than 100 mm long) and large (more than 100 mm long) brown trout on the distribution of Galaxias vulgaris (very similar in many respects to Galaxias olidus) in the Shag River in the South Island of New Zealand. They described the macrohabitat in riffles in the river in terms of substrate type, flow, elevation, and vegetation characteristics. Fish were sampled by electrofishing.

Galaxiid densities were lower in riffles containing large trout than in riffles with only small trout or no trout. Trout size was found to be the most important variable determining galaxiid density. Densities of galaxiids less than 80 mm long were reduced in the presence of large trout, whereas densities of galaxiids greater than 80 mm long were not affected. Riffles with large, small or no trout varied in water depth, substrate type and elevation, but the authors thought that these differences were unlikely to account for variations in galaxiid densities because selection for these particular habitat features accounted for only a small proportion of the observed variation in galaxiid density.

The authors suggested that a change in macrohabitat use by galaxiids from fast current velocities at sites without trout to slower velocities at sites with large trout may be explained by competition for areas of high velocity, which potentially were the better feeding areas. However, a combination of interspecific competition and predation by large trout was considered the most likely cause of the observed reductions in the density of smaller galaxiids.

Other Observations and Comments

In a study of the fish fauna of streams in the Western Port catchment, Koehn (1986b) noted that the absence of Galaxias maculatus from deep pools in Cardinia Creek may be attributable to the presence of large brown trout and rainbow trout; G. maculatus was abundant in the creek immediately below these pools where trout were not present. Furthermore, in an investigation of the distribution of freshwater fish in the Otway region of south-western Victoria, Koehn and O' Connor (1990) suggested that the distribution of Galaxias brevipinnis may be affected by the presence of brown trout which at some sampling sites appeared to restrict the galaxiids to shallow riffles which were not accessible to trout.

Davies (1989) reported that he had found a negative correlation between the abundance of non-trout fish species and the abundance of brown trout in Tasmanian streams. He pointed out that although the impact of the introduction of trout on the Tasmanian native fish fauna is unclear, the high proportion of brown trout in the total fish standing-stock of streams would suggest some considerable impact.

Comments and observations on the effects of introduced salmonids on the distribution and abundance of New Zealand taxa are summarised and reviewed by Thomson (1922), Phillipps (1940), Allen (1949, 1961), Waugh (1973), McDowall (1968, 1976, 1984, 1987, 1990a, b, c), Glova (1989), Crowl et al. (1992) and Townsend (in press).

3.2 Studies Undertaken During the Invasion of New Areas by Salmon ids

Tilzey (1976)

Tilzey (1976) sampled the fish fauna of all the major streams within the Lake Eucumbene catchment in south-eastern New South Wales by electrofishing and poisoning with rotenone during 1971. Galaxias brevipinnis was found in only four streams and Galaxias *olidus* was found in only one (Four Mile Creek) of the 27 streams sampled, whereas introduced salmonids (brown trout, rainbow trout or both) occurred in all but the stream containing G. *olidus*.

Fish biomasses in streams in the Lake Eucumbene catchment varied considerably, with biomasses in streams flowing through forest being usually significantly lower than those in streams flowing through grassland. Nevertheless, the biomass of G. brevipinnis in the four streams in which trout also occurred was markedly lower (0.01-0.30 grams per square metre of substrate) than that in Four Mile Creek which contained only G. *olidus* (8.08 grams per square metre). However, as Tilzey pointed out, total fish biomasses (i.e. the biomasses of trout and galaxiids combined) in these four streams were lower (0.94-6.10 grams per square metre) than 8.08 grams per square metre and the galaxiid species were different, so comparisons should be made with caution.

The streams containing *G,* brevipinnis all had steep gradients, with consequent rapid flows, and ran through forest before directly entering Lake Eucumbene. These streams were used annually by lake-dwelling trout for spawning. Four Mile Creek, containing *G. olidus,* was often inaccessible to trout because of a 3 m high waterfall which
became exposed when the lake level fell below 1155 m above sea level.
Subsequent sampling of Four Mile Creek in 1974 indicated that rainbow trout had invaded the stream below the 3 m high waterfall since 1971.
In 1971, *G. olidus* was abundant both above and below the waterfall, with biomasses of 8. 42 and 7.84 grams per square metre respectively. In 1974, no galaxiids were found below the waterfall in the same 0.5 km stretch of stream which was electrofished in 1971. Rainbow trout were found to have invaded this water and no other fish species were present; 25 trout with a biomass of 3346.3 g were taken from a 115 m stretch of stream, with two trout about 420 mm long making up 64. 4% of the total biomass. Galaxiids were still present above the waterfall, their biomass (10. 16 grams per square metre) being greater than that recorded in 1971. These observations suggested that the presence of rainbow trout was responsible for the disappearance of galaxiids below the waterfall.
Comparisons of the length frequency distributions of the *G. olidus* population in Four Mile Creek in 1971 and 1974 indicated that there had been little change in the population structure, so the disappearance of *G. olidus* below the waterfall could not be attributable to a change in population structure.
Four year-classes (1970-73) of brown trout were found below the waterfall. Comparison of their mean, back-calculated growth rates indicated that growth of the 1970 year-class was markedly higher than that of succeeding year-classes, and exceeded that of the 1970 year-class of rainbow trout in Lake Eucumbene and that of brown trout in a stream at a similar altitude and flowing through essentially similar terrain.
Furthermore, comparison of the growth curves of the 1970 year-classes from Four Mile Creek and Lake Eucumbene indicated that the Four Mile Creek trout had not resided in lentic waters.
Comparison of the stomach contents of some of the rainbow trout and *G. olidus* taken from Four Mile Creek on the sampling day in 1974 indicated that the species composition of the diets of the trout and galaxiids were essentially similar.
Tilzey reviewed historical data for the area and, although early records on the distribution of galaxiids were lacking, thought it was likely that galaxiids once occurred throughout the entire Lake Eucumbene catchment. Assuming that widespread populations or a series of contiguous populations of *G.* breuipinnis and *G. olidus* existed previously, Tilzey concluded that the introduction and subsequent success of trout were primarily responsible for the present much fragmented galaxiid distribution.

Raadik (1993)

In the Goulburn River catchment in central Victoria, Raadik (1993) reported that trout, particularly rainbow trout, had expanded their range into nearly all the extant *G. fuscus* populations, and were continuing to colonise further upstream-with a consequent contraction in the range of the galaxiids.
In waters such as the Taggerty River and Pheasant Creek, where there were no physical barriers to:prevent the invasion of trout, the range of *G. fuscus* was contracting rapidly. For example, in June 1991, rainbow trout were first reported to have moved into a stretch of Pheasant Creek occupied by *G. fuscus;* seven trout were collected and removed from a 500 m section of the creek and 86 adult *G. fuscus* were recorded. Six months later, in December, 31 rainbow trout were removed from the same section of creek and only 55 adult *G. fuscus* were recorded, a reduction of 36% in adult numbers in six months.
Furthermore, the stomachs of rainbow trout taken from Pheasant Creek and Taggerty River contained *G. fuscus.* One trout (167 mm long) out of seven taken from Pheasant Creek contained three galaxiids in its stomach and one in its mouth; the length range of the galaxiids was 40-60 mm. Three trout out of 16 taken from the Taggerty River contained *G. fuscus.*
Raadik concluded that trout predation on *G. fuscus* was a major threat to the survival of the galaxiid.

Class and Lake (in prep)

Closs and Lake (in prep) mapped the longitudinal distribution of brown trout and Galaxias olidus in the upper reaches of the intermittent Lerderderg River in central Victoria over four summers between 1985 and 1988. During this period, the distribution of the trout extended upstream and, coincident with this upstream expansion of the range of brown trout, there was a contraction in the distribution of G. olidus.

At the start of the study in the summer of 1985, brown trout occupied only a short section of stream at the downstream end of the study area. The distribution of trout and galaxiids overlapped for a short distance. Neither species was particularly abundant, suggesting that the populations of both species were recovering from the effects of the 1982-83 drought. Many pools throughout the upper reaches contained no fish.

The distribution of brown trout expanded about 1-1.5 km upstream each year between 1985 and 1988; the distribution of G. olidus correspondingly contracted upstream. The distribution of each species continued to overlap for a short distance during each summer of the survey, although the zone of overlap moved progressively upstream. In contrast to the situation at the start of the study in the summer of 1985, virtually all of the pools in the survey area contained either trout or galaxiids, suggesting that the total abundance (irrespective of species) had increased. By the time the river pooled in the summer of 1988, the distribution of G. olidus had contracted into very small headwater streams and had fragmented into two sub-populations. Between 1987 and 1988, brown trout had succeeded in moving upstream above a 1 m high waterfall.

In the summer of 1988, an extended period of dry weather resulted in high levels of mortality in trout at the upper limit of their range, suggesting that their upstream limit could ultimately be restrained by their inability to tolerate prolonged periods of low stream flow and high temperatures which occurred in the headwaters of the Lerderderg River.

The authors cited references which indicated that brown trout were abundant in the upper reaches of the Lerderderg River before the 1982-83 drought. Under the severe drought conditions, which resulted in the drying up of most of the pools along the river, they suggested that trout could only have survived in the deeper permanent pools further downstream. The elimination of trout from the upper reaches of the system during the drought would have created trout-free habitat for G. olidus to colonise. If trout had occupied the main channel of the river before the 1982-83 drought, it is likely that G. olidus survived within the catchment in the uppermost reaches of headwater streams.

3.3 Experimental Introduction Study

Fletcher (1979)

Before selecting a stream in which to make an experimental introduction of brown trout, Fletcher (1979) chose four streams in Victoria which contained parapatric populations of trout and Galaxias olidus separated by a waterfall for preliminary investigation. These sites included two lowland streams: Watchbox Creek and Running Creek, and two alpine streams: a tributary of Cope Creek on the Bogong High Plains and a tributary of Buffalo Creek on Mt Buffalo. In both alpine streams, G. olidus was the only fish species present above the waterfall and brown trout were the only fish present below the waterfall. In Running Creek, G. olidus and Gadopsis marmoratus occurred above the waterfall and had a total mean biomass of 8.82 grams per square metre. Below the waterfall, G. olidus, G. marmoratus and eels were present, but the dominant species was the brown trout which accounted for 70% of the total mean biomass of 5.87 grams per square metre.

In Watchbox Creek, G. olidus was the only fish species present above the waterfall and had a mean biomass of 1.92 grams per square metre. A few G. olidus were present below the waterfall, but the dominant fish species in this stretch of stream was the brown trout, with a mean biomass of 3.23 grams per square metre. The galaxiids at the sites below the waterfall had a mean biomass of 0.19 grams per square metre.

Fletcher compared the diets of the fish in the four streams on a seasonal basis and found that there was positive (often statistically significant) overlap in the diets of G. olidus and brown trout. The major items of overlap were terrestrial dipterans and hymenopterans. The diets of juvenile galaxiids and juvenile trout also positively overlapped. Their diets consisted primarily of chironomids, which were relatively less abundant in the benthos than in the diet, and were highly selected.

Ephemeropterans (mainly *Atalaphlebioides)* were eaten by both fish species, but they were relatively abundant in the benthos during all seasons so were not necessarily highly selected. There was also a positive overlap in the diets of brown trout and G. *marmoratus,* with the range of items taken by both species including similar benthic taxa, particularly *Atalaphlebioides;* chironomids were also taken by juveniles of both species.

A site above the waterfall on Watchbox Creek was chosen for the introduction experiment. Barriers were constructed in shallow areas at each end of the 70 m long experimental section. The barriers consisted of wire mesh supported by metal stakes, with nylon fishing net (10 mm aperture) attached to prevent fish moving through the barrier. The 70 m long control section was located immediately upstream of the upper barrier. The mean width of each section was 1.5 m, and their area approximately 105 square metres. Both sections were similar physically and consisted of a series of pools (to 1 m deep) and flat areas. Each section was marked out into ten 7 m long zones to facilitate recording fish observations and siting of invertebrate samples. The experiment was conducted during summer to include the anticipated peak feeding and activity periods of the fish, at a time when it was thought that low rainfall and consequent streamflow minima would reduce the possibility of the barriers being washed away. The duration of the experiment was to be four months. Samples of the benthic invertebrate fauna in each section were taken before the trout were introduced and each month throughout the experiment.

Estimates of the numbers and biomass of galaxiids in the experimental and control sections were similar before the start of the experiment.

The trout, including 30 young-of-the-year fish (47-60 mm long) and six fish about 18 months old (140-185 mm long), were stocked in the experimental section on 11 November. The biomass of the introduced trout was 10.1 grams per square metre to allow for a mortality of 60-90% which would yield a biomass at the end of the experiment of 1-4 grams per square metre, similar to that for trout in the main channel below the waterfall. The practical difficulties of such work soon became apparent. A flash flood, which raised the water level above the barriers at the boundaries of the experimental and control sections, caused trout to be lost from the experimental section. No trout were found to have moved upstream into the control section. A second stocking of trout was made on 9 December to bring the biomass of trout in the experimental section to 9.6 grams per square metre.

The experimental and control sections were electrofished in the following April, four months after the final introduction of trout. None of the large trout survived, probably because of the high ,summer water temperatures and shallow water. The mortality (= disappearance from the experimental section) of the two batches of young-of-the-year trout was 86.7% and 80%, similar to that reported in previous studies of hatchery-reared trout.

The establishment of the trout in the experimental section appeared to be at the expense of the galaxiids. Both the number and biomass of G. *olidus* were lower in the experimental section than in the control. section.

At the end of the experiment, one galaxiid was found in the stomach of a trout in the experimental section, and two galaxiids formed the entire stomach contents of a trout taken in the control section; this trout was thought to have entered this section during a flash flood which occurred two days before the end of the experiment.

Analysis of the length frequency distributions of the galaxiids in the experimental and control sections -indicated that the number of galaxiids greater than 60 mm in length was similar in the two sections, but the number of young-of-the-year galaxiids was significantly lower in the experimental section compared with the control section. This suggested that there may have been size-selective predation by the trout on the 0+ galaxiids.

The condition factors of the galaxiids, particularly the larger individuals, in the experimental section were significantly less than those of the galaxiids in the control section. Young galaxiids (0+ and 1+ age-classes) fed mainly on ephemeropterans and trichopterans; older galaxiids (2+ and 3+ age-classes) took more terrestrial items. The diet of brown trout showed positive correlations with the diets of all age-classes of G. olidus, and these correlations were significant in almost all cases. Ephemeropterans, trichopterans and terrestrial items were the main items of overlap. Trichopterans formed the bulk of the diet of the trout, constituting 49% by volume, with Ecnomus, *Aphilorheithrus* and a tasimid being the major taxa consumed; all had high electivity indices, indicating that they were highly selected. In the control section, tasimids formed 19.6% of the volume of the diet of galaxiids 70-90 mm long, whereas in the experimental section, where the trout consumed tasimids, these trichopterans were not eaten by galaxiids. These results imply that competition for food may have occurred, contributing to the poor condition of the galaxiids in the experimental section.

Some invertebrates were less dense in the benthos in the experimental section than in the control section, but others were found to be more abundant. The densities of most of the benthic invertebrates did not vary between the two sections, indicating that in the short term they were not affected by the change in predator pressure.

3.4 Feeding Studies, I ncluding Analysis of Dietary Overlap and Competition, and Predation

Introductory Comments

Since it is almost axiomatic that game fish should be carnivorous, it follows that one of the principal impacts of salmonids on the native freshwater fauna will be their predation on small native animals, both vertebrate and invertebrate. The extent to which the various food items are eaten depends on their abundance and on the extent to which their habits and structure make them available to and eatable by the salmonids. Amongst invertebrates, the main groups eaten by stream-dwelling salmonids are chironomids, ephemeropterans, trichopterans and molluscs. Considerably greater diversity exists in lakes. Small fish are eaten mainly by the larger salmonids, the particular species taken depending on the local fauna. Those native species which are most likely to be affected are those whose habits and appearance make them attractive to salmonids (Allen 1961).

As pointed out by Tilzey (1977), trout are opportunistic predators and usually select the largest and most readily accessible prey. In this context, the remarks made by James Youl (who was involved in the first successful introduction of brown trout and Atlantic salmon into Australia) in a letter to New Zealand are very interesting "... I beg you on no account to permit the brown trout to be introduced... until you have got the salmon fairly established... They are the greatest enemies the salmon can have. I can compare them to nothing, but wolves in a flock of sheep. Again and again I have warned Dr Officer, of Tasmania, of the danger of admitting these voracious fish into any stream suitable for salmon before the salmon are established therein..." (Thomson 1922).

Given the large size to which trout and salmon can grow compared to most of the native aquatic fauna of Australia, it is likely that the main impact of salmonids has been via predation rather than competition (Tilzey 1977) . However, competition for food and space between salmonids, particularly juveniles, and the larger, aquatic, native predators (mainly fish and the larger macroinvertebrates) is also likely to occur. This interspecific competition may involve either interference competition or exploitation competition. Interference competition occurs when one species establishes a territory and physically excludes other species: exploitation competition occurs when both species use a resource which is in short supply (Fletcher 1986). It is extremely difficult under field conditions to demonstrate that a particular food item is in short supply and, therefore, to demonstrate that competition for food is occurring.

From the point of view of providing evidence of an impact of salmonids on the native fauna, there are no quantitative or even qualitative data bases on the composition of aquatic communities before the introduction of salmonids into Australia and no accounts of the effects of the first introductions of salmonids on the composition of aquatic communities. Most studies on the feeding relationships between salmonids and the native fauna were undertaken long after salmonids had become established in Australia.

In relation to the effects of salmonid predation on aquatic communities, including the effects on native predators which may consume the same foods, the most substantive evidence of impacts comes from records of the events occurring during invasions of new areas by salmonids (e.g. Tilzey 1976, Sanger and Fulton 1991, Raadik 1993), of the composition of the invertebrate faunas in waters containing parapatric populations of salmonids and native fish (e.g. Fletcher 1979) and of the effects of experimentally introducing trout into a new area (e.g. Fletcher 1979) (see sections 3.2 and 3.3).

Although not providing evidence of an adverse impact, i.e. that trout are the cause of the demise of a particular species, several studies and observations on the food of trout in Australia, e.g. McKeown (1934a, b, c, 1936, 1937, 1955), Evans (1942). Butcher (1945, 1946), Jenkins (1952), Lake (1957), Williams (1965), Wilson (1966), Knott (1973), Frankenberg (1974), Bishop and Tilzey (1978), Cadwallader (1979), Faragher et al. (1979), Faragher (1980, 1983), Pidgeon (1981), Humphries (1989), Lintermans (1991,1992) and Sloane and French (1991) provide an inventory of the types of fauna eaten by salmonids, and indicate that the diets of introduced salmonids and native fish often overlap.

In some cases, these observations indicate the potential for trout to cause the demise of a particular species. For example, the observation reported by Humphries (1989) that Galaxias auratus in a Tasmanian alpine lake represented 99% of the number of food organisms in the stomachs of the 29 brown trout examined, suggests that predation by trout could have a severe impact on the galaxiids in this particular lake. Further, Lintermans' (1992) observation of predation by rainbow trout on the highland water skink Eulamprus tympanum and Gillespie's (1995) observations of predation by brown trout on the tadpoles of several frog species indicate the potential for salmonids to have an impact on aquatic vertebrates other than fish.

Other studies on the food and feeding relationships of salmonids in Australia, although not necessarily providing evidence of an impact, nevertheless provide insights into the mechanisms whereby impacts can occur or into the reasons why some native aquatic animals are more susceptible than others to predation or competition from salmonids. These studies, together with relevant New Zealand studies on the same or closely-related native taxa, are reviewed in the following sections.

Morrissy (1967)

Morrissy (1967) studied the food of brown trout and rainbow trout in several waters near Adelaide in South Australia. He found that there was an unusual absence of representatives of the larger native aquatic fauna in Sixth Creek, a tributary of the Torrens River, compared with other waters and postulated that this was brought about by the trout selectively eliminating, or reducing to very low numbers, species which were large and/or highly accessible to them. He suggested that the total biomass of aquatic animals had not been reduced, but that there had been a change in the relative abundance of the various species, and that such changes in aquatic community structure seemed to be a consequence of the introduction of trout to waters which had not previously been subjected to such large predators. Trout were abundant in Sixth Creek and had a continuous distribution throughout a wide range of habitat types, whereas in the other waters investigated they occurred in lower numbers and exhibited discontinuous distributions.

One of the missing groups in Sixth Creek was the Galaxiidae. Morrissy reported local farmers recalling "enormous numbers" of these fish before the, 1940s, when the trout started dispersing up the creek from the Torrens River, and attributed their elimination to the presence of trout. Galaxias kayi (= G. olidus) can still be found in the small tributaries of most streams where they can survive stagnation and drought during summer, conditions which trout cannot tolerate. Other animals which appeared to be highly vulnerable to predation by trout and which were absent from Sixth Creek were tadpoles, yabbies *Cherax destructor,* whirligig beetles of the family Gyrinidae which were numerous on the surface of pools in which there were no trout, and large water beetles of the family Dytiscidae which were observed in a tributary of Sixth Creek.

The larger animals which can still be found in Sixth Creek, e.g. the predatory dragonfly nymphs (Aeschnidae, Corduliidae and Gomphidae), apparently manage to persist because for part of their life cycle they remain inaccessible to trout under stones in shallow riffles and in algal beds. However, they are vulnerable when they drift and move in open, relatively quiet water when they are small and also when they emerge from the water.

Cadwallader (1975a)

Cadwallader (1975a) studied the seasonal feeding relationships of brown trout and Galaxias vulgaris (similar in many respects to Galaxias olidus), bullies *Gobiomorphus breviceps* (family Eleotridae) and eels Anguilla australis (which also occurs in Australia) and Anguilla *die, ffenbachii* in the Glentui River, Canterbury, New Zealand.

With few exceptions, the same food organisms were utilised by all fish species, but the relative proportions of each food type in the diet varied between species. Kendall rank correlation coefficients indicated that the diets of native fish were dissimilar, with the exception of galaxiids and bullies in autumn, but in six out of nine comparisons involving the introduced trout, the coefficients indicated varying degrees of similarity with the diets of the native species.

Since their feeding mechanisms and feeding localities were different, similarities in the diets of eels and trout, bullies and trout, and bullies and galaxiids were regarded as having the potential to give rise to indirect competition (i. e. where there is no contact between individuals). However, since trout (up to 200 mm long) and galaxiids occupied the same microhabitat and fed in the same manner, similarity in their diets was regarded as having the potential to give rise to direct competition (i.e. where there is contact between individuals).

Jackson (1978)

In a study of the benthic invertebrate fauna and the diets of brown trout and river blackfish Gadopsis marmoratus in the Aberfeldy River, Victoria, over a 12-month period, Jackson (1978) found that the range of food organisms utilised by the two species was very similar, as were the proportions of the various food categories in their diets. Kendall rank correlations indicated that the diets of the two species were similar on all but one occasion. Because of apparent differences in habitat preferences, the similarity in diets was considered as having the potential to give rise to indirect competition.

Cadwallader and Eden (1981, 1982)

The food and growth of one-year-old, hatchery-produced, chinook salmon released into Lake Purrumbete, Victoria, were investigated over a two-year period (1976-78) by Cadwallader and Eden (1981). Fish formed the bulk of the stomach contents of the salmon for most of the time, except in spring. Galaxias maculatus was usually the only fish species taken, but Galaxias truttaceus and pygmy perch *Nannoperca* australis were taken occasionally. Other items eaten included Amphipoda, Cladocera, Ostracoda and Decapoda (Crustacea), Odonata, Coleoptera, Diptera, Trichoptera and Hemiptera (Insecta) and gastropod molluscs.

At the end of their first three months in the lake, the salmon had increased 85% in length and 670% in weight. After two years in the lake, their mean length was 582 mm and their mean weight was 2.73 kg. Growth rate was lowest in spring when the relative amount of fish in the stomach contents was at its lowest and there was a greater diversity of food types in the diet. The availability of fish, particularly G. maculatus, appeared to be the major factor affecting the growth of chinook salmon in Lake Purrumbete. It was thought that G. maculatus moved from the lake into inflowing intermittent streams for spawning during late winter and spring, so they were not available as food for the salmon at that time of the year.

The food of rainbow trout (up to 6.6 kg in weight and 725 mm long) taken at the same time as the chinook salmon contained a much wider range of food types than the salmon (Cadwallader and Eden 1982). However, of the fish eaten, all were G. maculatus, with the exception of a few N. australis taken on one occasion. An earlier field investigation of the food of rainbow trout in April 1967 revealed that galaxiids had formed a substantial part of the diet of the trout, with 708 galaxiids being recorded from 28 trout (mean of 25 per stomach; range

12-47). Unfortunately, during April 1977, only eight rainbow trout were taken. These fish, which had similar length and weight ranges to the trout taken in 1967, had eaten 80 galaxiids (mean of 10 per stomach; range 1-25). Although the number of trout in the April 1977 sample was small, these figures nevertheless suggest that galaxiids were less common in the diet of the rainbow trout in Lake Purrumbete than they were in 1967.
Some extremely large rainbow trout had been produced in Lake Purrumbete. Wharton (1967) reported yearling trout from the lake weighing 1.4 kg, 3-year-olds weighing 8.4 kg and 4-year-olds weighing 9.3 kg. These growth rates were considered world records for rainbow trout at the time and reflected an excellent food supply. Such growth rates no longer occurred in the lake and this was attributable to the reduced availability of G. maculatus. Anecdotal reports from anglers and local residents suggested that G. maculatus (a well recognised, popular, local bait species) was much less common in the lake at the time of the study than formerly. Furthermore, smelt Retropinna semoni were recorded in the lake previously, but none were taken during the present study.
Predation by both chinook salmon and rainbow trout had most probably affected the abundance of G. maculatus in Lake Purrumbete. Stocking densities of trout in the past (1958-67) were generally less than in the years before this study (1969-76), so growth rates and the number of galaxiids per trout stomach could well have been directly related to differences in stocking density, both being affected by the number of salmonids present at a given time. Neither chinook salmon nor rainbow trout bred in Lake Purrumbete, their numbers depending solely on releases of hatchery-produced fish. Under these circumstances, it was concluded that introduced salmonids were unlikely to eliminate the galaxiids from the lake unless the lake was mismanaged by overstocking with trout or salmon or both.

Sagar and Eldon (1983)

Sagar and Eldon (1983) investigated the benthic macroinvertebrate fauna and the food and feeding relationships of several small fish in the unstable, braided Rakaia River, New Zealand, over a 12-month period. The fish species included juvenile brown trout, chinook salmon, long-finned eels Anguilla dieffenbachii, bullheads (family Eleotridae), Galaxias paucispondylus and Galaxi.as brevipinnis (which also occurs in Australia).
The proportions of the various benthic invertebrates in the diets of two of the bullheads, eels, G. brevipinnis, G. paucispondylus and juvenile brown trout were similar to the proportions of the prey items in the benthos. Deleatidium (Ephemeroptera) and chironomid (Diptera) larvae dominated the -benthos in all seasons and formed the bulk of the food of these_ species. Overlap in diet was high, suggesting potential for competition, but preferred habitat and differences in feeding habits, together with low fish population density and the abundance of the main prey items, were thought to "eliminate the occurrence of any serious competition". The diet of chinook salmon differed from the other species; it consisted largely of prey items of terrestrial origin, including adult Deleatidium and dipterans.

Glova (1990)

Glova (1990) commented that while there was little doubt that competition for food and space occurred between galaxiids and salmonids, these impacts were probably of minor importance compared to that of predation. In particular, galaxiid fry tended to shoal in large numbers in the water column in areas of slack water, making them easy prey for yearling and older trout. As stream- . dwelling galaxiids got older, they tended to become cryptic bottom-dwellers, which probably made them less easy targets for trout to prey upon.
To test the hypothesis that free-swimming prey were more vulnerable to predation by trout than bottom-dwelling prey, Glova carried out three sets of short-term experiments in glass tanks. The first set of tanks had a simple gravel substrate, the second set had a more complex gravel and cobble substrate, and the third set had a complex substrate with gravel, cobbles and a submerged willow branch. For each set of tanks, a control tank was used to determine mortality of the prey in the absence of predation.

The free-swimming prey were fry of Galaxias vulgaris (similar in many respects to the Australian Galaxias olidus) and the bottom-dwelling prey were juvenile bullheads of the family Eleotridae.

A yearling trout, about 150 mm long, was placed in each of the tanks, followed a day later by 20 each of the two prey types. The galaxiid fry were 22-42 mm long, and the juvenile bullheads 34-49 mm long. The same number of each prey type was included in each control tank, but with no trout present. The experiments were terminated on the day when only one live galaxiid fry remained in the water column, which varied from four to nine days after the start of the experiment.

The results were as predicted, with young free-swimming galaxiids eaten in greater proportion than the bullheads. Predation was greatest and fastest for both prey types in the tank with the simple substrate (92 galaxiids/66 bullheads), and was reduced markedly by adding cobbles to the substrate (77 galaxiids/40 bullheads). The addition of the willow branch did not reduce predation as expected (85 galaxiids/63 bullheads), probably because it did not provide a sufficiently complex environment, and the trout may have hid in it, making it easier to ambush prey. It was thought that not all the galaxiid fry were eaten by trout; the losses of galaxiids in the controls was on average 27%, indicating that the bullheads may have been responsible for some of the predation on galaxiids in the experimental tanks. There were no losses of bullheads in the controls.

Glova and Sagar (1991)

Glova and Sagar (1991) studied the benthic and drifting invertebrates, together with the fish, in the Ryton River, New Zealand, over a 24-h period during summer in order to investigate interactions for food and space between Galaxias brevipinnis (which also occurs in Australia) and juvenile brown trout and rainbow trout.

Galaxias brevipinnis fed almost exclusively at night on the benthos, whereas both brown trout and rainbow trout juveniles fed mostly during the day on drifting and benthic prey. Larvae of Deleatidium (Ephemeroptera), *Hydrobiosis* and *Oxyethira* (Trichoptera), and Austrosimulium and Chironomidae (Diptera) formed the bulk of the prey of all three species. Small prey items made up a greater proportion of the diet of G. *brevipinnis* than for either trout species. The narrower breadth of the diet of G. brevipinnis in this study compared to the more diverse diet reported by other researchers was thought by Glova and Sagar to perhaps indicate that the feeding of G. brevipinnis in the Ryton River was restricted to some extent by their interaction with trout.

All three species were found primarily in riffles and runs in water depths of 0.1-0.3 m with G. brevipinnis often being in faster flowing areas (water velocity 0.8-1.1 m per sec) than either brown trout and rainbow trout (0.4-0.7 m per sec). Glova and Sagar concluded that these differences in diel feeding patterns and microhabitat no doubt reduced the interaction between the galaxiids and trout.

Kusabs and Swales (1991)

Kusabs and Swales (1991) examined the diet of sympatric populations of migratory juvenile rainbow trout and Galaxias brevipinnis (which also occurs in Australia) in the Waipehi and Omori Streams, which drain into Lake Taupo, New Zealand.

The diets of both species were dominated, both numerically and by weight, by aquatic prey, with ephemeropteran, trichopteran and dipteran larvae being the most numerous prey items. Adult G. brevipinnis and juvenile rainbow trout both fed on juvenile galaxiids. Terrestrial prey items were present in the diets of both galaxiids and trout; although present in low numbers they were important in terms of weight. Resource partitioning was found to be weak, although G. brevipinnis ate more small benthic invertebrates such as chironomid larvae, whereas the rainbow trout took more ephemeropteran larvae and terrestrial insects. In Waipehi Stream, G. brevipinnis ate both rainbow trout ova and G. brevipinnis ova; in Omori Stream trout ova were taken by the juvenile rainbow trout.

Since the diets of G. brevipinnis and juvenile rainbow trout in these Lake Taupo inlet streams were similar, Kusabs and Swales concluded that the populations may co-exist by temporal and/or spatial partitioning of food resources, whereas predation by adult trout on small G. brevipinnis may be a limiting factor for G. brevipinnis populations.

Crowl et al. (1992)

Crowl et al. (1992) reported that in a series of laboratory experiments all sizes of Galaxi.as vulgaris (very similar in many respects to Galaxias olidus) were vulnerable to predation by brown trout. Very young galaxiids were especially vulnerable to predation by young trout, with consumption rates of up to 135 galaxiids per day. Even the largest galaxiids were vulnerable to larger brown trout (up to 200 mm long).

This study, like that of Glova (1990), can be criticised on the grounds that the experimental conditions bear little resemblance to conditions in nature, but they both demonstrate that trout consume native fish and that predation rates can be exceedingly high.

Glova et al. (1992)

Glova et al. (1992) investigated the feeding and spatial inter-relationships between juvenile brown trout and Galaxias vulgaris (very similar in many respects to Galaxias olidus) over a 24-h period during summer in Weydon Burn, a small tributary of the upper Oreti river in the South Island of New Zealand. Fish were sampled by electrofishing. The mean sizes of the galaxiids and the juvenile trout in the samples were similar.

Interspecific overlap in feeding was found to be greatest at dusk and dawn, with G. vulgaris feeding primarily from dusk to postdawn and juvenile trout feeding primarily from pre-dawn to post-dusk. Both galaxiids and trout fed mainly on benthic and drifting aquatic invertebrates, with larval Deleatidium (Ephemeroptera), Hydora (Coleoptera) and Chironomidae (Diptera) being the preferred prey, although trichopteran imagoes also formed an important part of the diet of juvenile trout.

The stream channel at the study site was about 4-7 m wide, with extensive areas of shallow riffles and runs and relatively unstable bed and banks composed mainly of gravel and small cobbles. Galaxiids and trout were found in both riffles and runs, with the galaxiids occupying slightly shallower (up to 0.3 m) and faster (0.3-0.7 m/sec) waters than did trout (up to 0.5 m; 0.2-0.4 m/sec).

The authors suggested that the slight differences in feeding times, diets and microhabitats were important in reducing competitive interactions between co-occurring populations of G. vulgaris and brown trout.

Glova and Sagar (1993)

Glova and Sagar (1993) examined the feeding and spatial inter-relations between two galaxiids, *Galaxias vulgaris* (similar in many respects to the Australian Galaxias olidus) and Galaxias paucispondylus, and juvenile brown trout and chinook-salmon in Deep Creek, a tributary of the upper Rangitata River in the South Island of New Zealand. Fish were sampled by electrofishing.

Interspecific overlap in the timing of feeding of the four species was greatest between predusk and pre-dawn. Aquatic invertebrates were eaten by all fish, with the chinook salmon also taking trichopteran imagoes. Similarities in diets were least between G. vulgaris and G. paucispondylus, moderate between the galaxiids and salmonids, and greatest between the two salmonids.

Both galaxiids were found primarily in riffles, with G. uulgaris occupying slightly deeper (up to 0.3 m) and slower (0.5-0.8 m/sec) waters than those occupied by G. paucispondylus (up to 0.2 m; 0.7-1.0 m/sec). The salmonids were found mainly in pools and runs, with the chinook salmon occupying slightly deeper (up to 0.5 m) and slower (0.1-0.2 m/sec) waters than those occupied by brown trout (up to 0.4 m; 0.2-0.5 m/sec).

The authors concluded that that mixed populations of galaxiids and juvenile salmonids in streams with a gravel/cobble substrate were likely to overlap considerably in their use of food and space, but that interspecific differences in feeding and microdistribution reduced interactions between the galaxiids and salmonids.

Gillespie (1995)

Gillespie (1995) pointed out that frogs which coexist with fish, such as those living in streams, have evolved strategies for avoiding or minimising predation on their tadpoles. These strategies may include laying eggs in inaccessible places, activity patterns which are different from the activity patterns of fish and the production of unpalatable or poisonous chemicals. In many instances, fish species have been found not to eat the tadpoles with which they coexist. However, these strategies may not be effective against introduced species, which may forage in different ways, be more effective predators or be unaffected by the chemicals produced by the tadpoles. Therefore, tadpoles of some amphibian species may be vulnerable to increased predation pressure from introduced fish such as trout.

In laboratory feeding experiments, it was found that brown trout ate the tadpoles of three species of frog, whereas Galaxias *olidus,* which coexists with the three frog species in nature, did not eat any of the tadpoles of these three species. The author indicated that further investigation of the effects of trout on tadpoles is required, but speculated that trout have probably had a substantial impact on frogs in south-eastern Australia.

Other Observations and Comments

Tilzey (1977) pointed out that even though angling and scientific records for the years immediately following the introduction of trout into Australia (1870-1910) are scarce, they indicate that the trout at that time were substantially larger than those taken from the same waters today, and that such growth probably reflected low trout population densities and an abundant food supply.

Lyne (1948) mentioned that in 1897 a brown trout of 6.6 kg was taken in the Yarra River, and provided an anecdotal description of what conditions in southern Victorian, streams would have been like at the time. Native fish such as galaxiids, grayling and smelt would have abounded, but having no innate defence mechanisms to avoid such "a fast and ferocious feeder" as the trout they would have been soon thinned out. The food supply was not sufficient to withstand the ever-increasing natural reproduction and artificial stocking of trout, and the large fish gradually disappeared to be followed by fish of a much smaller average size.

The early prodigious growth of trout in the lakes of the central North Island of New Zealand has been attributed to the abundance in these lakes of Galaxias brevipinnis, which declined dramatically following the introduction of trout. In Lake Taupo the high quality of the trout deteriorated rapidly in the years after they were established, the average weight of rainbow trout dropping from 4 kg in 1910-1911 to about 1 kg in 1917. This decline has been attributed to a decline in the number of G. brevipinnis as a result of trout predation. Further evidence that the decline of G. brevipinnis is related to trout predation is provided by the abundance of these galaxiids in other lakes where trout have not been introduced (McDowall 1987). A summary of the food of trout in New Zealand waters is given by McDowall (1990a), and comments and observations on the effects of trout feeding and predation on the New Zealand fauna are reviewed by Thomson (1922), Phillipps (1940), Allen (1961), Waugh (1973), McDowall (1984, 1987, 1990a, b, c). and Crowl et al. (1992).

3.5 Behavioural Studies

Glova (1989)

Glova (1989) reported that behavioural studies had provided some insight into the potential impact of salmonids on native fish stocks, and mentioned that in various stream simulation projects he had observed that juvenile salmonids were generally behaviourally dominant over various galaxiid species. Galaxiids entering the territories of salmonids were invariably threatened, chased or nipped in an effort to make them leave or retreat into the substrate. Occasionally galaxiids were observed to fight back by charging and nipping their attackers, but seldom did they win in the end. Glova pointed out that there was now good evidence that juvenile salmonids were territorially-active only during daylight, whereas most galaxiids and other New Zealand fish species were active at night. Typically, the native fish became active at dusk, and at dawn they retreated to the substrate, so that direct interactions between galaxiids and salmonids in nature may be limited primarily to twilight conditions.

McIntosh et al. (1992)

McIntosh et al. (1992) investigated microhabitat used by Galaxias vulgaris (very similar in many respects to Galaxias *olidus)* in the presence and absence of brown trout in the Shag River, New Zealand.

Several microhabitat variables were measured at random locations where G. vulgaris was present during the day. The galaxiids preferred coarse substrates, using them as resting places, but showed no other microhabitat preferences. This pattern of microhabitat use did not change in the presence of brown trout although galaxiid densities were considerably lower.

The field observations were followed by experiments using trout (120-150 mm long) and galaxiids (75-85 mm long) in six artificial stream channels constructed from 2 m long sections of 400 mm-diameter PVC stormwater pipe cut in half longitudinally. Each channel was fitted at each end with 5 mmdiameter stainless-steel mesh and was covered by a tightly-fitting perspex lid. The channels were positioned in pairs in three riffle areas of the Silver Stream about 80 m apart. They were secured in position using steel stakes and were placed so that, during base flow, water flowed evenly through the channels at a depth of 150 mm. All channels received similar water flows. Drift nets set inside and beside the channels showed that food availability inside the channels was similar to that outside.

Experiments in the channels confirmed that competition for space did not occur during the day even at high galaxiid densities. However, the situation changed dramatically at night, with the galaxiids spending significantly more time in slower areas when trout were present. Since G. vulgaris fed on drifting invertebrates, McIntosh *et* at. concluded that brown trout could affect the galaxiids deleteriously by forcing them to occupy less profitable feeding positions. Further, they speculated that interspecific competition for space, combined with competition for foodand predation by trout, could explain observed declines in G. vulgaris populations.

Edge et al. (1993)

Edge *et* al. (1993) investigated the antipredator behaviour of three genetic types of Galaxias vulgaris (very similar in many respects to Galaxias olidus) in the presence of brown trout in two, recirculating stream channels. Fish behaviour was recorded using photography and a video recorder.

The responses of the three genetic types (A, B and C) of G. vulgaris to trout differed. Type A - galaxiids exhibited more inactive behaviour (increasing the frequency of the cryptic "flat on the substrate" posture, FS) during the day, but not at night. Type B galaxiids showed no significant effect of trout on the proportion of its behaviour that was inactive, either during the day or night, but the relative frequency of FS postures increased at both times. Type C galaxiids exhibited more active behaviour both during the day and at night, but the relative frequency of cryptic FS postures was greater during the day than at night. The proportions of galaxiids feeding were reduced for all types A, B and C, but was least marked for type C. Feeding rates were reduced during both day and night for types A and B, but not for type C.

The authors acknowledged that the behaviour of both galaxiids and trout could have been modified by the artificial conditions of the experiment. However, their results indicated that the galaxiids modified their behaviour in the presence of trout, and that the three genetic types responded differently.

3.6 Studies on the Disease Impacts of Salmonids

Introductory Comments

In the early days of fish introduction, prolonged transport times may have contributed to the death of eggs carrying disease *or* infectious agents. Faster transport eliminated the time factor, making it more likely that diseases could be introduced with fish and eggs (Ashburner 1976). However, Australia still appears to be free of most of the serious pathogens which affect salmonids in many other countries (Humphrey 1985). To maintain this situation, there is a total ban on imports of trout and salmon products, other than those canned or hot smoked, although this ban is constantly challenged by foreign exporters (Kailola *et* al. 1993).

The importation of live fish and eggs is the most efficient way of importing pathogens for that species. Imported- fish bring with them - not only pathogens specific to them, but also pathogens which may affect other fish or they may be hosts and vectors for pathogens found previously in other organisms (Langdon 1988a) . Furthermore, infectious agents maybe more pathogenic in atypical hosts than in typical hosts, and may cause major disease outbreaks when atypical hosts come into contact with typical hosts (Langdon 1989b).

Although the likely role of introduced fish in introducing and disseminating fish diseases in Australia is well described (Fletcher 1986, Langdon 1988b, 1989b, Morison 1988), most research has been focused on the identification and treatment of diseases in aquaculture (Ashburner 1983, Humphrey and Langdon 1985, Rowland and Ingram 1991). Furthermore, as new pathogens are discovered, it is becoming increasingly difficult to determine whether they originated from introduced fish or from native fauna (Fletcher 1986).

It is assumed that parasites such as *Ichthyophthirius multiftlis,* which causes white spot disease, and *Ichthyobodo necator* (formerly *Costia necatrix)* were brought into Australia with live fish some time between 1880 and 1930 (Ashburner 1976). Whether they were introduced with salmonids or with other fish species, or with both salmonids and other species, is debatable and perhaps will never be known. Butcher (1941) attributed an outbreak of white spot disease, which caused massive mortalities in trout at the hatchery of the Ballarat Fish Acclimatisation Society, to ornamental carp. An earlier outbreak of the disease (apparently not associated with the presence of carp) had been reported in trout at the Plenty Hatchery in Tasmania in 1933 (Butcher 1941, Ashburner 1976). Similarly, Saville-Kent (1888) and Hardy (1910) reported fungal infections at the Plenty and Studley Park (Melbourne) salmonid hatcheries respectively.

Whether pathogens were introduced into Australia with salmonids or not, the widespread stocking of salmonids, mainly trout, by the Ballarat, Plenty, Studley Park and, later, other hatcheries would have spread parasites such as I. *multif its* and other pathogens widely throughout Tasmania, Victoria and New South Wales, then to South Australia and Western Australia.

Unfortunately, there have been few studies on the role that hatchery-produced salmonids have played in acting as vectors for the dissemination of the wide range of protozoan, metazoan, bacterial and fungal pathogens typically found in Australian salmonid hatcheries (Ashburner 1978, 1983, Humphrey and Langdon 1985) or on other possible disease impacts of salmonids on the Australian fauna. The few studies which have been undertaken are reviewed here.

Saville-Kent (1888)

The remarks made by Saville-Kent (1888) in relation to the impact and origin of the fungus *Saprolegnia* are extremely interesting. He pointed out that the fungus occurred each breeding season at the salmon hatchery on the River Plenty (where brown trout and Atlantic salmon had been held since 1864). On some occasions, it was said to be "so abundantly developed as to constitute a veritable epidemic which may be communicated to apparently healthy fish".

Saville-Kent then went on to consider the apparent epidemic some 17-18 years previously which had caused the demise of the Australian grayling *Prototroctes maraena.* The grayling were said to "have been seen floating down the rivers in thousands, covered more or less extensively with a cottony fungoid growth. So virulent and exhaustive was this epidemic that many, more especially of the southern rivers, were more or less completely denuded of their stock of this species and have so remained up to the present date". Saville-Kent posed the questions of how, when and where the epidemic originated and whether at the time there were any abnormal conditions associated with the rivers carrying the infected fish. He went on to say: "The approximate date of the appearance of this epidemic would appear to be about the year 1869 or 1870, periods it may be remarked of great activity in association with the distribution of the fry of the newly acclimatised Salmonidae in the rivers of this colony. Is it possible ...that the fungus, Saprolegnia, was hitherto unknown to Tasmania and was introduced with the ova of these Salmonidae, or more probably in the moss wherein they were packed? Under such conditions the germs or spores, like the microbes of measles or smallpox, arriving on a virgin and congenial soil, might be expected to spread with devastating virulence among the aboriginal inhabitants."

Parisot et al. (1965)

In July 1963, a batch of chindok salmon eyed eggs was sent by air from the Coleman Fish Hatchery on Battle Creek, a tributary of the Sacramento River in northern California, USA, to the Victorian State Fish Hatchery at Snobs Creek. The eggs hatched normally in August and at the "swim-up "stage in September the fry appeared normal. However, a sudden rise in mortalities occurred about ten days after the fry started feeding. The moribund fry were reported to have pale gills and a red blotch on the skin in front of the dorsal fin. Haemorrhages were seen in some cases on the side of the fish below and behind the dorsal fin and stretching to the ventral surface, on the opercles and on the branchiostegal skin. The disease outbreak lasted for three weeks and resulted in losses of about 11%.

According to Parisot *et al. (1965),* except for the lateral haemorrhaging, the symptoms were almost a classic description of Sacramento River chinook disease (= infectious haematopoietic necrosis or IHN - J. D. Humphrey, Australian Animal Health Laboratory, pers. comm.). Subsequently, all fish in the infected batch at the Snobs Creek Hatchery were destroyed and the disease has not recurred.

Ashburner and Ehl (1973)

Ashburner and Ehl *(1973)* reported the occurrence of the parasitic protozoan *Chilodonella cyprini* on brown trout held at the Victorian State Fish Hatchery at Snobs Creek, the parasite normally being found on the gill filaments of the trout. It was found to cause little or no damage to adults, but in fry *(20-40* mm long) heavy mortalities associated with gill hyperplasia resulted from as few as two or three of the protozoans per gill filament.

The stocking of waters with infected trout would have assisted in the spread of C. *cyprini* throughout Victoria. Fish samples taken in Victoria during the previous ten years had shown that C. *cyprini* occurred on several native and introduced fish species. Infected native fish included galaxiids, Australian smelt *Retropinna semoni,* Macquarie perch *Macquaria australasica,* Murray cod *Maccullochella peeli,* trout cod *Maccullochella macquariensis,* southern pygmy perch *Nannoperca australis,* river blackfish *Gadopsis marmoratus,* and striped gudgeon *Mogurnda adspersa;* infected introduced fish included brown trout, rainbow trout and goldfish *Carassius auratus.*

Pollard (1974)

Pollard *(1974)* found that *Galaxias maculatus* in landlocked Lake Modewarre, southern Victoria, was infected with *Ligula,* a parasitic cestode, and *Eustrongylides,* a parasitic nematode.

Ligula was present as the plerocercoid stage in the coelomic cavity of the galaxiid. The mean percentage weight of plerocercoids per infected fish was about *9%* (maximum *50%)* of the intact host weight. The mean number of plerocercoids per infected fish was *1.5,* the maximum number per fish being five. The mean incidence of infection was *50%.* The effects of these cestodes on the host galaxiids included a reduction in general body condition, an inhibition of gonadal maturation, and an inhibition of movements to the spawning areas during the breeding season.

Eustrongylides was usually found encysted in the visceral peritoneum. The mean number of nematodes per infected fish was *5.4,* and the maximum number per fish was *44.* The mean incidence of infection was 80%. One of the effects of this nematode on its host was the inhibition of egg laying by female fish when the nematode was encysted in the ovary or vent. In Lake Modewarre, *Eustrongylides* was also found in rainbow trout and an eleotrine goby and, and a similar form (thought to be an intermediate-adult stage of the same species) was found in a cormorant.

The finding of *Ligula* in the Australasian region constituted a new zoogeographic record, and its occurrence in *G. maculatus* constituted a new host-family record. Regarding the origin of the *Ligula* infecting these landlocked galaxiids, and thus the presence of this parasite in the Australasian region in general, Pollard speculated that possible agents for its introduction were the brown trout, rainbow trout and redfin perch *Perca fluviatilis,* all of which have been introduced into Lake Modewarre and all of which have been recorded as a host of *Ligula* in the Northern Hemisphere. The arrival of *Ligula* in Australasia via a migratory bird host would be much less likely because of its short adult life-cycle stage in the bird (less than five days) compared with the fish host , (up-to *12-14* months).

Ashburner (1977)

Ashburner (1977) described the incidence of mycobacteriosis in hatchery-confined chinook salmon derived from a presumed "disease-free" consignment of 50,000 eyed eggs received at the Victorian State Fish Hatchery at Snobs Creek from Oregon, USA, in 1966. Before the salmon eggs were imported, mycobacteriosis had not been observed at Snobs Creek, although other acid-fast bacteria *(Nocardia)* had been isolated from rainbow trout. Mycobacteria appear to have been introduced with the eggs, particularly since the strains appear similar to those isolated in the USA. The possibility that the infection was transmitted to the salmon in the food they received at Snobs Creek was ruled out because no cases of mycobacteriosis were found in the hatchery stocks of brown trout and rainbow trout which at the time were fed on the same food as the salmon. It is also unlikely that the salmon contracted the disease from their immediate surroundings, which were indistinguishable from those of the trout held at Snobs Creek.

Ashburner reported that it took two years for the number of mycobacteria to increase to readily detectable numbers, but noted that the incidence of infection decreased in subsequent year-classes. The occurrence and effects of mycobacteria in the Goulburn River system, in which Snobs Creek is located, or in Lakes Purrumbete and Bullen Merri, in which chinook salmon derived from the Oregon shipment of eggs were stocked, is unknown.

Whittington and Cullis (1988), Carson and Handlinger (1988)

Whittington and Cullis (1988) found that an atypical strain of the bacterium *Aeromonas salmonicida,* which causes goldfish ulcer disease (GUD), had attributes typical of virulent, typical strains which cause furunculosis in salmonids. They isolated the bacterium from diseased goldfish *Carassius auratus* in Australia and inoculated it into Atlantic salmon, brown trout, rainbow trout and brook trout by intraperitoneal injection and by bath immersion. The results of their experiments demonstrated that the strain of *A. salmonicida* in populations of goldfish in south-eastern Australia is highly pathogenic for salmonids, with Atlantic salmon being the most susceptible and rainbow trout the least susceptible of the salmonids tested. Furthermore, the organism was transmitted from inoculated fish to within-tank control fish via water and established a carrier state in Atlantic salmon.

Similarly, Carson and Handlinger (1988) found that an atypical strain of *A. salmonicida* isolated from goldfish with cutaneous ulcerative lesions proved to be highly virulent to Atlantic salmon challenged by intraperitioneal injection and by bath immersion. The salmon developed lesions bearing a close resemblance to classical furunculosis in salmonids.

Although this atypical strain of *A. salmonicida* was introduced into Australia via goldfish imported from Japan in 1974 (Humphrey and Ashburner 1993), it is likely to be disseminated by both goldfish and salmonids. Whittington and Cullis (1988) and Carson and Handlinger (1988) predicted that outbreaks of furunculosis in salmonid fish are likely to occur in south-eastern Australia if this strain of *A. salmonicida is* transmitted from goldfish with GUD to salmonids. They concluded that the organism posed a significant threat to the aquaculture industry and wild salmonid stocks in Australia. Its potential impact on native fauna is unknown.

Langdon et al. (1988), Langdon (1989a, b)

Langdon *et al.* (1988) reported two outbreaks of a disease in hatchery-confined rainbow trout caused by the epizootic haematopoietic necrosis (EHN) virus of redfin perch *Perca fluviatilis* which was first isolated in north-eastern Victoria in 1984. The outbreaks in trout represented the first verified instance of a viral disease in Australian salmonid stocks. Extensive virological surveys using appropriate techniques had previously failed to detect viruses or viral diseases in salmonids (Langdon *et aL* 1986).

Langdon (1989a) subsequently found that several native species, viz. Macquarie perch *Macquaria australasica,* silver perch *Bidyanus bidyanus* and the galaxiid *Galaxias* olidus were all highly susceptible to the virus; Murray cod *Maccullochella peeli* was a potential carrier, and golden perch *Macquaria ambigua* and Australian bass *Macquaria novemaculeata* were considered unlikely to be naturally susceptible hosts. He considered that carrier individuals of redfin perch, rainbow trout and Murray cod, and possibly other fish, represented a further reservoir of infection. This case illustrates the hazards of transmission of infectious diseases between different families and species of fish, and the risks of moving fish from one area to another. Langdon recommended that translocations of *P, fluviatilis*, salmonids, percichyids and teraponids at least should be subject to health certification of freedom from EHN virus. Further, Langdon (1989b) pointed out that although the EHN virus was not introduced into Australia with the naturally susceptible redfin or salmonids, it had been spread insidiously by their translocations on mainland south-eastern Australia. For example, hatchery-reared trout infected by wild redfin were moved from the upper Murray catchment to the upper Murrumbidgee drainage where the disease had since occurred on a trout farm.

Davies (1991)

The bacterium *Yersinia ruckeri is* responsible for enteric redmouth disease, an acute and chronic infection of salmonids, and has been known to exist in Australia since the 1960s. Davies (1991) reported two clonal types of Y *ruckeri* from Australia, one of which appeared to be unique to Australia and one of which shared characteristics with isolates from Europe and the USA, suggesting that at least one biotype of *Y ruckeri* was introduced with salmonids or their eggs (J. D. Humphrey, Australian Animal Health Laboratory - pers. comm.). The effect of *Y ruckeri* on native Australian fauna is unknown.

3.7 Overview of Studies on Impacts of Salmonids

Studies on the impacts of salmonids on Australian fauna reviewed in sections 3.1-3.6, including New Zealand studies on *Galaxias brevipinnis* but excluding those on taxa not found in Australia, are listed in Table. 2. It is immediately apparent that there have been few studies on or relating to the impacts of salmonids on fauna other than fish and, considering the families of fish which occur in areas in which trout have been introduced in Australia, including estuarine as well as freshwater habitats, the studies cover a relatively small part of the native fish fauna.

The most substantive evidence of impacts of salmonids in Australia comes from Fletcher's (1979) experimental introduction study and the observations of Tilzey (1976), Raadik (1993) and Closs and Lake (in prep) during the invasion of trout into new areas. Much of the information on the distributions of salmonids and native fish presented in section 3.1 was derived from general fish surveys not specifically undertaken to investigate the effects of salmonids on particular species or aquatic communities. Exceptions to this approach were the studies of Jackson and Williams (1980) and Ault and White (1994). Jackson and Williams .(1980) compared the distributions of native fish in areas with and without trout. It was apparent that when trout were present, galaxiids such as *Galaxi.as olidus* and *Galaxias brevipinnis* were restricted to the upper reaches of river catchments in areas which were inaccessible to trout. However, when trout-were absent, galaxiids were not restricted to such areas. Observations made by Closs and Lake (in prep) in their invasion study indicated that as trout moved progressively upstream the galaxiid population became progressively fragmented, giving rise to a series of isolated populations, and producing the type of trout/galaxiid distribution pattern described in many of the distribution studies presented in section 3.1. Ault and White (1994), using a similar approach to that adopted by - Townsend and Crowl (1991) in New Zealand, were able to demonstrate that the presence of brown trout rather than habitat characteristics was responsible for the observed distribution of *Galaxias truttaceus* in their study streams.

Taken together, the numerous and widespread instances of fragmented galaxiid distribution patterns in the presence of trout (in a wide range of catchments, some in areas of natural vegetation, some in cleared areas), the more widespread distribution of these galaxiids in the absence of trout, and the observations of fragmentation of the galaxiid distribution pattern as trout progressively move upstream, provides a substantial body of evidence for an adverse impact of trout on these stream-dwelling galaxiids.

Studies on the mechanisms by which salmonids have had an impact on the native fauna are sparse, but nevertheless indicate that predation has been the major cause of the impact. This is hardly surprising given the large size to which salmonids can grow and the relatively small size of individuals in families such as the Galaxiidae, which appears to have been the fish family most affected by salmonids, at least on the basis of the present evidence.

The studies which have been done on the interactions between juvenile salmonids and the native fauna indicate that direct competitive encounters may occur between juvenile trout and those species which occupy the same microhabitat and feed in the same manner on the same foods. Conversely, those native species which, because of their particular life histories and habitat requirements, are able to avoid direct encounters are likely to be able to co-exist with salmonids. Evidence of exclusion based on competition is extremely difficult to demonstrate in field situations. However, the few studies which have been done on the interactions between stream-dwelling galaxiids and salmonids in artificial stream channels indicate that competitive exclusion of galaxiids by salmonids can occur.

The impact of salmonids on the native fauna via the spread of pathogens, particularly via the widespread releases of hatchery-produced fish, is unknown. However, the occurrence of pathogens in salmonid hatchery stocks indicates that salmonids have undoubtedly played a major role in the spread of these disease organisms, irrespective of whether or not the pathogens were introduced into Australia with the salmonids.

Table 2. Studies on impacts of salmonids on Australian fauna.

Author(s)	*Native fauna*	*Salmonid* species
Saville-Kent (1888)	*Prototroctes maraena*	brown trout/Atlantic salmon
Gray (1929) Whitley (	*Galaxias brevipinnis*	rainbow trout trout
1935) Williams (1964)	galaxiids	brown trout
Frankenberg (1966, 1969)	*Galaxias brevipinnis*	brown trout
Morrissy (1967)	Galaxias *olidus*	brown trout/rainbow trout
	Galaxias olidus	brown trout/rainbow trout
	Cherax destructor	brown trout/rainbow trout
	tadpoles	brown trout/rainbow trout
	Dytiscidae	brown trout/rainbow trout
	Gyrinidae	brown trout
Renowden(1968)	*Galaxias brevipinnis*	brown trout
Ashburner and Ehl (1973)	several fish species	brown trout/rainbow trout
Pollard *(1974)* Andrews (	*Galaxias maculatus*	trout
1976) Knott *et al.* (1978)	*Galaxias brevipinnis*	trout
Tilzey (1976)	*Anaspides tasmaniae*	rainbow trout
	Galaxias olidus	brown trout/rainbow trout
Fletcher (1979)	*Galaxias brevipinnis*	brown trout
Jackson (1978)	*Galaxias olidus*	brown trout
Cadwallader (1979)	*Gadopsis marmoratus*	brown trout
Jackson and Williams (1980)	*Galaxias olidus*	brown trout
	Galaxias olidus	brown trout
Cadwallader and Eden (1981)	*Galaxias brevipinnis*	chinook salmon
Cadwallader and Eden (1982)	Galaxias *maculatus*	rainbow trout
Jackson and Davies (1983)	Galaxias *maculatus*	brown trout
Sagar and Eldon (1983), NZ	*Galaxias olidus*	brown trout
Koehn (1986a) Koehn (1986b)	*Galaxias brevipinnis*	brown trout
Davies (1989)	*Galaxias olidus*	brown trout/rainbow trout
Humphries (1989)	*Galaxias maculatus*	brown trout
Langdon (1989a, b)	"non-trout" species	brown trout
Jones *et al.* (1990)	*Galaxias auratus*	rainbow trout
Koehn and O'Connor (1990)	several fish species	brown trout/rainbow trout
Lintermans and Rutzou (1990)	*Galaxias olidus Galaxias*	brown trout
Glova and Sagar (1991), NZ	*brevipinnis* Galaxias	rainbow trout
Kusabs and Swales (1991), NZ	*olidus Galaxias*	brown trout/rainbow trout
Sanger and Fulton (1991)	*brevipinnis Galaxias*	rainbow trout brown trout
	brevipinnis Galaxias	brown trout
Sloane and French (1991)	*fontanus Galaxias*	brown trout
Shirley (1991) Hamr (1992)	*johnstoni Galaxias*	trout
Raadik (1993) Ault and	*tanycephalus*	brown trout/rainbow trout
White (1994) Gillespie (	galaxiids	brown trout
1995) Closs and Lake (in	*Galaxias fuscus*	rainbow trout
prep)	Galaxias *pedderensis*	brown trout
	Galaxias fuscus	brown trout
	Galaxias truttaceus	brown trout
	tadpoles	
	Galaxias olidus	

4. CRITIQUE OF RESEARCH METHODS, RECOMMENDATIONS ON METHODS AND PRIORITIES FOR RESEARCH, AND MANAGEMENT ACTIONS

4.1 General Considerations

Taylor *et al. (1984)* pointed out that although the effects of introductions may not be in doubt, at least on theoretical grounds, rigorous documentation of specific examples of impacts is generally lacking because investigators have not accommodated the consequences of multiple causality in the design of impact studies. The demonstration of an impact by an introduced species on a native species requires verification of a causal relationship between observed or measured changes in a population of the native species and the presence of the introduced species. This requires an experimental design with appropriate controls and replicates. As pointed out by Morison *(1988),* such experimental manipulations can seldom be achieved in nature, so there is then a compromise between the need to control all potential variables and the need to prevent the experiment from becoming an oversimplification and artificial representation of the natural situation.

Comparison of differences in the composition of natural communities between areas with and without an introduced species can provide evidence for impact, but only to the extent to which alternative causal agents can be eliminated as explanations for the observed differences. Furthermore, such approaches do not usually provide information on underlying mechanisms. The occurrence of a correlation between the introduction of a species and a subsequent change in a native population does not establish causality. Similarly, trying to demonstrate an impact at a site after an introduced species has become established lacks the controls required to demonstrate causality (Taylor *et al. 1984,* Morison *1988).*

4.2 Review of Experimental Methods and Recommended Approaches for Investigating the Impact of Salmonids on Native Fauna

Future studies of distributions or, more specifically, mutually exclusive distributions of salmonids and native species in Australia, should adopt the approach taken by Townsend and Crowl *(1991).* Their statistical analyses incorporating various physical, chemical and biological variables from a large number of sampling sites in one catchment indicated that the presence and abundance of galaxiids were best predicted by the presence or absence of trout rather than by any of a wide range of other possible variables such as changes in land use, the nature of bankside vegetation and the substrate type. Their study was specifically designed the test the hypothesis that the occurrence of *Galaxias vulgaris* was affected by the presence of brown trout. This sort of approach is much more useful than merely recording the absence of native species in the presence of salmonids because it provides information on the likely cause of the observed distribution patterns of the native species which presence/absence studies do not provide.

The approach of Minns *(1990)* who analysed the data base on freshwater fish distributions in New Zealand to examine patterns of overlap and exclusion also has merit. The main difficulty in this approach is that information in the various State data bases may not be site-specific and, therefore, not detailed enough to demonstrate mutually-exclusive distribution patterns. Again, this approach provides no information on the cause of the observed distribution patterns unless appropriate habitat characteristics and land use information is also included in the data base. However, it can provide the basis for more detailed investigations of the Townsend and Crowl (1991) type.

Introduction experiments in the field, like that of Fletcher (1979), provide the most convincing evidence of an impact of salmonids on native fish. Similar experiments have also been done to examine the impacts of salmonids on macroinvertebrates and tadpoles, e.g. see Cooper (1988), Feltmate and Williams (1989) and Andersen et al. (1993). There are many practical difficulties in setting up and running such experiments in lotic situations, not the least of which is the construction and maintenance of the barriers at each end of the experimental and control sections. It is also important to run the experiments over long time periods in order to monitor progressive changes in macroinvertebrate community structure. For example, initially, the most obvious impact may be that galaxiids are eliminated, followed by some of the larger macroinvertebrates, and so on. Only by long-term monitoring will these changes become apparent. It is not possible to run true replicates of this type of experiment under natural conditions because no two streams are identical. However, the experiment can be repeated one or more times in nearby streams.

Replicated introduction experiments could be set up in paired raceways in aquaculture facilities such as occur in trout hatcheries. These units are often big enough (20-30 m long) to simulate sections of small streams and have the advantage that the water flow can be regulated.

Rather than investigating the effects of trout on macroinvertebrates by comparing the fauna in sections of stream with and without trout, Reice and Edwards (1986) adopted a different experimental design whereby they used a series of benthic cages some of which contained trout and some of which did not. The advantage of this approach is that replicates can be run for experimental and control treatments. Their experimental protocol was as follows. Twenty cages were set in the stream substrate and filled with cobble-sized rocks (up to 100 mm diameter), the rocks taking up about 50% of the cage volume, the remaining volume being made up by the spaces between the-rocks. Cages were left open (i.e. top removed) for an initial period, then five cages were sampled to provide information on initial invertebrate community structure. The remaining 15 cages were searched in situ for vertebrate predators which may-have-colonised them (no trout were found). A single predator (trout) was placed in each of five cages and the top fixed to each cage; these were the trout inclusion cages. In another five cages; tops were fixed without adding a trout; these were the trout exclusion cages. The remaining five cages were left open to allow free access of all animals in the stream. The complete design was run twice, and the composition of the invertebrate community in all cages recorded. This sort of approach has great potential for investigating the effects of salmonids on macroinvertebrates in Australian waters.

It is important to obtain local knowledge of the previous history of trout in any catchment in which introduction experiments are contemplated since prior occupation of an area by trout may well have already modified the structure of the aquatic community.

Introductionexperiments in nature imply setting up the experiment in an area in which trout have not previously occurred, e.g. as in Fletcher's (1979) study, in a stretch of stream above a waterfall which previously had been inaccessible to trout. In situations where evidence of impact is being sought for threatened species it may be inappropriate to introduce trout into an area which they had not previously occupied. In such - circumstances, one approach would be to monitor the aquatic community in a stretch of stream in which trout occur, then remove the trout downstream to a natural or artificial barrier and monitor the subsequent changes in the aquatic community. This approach of removing trout is being adopted by necessity in the recovery program for Galaxias fuscus - by Raadik (1993), but is also being used experimentally with Galaxias olidus in a small upland stream in the Australian Capital Territory (M.: Lintermans, Parks and Conservation Service, ACT Department of the Environment, Land and Planning - pers. comm.). In the latter situation, trout were eradicated from a section of stream using rotenone, and existing barriers to upstream movement were augmented to prevent reinvasion; G. *olidus* are now recolonising the stream from which they had been previously absent.

Data from Renowden's (1968) study on the distribution of galaxiids and trout in pools in a small stream are presented in Table 1 as an indication of the relatively small numbers of fish likely to be encountered in field studies of the impact of salmonids on native fauna. Such small numbers do not detract from the value of the observations because, at the field level, elimination of one species by another ultimately involves interactions between individuals, e.g. one trout eating one or more galaxiids. However, observations involving such small numbers of individuals highlight the need for replication of experiments or several sets of observations of similar events to build up a convincing body of evidence to demonstrate that predation, for example, is the causal agent for observed trout/galaxiid distribution patterns.

The use of artificial stream channels to investigate interactions between salmonids and native fish or between salmonids and native macroinvertebrates has great potential. These studies can be set up either in the field, e.g. McIntosh *et at.* (1992), or in the laboratory, e. g. Edge *et at.* (1993), and enable interactive mechanisms to be investigated under controlled conditions. The literature contains examples of a wide range of flow-through and recirculating stream channels, e.g. see Brocksen *et al.* (1968), Ringstad (1974), Cadwallader (1975b). Fausch and White (1983) , McIntosh *et al.* (1992) and Edge *et al.* (1993), and Warren and Davis (1971) have reviewed the possibilities and constraints of their use. Even basic glass aquaria can be used to good effect, e.g. see Glova (1990), to investigate predation and other interactions between salmonids and native fish and macroinvertebrate, particularly to investigate the mechanisms of impact of salmonids on the fauna of lentic waters.

The most difficult area in which to investigate the impact of salmonids is that of fish disease, primarily because most of the damage in spreading pathogens has probably already been done and because other species, in addition to salmonids, may also be involved in the spread of particular disease organisms. In addition, working with pathogens, particularly viruses, requires quarantine facilities. However, it would be of interest to compare the incidence of pathogens in populations of native fish (and macroinvertebrates) which have not had contact with salmonids with their incidence in populations which have had contact with salmonids; for example, in the case of the study by Closs and Lake (in prep), in which the trout population had expanded upstream then contracted downstream because of a drought, would the pathogens in the galaxiid fauna be any different from that in gala-)did populations which had had no contact at all with trout?

In summary, experimental studies have the potential to provide the most compelling evidence of the impacts of salmonids on native fauna. Unfortunately, very little of this type of research has been undertaken in Australia. The most useful and practical techniques for demonstrating impacts in the field are introduction experiments conducted either in stream sections or in cages. Experimental stream channels and even basic aquaria are ideal tools for investigating impact mechanisms. Studies on salmonid/native fauna distribution patterns in nature should be designed to incorporate an analysis of all possible variables which could contribute to the observed distribution patterns.

4.3 Research Priorities

Salmonids, mainly brown trout, have been implicated in the demise of ten of the fish species classified as threatened (i.e. those in the endangered, vulnerable, potentially threatened and indeterminate conservation status categories) in the Australian Society for Fish Biology 1992 listing (Table 3).

Of these ten species, five are galaxiids (four of which, G. *fontanus,* G. *johnstoni,* G. *pedderensis* and G. *tanycephaius* occur only in Tasmania), two are nannopercids (pygmy perches), two are percichthyids (trout cod and Macquarie perch), and one is a prototroctid (Australian grayling). Macquarie perch and trout cod are relatively large fish compared with the other threatened species, and habitat degradation is thought to have played a major part in their demise (Cadwallader and Backhouse 1983, Douglas *et al.* 1994). Faragher *et al.* (1993) suggested that both brown trout and rainbow trout were likely to be major predators of juvenile trout cod. The effect of trout on these

percichthyids still requires clarification, but priority should be given to research on the threatened galaxiids, for which the impact of trout is thought to be the primary threatening process (Jackson *et al.* 1993), the pygmy perches for which we have little information on what caused their demise, and the Australian grayling. The role of salmonids, particularly trout, in the extinction of the closely-related New Zealand grayling *Prototroctes oxyrhynchus* still has not been satisfactorily explained, although it has been discussed at length (Thomson 1922; Phillipps 1940; Allen 1949, 1961; Waugh 1973; McDowall 1968, 1976, 1987, 1990a, c). It is, therefore, imperative that the impact of trout on the Australian grayling is investigated. As pointed out by Jackson and Koehn (1988), it would be unwise to contemplate stocking trout in waters containing Australian grayling until the relationships between this species and introduced salmonids are better understood.
The effects of salmonids on fish in the families Petromyzontidae (particularly juvenile lampreys), Anguillidae (particularly juvenile eels), Aplochitonidae, Retropinnidae and Gadopsidae also requires investigation. There is a pressing need to clarify the impact of salmonids on the large Tasmanian crayfish *Anaspides tasmaniae,* for which concern over the impact of brown trout has been expressed (Williams 1965, 1969; Knott 1973, Knott *et al.* 1978), and to investigate the impact of salmonids on other freshwater crayfish species, including *Euastacus spp., Cherax spp.* and *Geocherax spp.,* which occur in areas occupied by trout.
The impact of trout on macroinvertebrates and aquatic vertebrates other than fish has been largely ignored and requires urgent assessment. It is likely that trout have had a substantial impact on the structure of faunal communities in fresh waters throughout the cooler parts of Australia, but this issue, with the exception of Morrissy's (1967) study, has also largely been ignored.

Table 3. Species in the Australian Society for Fish Biology 1992 listing of threatened fish in whose demise trout, mainly brown trout, have been implicated (after Jackson *et al.* 1993).

Endangered	
Galaxias fontanus	Swan galaxias
Galaxias fuscus	Barred galaxias
Galaxias johnstoni	Clarence galaxias
Galaxias pedderensis	Pedder galaxias
Maccullochella macquariensis	Trout cod
Vulnerable	
Galaxias tanycephalus	Saddled galaxias
Nannoperca variegate	Variegated pygmy perch
Potentially threatened	
Edelia obscura	Yarra pygmy perch
Prototroctes maraena	Australian grayling
Indeterminate	
Macquaria australasica	Macquarie perch

4.4 Management Actions

The most threatened species in whose demise salmonids are implicated are the three Tasmanian galaxiids, *G. peddererensis, G. fontanus* and *G,* johnstoni, and the Victorian galaxiid, *G.* fuscus. Galaxias pedderensis appears to be the species most at risk (although Galaxias brevipinnis, as well as trout, is implicated in its demise).
Recovery plans, including estimated costs, for these and the other species of threatened fish listed in Table 3 are outlined by Wager and Jackson (1993).
In Tasmania, management actions as part of recovery plans are being implemented for *G. pedderensis, Gs fontanus* and *G,* johnstoni, as well as for *G.* tanycephalus (Sanger and Fulton 1991, Gaffney *et al.* 1992, Hamr 1992, Sanger 1993). The protection of existing populations of *G.* pedderensis by invasion from brown trout and Galaxias brevipinnis was considered to be both difficult and likely to be unsuccessful, so specimens of *G.* pedderensis were translocated to another lake which had a rich (but not locally endemic) invertebrate fauna (Gaffney *et al.* 1992, Hamr 1992). However, this translocation of galaxiids to a previously fish-less lake has been criticised as inappropriate on ecological grounds (Horwitz 1995).
The recovery plan for *G.* fontanus involves translocations of fish into upstream sections of streams devoid of brown trout and the

augmentation of a small natural barrier to the upstream movement of trout on one stream (Sanger 1993).

Habitat protection measures and translocations to suitable streams and lakes devoid of brown trout are advocated for the conservation of *G. johnstoni.* An interesting and practical solution to the problem of preventing the introduction of brown trout into Clarence Lagoon is to continue stocking the lagoon with brook trout to provide fishing for the many recreational anglers who use the water, thereby reducing the risk of the illegal introduction of brown trout. Brook trout and Gi johnstoni appear able to coexist.

Proposals to safeguard *G.* tanycephalus include a cessation of brown trout stocking in Woods lake, one of the only two waters in which this galaxiid occurs (Sanger and Fulton (1991).

Sanger and Fulton (1991) pointed out that the speed with which the decline in abundance of *G. pedderensis* occurred highlighted the need for routine fish survey work in order to recognise declines before they become irreversible. They considered that the other six species of endemic galaxiids in Tasmania could undergo similar declines at any time and recommended that refuge populations of all Tasmanian galaxiids be established, where the impact from brown trout predation is absent.

In Victoria, a recovery plan for Galaxias fuscus *is* being implemented (Raadik 1993). Part of the program includes the building of trout exclusion structures on two streams to determine their effectiveness in preventing trout access to the galaxiid populations, and to assess whether the *G.* fuscus populations will increase following trout eradication. Weirs will be built at the downstream end of the sections of stream to be secured for *G.* fiscus and trout will be eradicated upstream of the barriers. Two barriers will be constructed at each site, with the zone between them being monitored for the presence of trout. The galaxiids upstream of the barriers will be monitored to record changes in population structure.

Specific management actions for the protection of other fauna thought to be affected by salmonids cannot be undertaken until the nature and extent of the impacts are understood. However, as high-level predators, it is likely that salmonids, particularly brown trout and rainbow trout, have had a marked impact on aquatic fauna and the structure of aquatic communities throughout the cooler parts of Australia, so that fisheries and conservation agencies should ensure that waters or catchments are set aside specifically for the maintenance of natural communities and that trout are excluded from these areas. In some instances it may be necessary to remove salmonids from particular waters as is being done in the *G.* fuscus recovery program in Victoria (Raadik 1993). The setting aside of such waters or catchments can be accommodated in strategic plans for the management of inland fisheries and aquatic resources in all affected States and Territories (section 5.9).

5. POLICIES AND REGULATIONS RELATING TO THE STOCKING AND TRANSLOCATION OF SALMONIDS IN AUSTRALIA

5.1 Introductory Comments

Since their introduction into Australia last century, salmonids, particularly trout, have been released into most waters thought to be suitable for them and have now established self-sustaining populations in many of these waters, particularly in Tasmania and the cooler parts of Victoria and New South Wales (section 2). Consequently, a great deal of the damage has probably already been done as far as impacts on the native fauna is concerned. This of course took place long before codes of practice (e.g. Turner 1988) and issues such as the maintenance of biodiversity (e.g. Kitching and Lyonns 1993) were regarded as being important. However, a review of the current policies, regulations and guidelines of the various State and Territory agencies on salmonid stocking and translocation in relation to impact on native fauna reveals a wide range of attitudes and responses to the problem.

5.2 Victoria

The Department of Conservation and Natural Resources, specifically the Fisheries Branch, is the agency responsible for salmonid stocking in Victoria. The Department considers trout to be "desirable introduced species" and manages the State's recreational fishery on that basis. The Department also supports the commercial aquaculture of salmonids.

The current policy on stocking trout in public waters has been in place since 1988. The policy states that the Department will produce trout for stocking inland waters and that stocking will be confined to public waters except where recognised alternative arrangements exist or special management or research needs exist or arise. "Recognised alternative arrangements" refer to formal, usually long-standing, arrangements for the stocking of trout in particular waters by bodies such as the Ballarat Fish Acclimatisation Society. "Special management or research needs" are those needs which in the view of the Fisheries Branch are sufficient to merit variation in general policy for the overall benefit of angling in the State. A recent example is the stocking of trout eggs via Whitlock-Vibert boxes in a small number of streams by members of angling bodies.

The policy states that waters will be considered for stocking with trout when all of the following conditions are satisfied:

- sufficient acceptable or marginal habitat for their maintenance and/or growth exists;
- natural reproduction is insufficient to support a fishery;
- the fish are accessible to anglers; and
- there is a reasonable expectation that enough anglers will fish the water to justify the expenses involved.

Priorities for waters considered for stocking are determined by habitat suitability criteria, existing or potential trout population levels and the needs of the angling public.

The policy states that stocking of trout will not occur in waters in the following categories:

- where the released fish may constitute a threat to a population of a species of special concern or where an unique faunal assemblage occurs;
- where natural reproduction adequately supports a fishery;
- waters east of the Snowy River catchment; and
- waters identified as unacceptable habitat.

The Victorian *Fisheries Act 1968* requires that all persons wishing to release fish into Victorian waters must first have written permission from the Department of Conservation and Natural Resources (a standard application form is provided for this purpose). Further, a person is required to notify the Department if bringing fish or fish eggs from interstate. Trout releases are not permitted in private waters in the Mallacoota basin in east Gippsland; few introduced fish occur in this area, which is managed by the Department of Conservation and Natural Resources for the protection of its natural aquatic fauna.

The Victorian *Flora and Fauna Guarantee Act* was proclaimed in Victoria in 1988. The Department of Conservation of Natural Resources, specifically the Flora and Fauna Branch, is responsible for the administration of the Act.

The relevant objectives of the Act are:

- to guarantee that all taxa of Victoria's flora and fauna can survive, flourish and retain their potential for evolutionary development in the wild;
- to conserve Victoria's communities of flora and fauna;
- to manage potentially threatening processes;
- to ensure that any use of flora and fauna by humans is sustainable;
- to ensure that the genetic diversity of flora and fauna is maintained;
- to provide programs of community education in the conservation of flora and fauna; and
- to encourage the conserving of flora and fauna through co-operative community endeavours.

Any person or organisation can nominate threatened taxa and communities or potentially threatening processes for listing under the *Flora and Fauna Guarantee Act*. An independent Scientific Advisory Committee assesses the validity of the nominations and makes recommendations for listing either on Schedule 2 of the Act (threatened taxa or communities) or Schedule 3 of the Act (potentially threatening processes). Once a threatened taxon or community or a potentially threatening process is listed, the Department of Conservation and Natural Resources must prepare an action statement as soon as possible. An action statement sets out what has been done to conserve and manage a taxon, a community or, potentially threatening process and what is intended to be done. Action statements become public documents.

Two examples of relevant nominations for listing under the *Flora and Fauna Guarantee Act* are given below.

The "deliberate or accidental introduction of live fish into public or private waters within a Victorian river catchment in which the taxon to which the fish belongs cannot reliably be inferred to have been present prior to the year 1770 AD" was recommended by the Scientific Advisory Committee on 10 March 1992 for listing as a potentially threatening process on Schedule 3 of the *Flora and Fauna Guarantee Act 1988.*

"Galaxias olidus var. fuscus - Tiger or Brown Galaxiid" was recommended by the Scientific Advisory Committee on 22 May 1991 for listing as a threatened taxon on Schedule 2 of the *Flora and Fauna Guarantee Act 1988.* The impact of trout was recognised as a threat which was likely to lead to the extinction of the taxon.

5.3 New South Wales

New South Wales Fisheries is the agency responsible for salmonid stocking. Trout are considered "beneficial" and are stocked on a regular basis. The commercial aquaculture of salmonids is supported.

The New South Wales *Fisheries and Oyster Farms Act 1935* prohibits the stocking of fish, or the eggs or fry of any fish, into any waters without the consent of the Minister.

The objectives of stocking salmonids are:

- to maintain adequate stocks in public waters by stocking streams and impoundments in which there is inadequate natural reproduction or in which environmental factors have had a deleterious effect on stocks; and
- to ensure that all fish stocked in public waters are free of specified diseases.

The number of each species produced is determined in consultation with recreational fishers.

The principles governing stocking include:

- all proposed stockings of public waters must be approved by NSW Fisheries before the stocking takes place;

- all stockings of salmonids into public waters, regardless of the source of the stock, must be reported immediately to NSW Fisheries on stocking data forms;
- all salmonids stocked into public waters must be from hatcheries which are certified free from EHN virus, goldfish ulcer disease, yersiniosis and any other disease stipulated by NSW Fisheries;
- in general, salmonids should not be stocked in areas where they have not previously been stocked;
- in general, salmonids should not be stocked into areas where they could compete with populations of endangered species;
- salmonids supplied to acclimatisation societies must be stocked into public waters which have open access; and salmonids should not be stocked into streams to which they are not biologically suited and in which lethal or sub-lethal temperatures have regularly been experienced in the past.

5.4 Australian Capital Territory

The ACT Parks and Conservation Service is the agency responsible for salmonid stocking. Current policy is that there is no stocking of salmonids (or native species) in streams in the ACT, but trout are stocked for recreational fishing purposes in Canberra's urban lakes. In practice, there has been little stocking of salmonids in these lakes because of poor survival rates.

Salmonids are not stocked in the three Cotter River water storages, viz. Corin, Bendora and Cotter Reservoirs, because all three are closed to fishing. Furthermore, Cotter and Bendora Reservoirs are in the Namadgi National Park and, together with their feeder streams, are managed as a "fish conservation zone", with the reduction of existing trout populations as a management aim.

Googong Reservoir is managed jointly by the ACT Parks and Conservation Service and NSW Fisheries. Trout are currently stocked in an attempt to enhance the recreational fishery (M. Lintermans, Parks and Conservation Service, ACT Department of the Environment, Land and Planning - pers. comm.).

5.5 Tasmania

The Inland Fisheries Commission is responsible for salmonid stocking in the inland waters of Tasmania.

In its April 1987 newsletter, it was reported that the Inland Fisheries Commission had adjusted its trout stocking policy "to avoid conflict with sensitive native species". As a general policy, salmonids are only stocked in waters in which they already occur. This has been the case for some years. A general rule is that trout stocking also does not occur in National Parks, although present trout stocks in parks are self-sustaining.

In specific areas such as Clarence lagoon where *Galaxias johnstoni* occurs, the development of a recreational fishery based on stocking with brook trout rather than brown trout is encouraged because brook trout and *G. johnstoni* appear to be compatible, unlike brown trout and *G. johnstoni (W.* Fulton, Inland Fisheries Commission, Tasmania - pers. comm.).

5.6 South Australia

The Department of Primary Industries, specifically the Fisheries Branch, is the agency responsible for salmonid stocking in South Australia.

The introduction and control of all non-native fish is covered by the *Fisheries (Exotic Fish, Fish Farming and Fish Diseases) Regulations, 1984.* This legislation prohibits the importation of all non-native fish to South Australia, but allows the Department of Primary Industries to issue permits allowing the importation and farming of exotic fish if it is satisfied that the fish are certified diseasefree and that they will be stocked or farmed in a manner consistent with the aim of the *Fisheries Act* 1982 to conserve and enhance fish stocks in South Australia.

Under permit, the South Australian Fly Fishers' Association is the body which undertakes the importation and stocking of salmonids, mainly brown trout and rainbow trout. Eyed eggs are obtained usually from Tasmania, hatched and the young trout are either stocked into public waters or sold for stocking private waters (farm dams), usually in the Adelaide Hills area.

In the past, the Fly Fishers' Association attempted to stock any water which would support trout through a normal season. Any stretch of water which held trout for four out of five years was considered worth stocking (J. Williams, South Australian Fly Fishers' Association - pers. comm.). The public waters which can now be stocked by the Fly Fishers' Association are limited by the Department of Primary Industries to about 5-6 rivers so as to avoid potential conflict with threatened native fauna.

5.7 Western Australia

The Fisheries Department is the agency responsible for stocking salmonids. It has recently released a discussion paper on the issues relating to the introduction of fish, crustaceans and molluscs in Western Australia (Lawrence 1993).

In relation to brown trout and rainbow trout, it is recognised that the cost of their introduction into Western Australia is their impact on natural ecosystems. On the other hand, the benefits arising from their introduction are the establishment of a recreational fishing industry and an aquaculture industry. It is seen as a benefit that trout are unable to establish-self-sustaining populations in many waters, despite having been stocked for over 90 years. In order to preserve "the integrity of existing trout populations" it is recommended that any further importation of trout into Western Australia should continue to be discouraged in order to minimise the risk of introducing pathogens. Although trout are released to enhance the recreational fishery in specific areas of the south-west of the State, stocking is not now widespread because of conservation concerns.

The introduction of aquatic species for the aquaculture industry is strictly controlled. All interstate translocations of aquatic organisms for aquaculture purposes currently require health certification to prevent the introduction of disease.

5.8 Queensland

Salmonids are not a significant component of the Queensland fish fauna and their impact in that State is negligible. However, it is worth mentioning that a comprehensive policy for the translocation of freshwater fish in Queensland is currently being developed, which incorporates both decision making protocols and disease risk assessment protocols (P. D. Jackson, Department of Primary Industries, Queensland - pers. comm.).

5.9 Future Directions

Historically, in Australia the value of salmonids as sport-fish and, later, as aquaculture species has overshadowed consideration of their effects on native fauna and, in general, legislation to safeguard native fauna from the impacts of salmonids has been lacking. Given the more enlightened public attitudes of recent years and the adoption by, fisheries management agencies of the principles of ecologically sustainable development, incorporating the maintenance of biodiversity, it is time for the various agencies responsible for salmonid management to re-assess their attitudes towards the- adverse impacts of salmonids and to take a more pro-active approach to protecting native fauna.

It is not good enough to say that no new waters will be stocked with salmonids when every inland fisheries manager in Australia knows that almost every water which was thought to have been suitable for the survival of salmonids has already been stocked with them! What is required is a more positive - approach in setting aside waters or catchments specifically for the management of native fauna and: from which salmonidsare excluded and, if necessary, removed. The Victorian *Flora* and :Fauna *Guarantee Act 1988* is a good model for providing the legislative framework for such an approach. The approach is not one of trying to turn back the clock to a time when there were no salmonids in Australia, but to recognise that as well as providing substantial recreational and economic benefits, salmonids do have an adverse impact on Australia's aquatic fauna and that this fauna must be protected. Currently, this protection is most needed in Tasmania.

Within a strategic framework for the management of fisheries and-aquatic fauna, it is possible to accommodate salmonid fisheries as well as the conservation of native fauna. For example, recognising the need to balance the various demands being made on the aquatic environment and the resources it supports and at the same time ensuring that all such demands are ecologically sustainable, a proposal has been developed for a Victoria-wide strategic plan to accommodate the conflicting demands of conservation, recreational fishing and aquaculture (Cadwallader 1992). Within the strategic framework, it is proposed that some water bodies or catchments would be managed primarily for the protection or rehabilitation of threatened fish species and other aquatic organisms and for the maintenance of aquatic habitats and their communities in a natural or undisturbed state. Other water bodies or catchments would be managed primarily for recreational fishing in its various forms, and yet others would be managed for commercial fishing, including aquaculture. There is a need for such an approach to be adopted more widely in order to ensure the survival of native fauna at the same time as enabling the continuation of the enjoyment of salmonids as fine sport-fish.

6. CONCLUSIONS AND RECOMMENDATIONS

1. There have been few studies on the impacts of salmonids on fauna other than fish and, considering the families of fish which occur in areas in which trout have been introduced in Australia, including estuarine as well as freshwater habitats, the studies cover a relatively small part of the native fish fauna.
2. The most substantive evidence of impacts of salmonids in Australia comes from Fletcher' s (1979) experimental introduction study and from observations such as those of Tilzey (1976), Raadik (1993) and Closs and Lake (in prep) during the invasion of trout into new areas.
3. With few exceptions, much of the information on the distribution of salmonids and native fish is derived from general fish surveys not specifically designed to investigate the effects of salmonids on particular species or aquatic communities.
4. Taken together, the numerous and widespread instances of fragmented galaxiid distribution patterns in the presence of trout, the more widespread distribution of these galaxiids in the absence of trout, and the observations of fragmentation of the galaxiid distribution pattern as trout progressively move upstream, provides a substantial body of evidence for an adverse impact of trout on these stream-dwelling galaxiids.
5. Studies on the mechanisms by which salmonids have had an impact on the native fauna are sparse, but nevertheless indicate that predation has been the major cause of the impact.
6. Studies on the interactions between juvenile salmonids and native fauna indicate that direct competitive encounters may occur between juvenile salmonids and those species which occupy the same microhabitat and feed in the same manner on, the same foods. Conversely, those native species which, because of their particular life histories and habitat requirements are able to avoid direct encounters are likely to be able to co-exist with salmonids.
7. The impact of salmonids on native fauna via the spread of pathogens, particularly via the widespread releases of hatchery-produced fish, is unknown. However, the occurrence of pathogens in salmonid hatchery stocks indicates that salmonids have undoubtedly played a major role in the spread of these disease organisms, irrespective of whether or not the pathogens were introduced into Australia with the salmonids.
8. Future studies of the distributions of salmonids and native species in Australia should adopt the approach taken by Townsend and Crowl (1991). Their statistical analyses incorporating various physical, chemical and biological variables from a large number of sampling sites indicated that the presence and abundance of a particular species were best predicted by the presence or absence of trout rather than by any of a wide range of other possible variables. Their study was specifically designed to test the hypothesis that the occurrence of a particular native species was affected by the presence of brown trout. This sort of approach is much more useful than merely recording the absence of native species in the presence of salmonids because it provides information on the likely cause of the observed distribution patterns of the native species which presence/ absence studies do not provide.

9. Introduction experiments in the field provide the most convincing evidence of an impact of salmonids on native fish.
10. Introduction experiments in nature imply setting up the experiment in an area in which trout have not previously occurred. In situations where evidence of impact is being sought for threatened species it may be inappropriate to introduce trout into an area which they had not previously occupied. In such circumstances, one approach would be to monitor the aquatic community in a stretch of stream in which trout occur, then remove the trout downstream to a natural or artificial barrier and monitor the subsequent changes in the aquatic community.
11. Data from Renowden's (1968) study on the distribution of galaxiids and trout in pools in a small stream indicate the relatively small numbers of fish likely to be encountered in field studies of the impact of salmonids on native fauna. Such small numbers do not detract from the value of the observations because, at the field level, elimination of one species by another ultimately involves interactions between individuals. However, observations involving such small numbers of individuals highlight the need for replication of experiments or several sets of observations of similar events to build up a convincing body of evidence.
12. The use of artificial stream channels to investigate interactions between salmonids and native fish or between salmonids and native macroinvertebrates has great potential.
13. The most difficult area in which to investigate the impact of salmonids is that of fish disease, primarily because most of the damage in spreading pathogens has probably already been done and because other species, in addition to salmonids, may also be involved in the spread of particular disease organisms.
14. Salmonids, -mainly brown trout, are . implicated in the demise of ten of the fish species classified as threatened by the Australian Society for Fish Biology. Of these species, five are galaxiids, two are nannopercids (pygmy perches), two are percichthyids (trout cod and Macquarie perch), and one is a prototroctid (Australian grayling). The effect of trout on the percichthyids still requires clarification, but priority should be given to research on the threatened galaxiids, for which the impact of trout is thought to be the-primary threatening process, the pygmy perches for which there is little information on what caused their demise, and the Australian grayling.
15. The impact of trout on macroinvertebrates and aquatic vertebrates other than fish has been largely ignored and requires urgent assessment. It is likely that introduced trout have had a substantial impact on the structure of faunal communities in fresh waters, throughout the cooler parts of Australia.
16. In Tasmania, recovery plans are being implemented for Galaxias pedderensis, *G.* fontanus, *G,* johnstoni, and *G.* tanycephalus. The speed with which the decline in abundance of *G.* pedderensis occurred highlights the need for routine fish survey work in order to recognise declines before they become irreversible.
17. It is recommended that reserves for all Tasmanian galaxiids be established.
18. In Victoria, a recovery plan for *Galaxias fuscus is* being implemented. The program involves the building of trout exclusion structures to determine their effectiveness in preventing trout access to galaxiid populations and to assess whether the *G. fuscus* populations will increase following trout eradication.
19. The value of salmonids as sport-fish and as aquaculture species in Australia has overshadowed consideration of their effects on native fauna and, in general, legislation to safeguard native fauna from the impacts of salmonids has been - lacking.

20. It is recommended that the various agencies responsible for salmonid management re-assess their attitudes towards the adverse impacts of salmonids and take a more pro-active approach to protecting native fauna.
21. It is recommended that waters or catchments be set aside specifically for the management of native fauna and from which salmonids are excluded or, if necessary, removed. The *Victorian* Flora and Fauna Guarantee Act *1988* is a good model for providing the legislative framework for such an approach. The approach is not one of trying to turn back the clock to a time when there were no salmonids in Australia, but to recognise that as well as providing substantial recreational and economic benefits, salmonids have an adverse impact on Australia's aquatic fauna and that this fauna must be protected. Currently, this protection is most needed in Tasmania.
22. Within a strategic framework for the management of fisheries and aquatic fauna, it is possible to accommodate salmonid fisheries as well as provide for the conservation of native fauna. There is a need for such an approach to be adopted more widely in Australia.

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