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A Review of Exotic Marine Organisms Introduced to the Australian Region. I. Fishes

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Abstract

The occurrence of exotic marine fishes introduced to the Australian region is reviewed, with particular emphasis being placed on those species which might have significant ecological impact on endemic biota and/or their habitats or on fisheries in this region. All marine and estuarine fishes known or thought to have been introduced, either deliberately or accidentally, are considered, together with their probable areas of origin, probable dates and means of introduction, and their present areas of occurrence. General comments on relevant aspects of their biology and status, as appropriate, are made. Those species which might have significant ecological impacts are discussed in more detail, probable pathways for their introduction (particularly ships' ballast water) discussed, and some recommendations made regarding their future control.

Introduction

Until relatively recently, few reports have appeared on introduced marine fishes which might have significant ecological impacts on endemic fauna and habitats in the Australian region.

In contrast, general reviews which have discussed the introduction of exotic freshwater fishes and their possible ecological effects include those of Whitley (1951), Pollard and Scott (1966), Weatherley and Lake (1967), Lake (1971), Tilzey (1980), McKay (1984), Fletcher (1986), Pollard and Burchmore (1986), Arthington

(1989) and McKay (1989) for Australia; and McDowall (1968, 1978, 1984) and West and Glucksman (1976) for New Zealand and Papua New Guinea, respectively.

With regard to exotic marine organisms in general, Williams et al. (1978) listed 20 such species (including two fishes) which had apparently been introduced to Australian waters. Carlton (1985), in his worldwide review of marine introductions attributed to the discharge of ships' ballast water, also listed a number of marine organisms which were though to have been introduced to Australian waters by this means. Carlton (1987) subsequently identified 14 major routes of transoceanic dispersal of introduced species in the Pacific, and listed Australia as one of the major receiver areas. The most recent and comprehensive listing of introduced marine organisms in Australia (which, however, made only brief mention of fishes) was that by Hutchings et al. (1987).

The present paper assesses the extent of both deliberate and accidental introductions of fishes to marine and estuarine waters in the Australian region, with particular emphasis being placed on those species which might have significant impacts on native marine fauna and habitats, or on fisheries, in this region. The probable pathways by which these introduced marine fishes may have entered Australian waters are then discussed and some recommendations made regarding their future control. A second paper in this series (Pollard and Hutchings, this vol.) reviews the occurrence of exotic marine invertebrates and algae from the same perspectives.

Introduced Marine Fishes

Table 1 lists those species of exotic marine fishes known or claimed to have been introduced to Australian waters. This table includes notes on their probable areas of origin, probable dates and means of introduction, and their present areas of occurrence within Australia. Those species which could have significant ecological impacts are discussed in more detail below.

Gobiids

The yellowfin goby Acanthogobius flavimanus

The yellowfin goby, or "mahaze", is native to brackish estuarine and sheltered inshore coastal waters of Japan and the adjacent

Table 1. List of exotic marine fishes introduced to Australia.

Species	Possible origin of introduction	Possible date of intro-duction	Probable means of intro-duction	Locations within Australia	References
Acanthogobius flavimanus (Temminck & Schlegel)	Japan	1971	B*	NSW	Hoese 1973; Middleton 1982; Bell et al. 1987
Tridentiger trigonocephalus (Gill)	Japan	1973	B*	NSW WA, Vic	Hoese 1973 Paxton and Hoese 1985
Lateolabrax japonicus (Cuvier	Japan	1982	B*	NSW	Paxton and Hoese 1985
Sparidentex hasta (Valenciennes)	Arabian Sea (west coast of India) and Persian Gulf	1985	B*	WA	Bodeker 1985; Harvey and Beard 1985; Anon. 1985
Salmo trutta Linnaeus	United Kingdom	1864	D**	Tas, NSW, Vic, SA, WA	Merrick and Schmida 1984
Salmo salar Linnaeus	Northeastern America	1963	D**	NSW, Tas	Merrick and Schmida 1984
Oncorhynchus mykiss (Walbaum)	Northwestern America (via New Zealand)	1894	D**	NSW, Tas, Vic, WA, SA	Merrick and Schmida 1984
Oncorhynchus tshawytscha (Walbaum)	Northwestern America	1966	D**	Vic	Merrick and Schmida 1984

*B = Ballast water.
**D = Deliberate.

mainland of northeastern Asia, including northern China, the Korean peninsula and southeastern USSR (Matsuda et al. 1984). In Japan this species is abundant and important as both an angling and a food fish (Okada 1955). Details of its life history and biology in Japan are outlined by Miyazaki (1940) and Dotu and Mito (1955).

Brittan et al. (1963) were the first to record the introduction of the yellowfin goby to the San Francisco Bay area, California, USA. The first small specimens were found in 1966, indicating a self-reproducing population, and in 1967 over half of the 10,000 or so fish found following a fish kill in a freshwater reservoir in this area belonged to this species. Although it probably arrived in California no earlier than 1960, the yellowfin goby had "explosively" spread to occupy most suitable habitats in the San Francisco Bay - Delta area within only 6 or 7 years of its arrival (Brittan et al. 1970; Miller and Lea 1972). It was also subsequently recorded from the Los Angeles area in 1977-78 (Haaker 1979), and Courtenay et al. (1984) have more recently reported it as occurring as far south in California as San Diego, and perhaps into Mexico.

Notes on the biology of this species in California by Brittan et al. (1970) and Baker (1975) indicate that it breeds there between January and March, as it does at similar latitudes in Japan (Dotu and Mito 1955).

As in Japan, this species was found to be capable of penetrating mud-bottomed lowland rivers to their freshwater reaches in California, although it was mainly collected in brackishwater habitats. It was also often found in highly disturbed (e.g., channelized stream) habitats which had silt and sand substrates and little aquatic vegetation (Leidy 1984).

Moyle (1976) summarized the status of the yellowfin goby in California as follows: "Yellowfin goby populations in California have exploded since they were first noticed in 1963. They are now one of the most abundant bottom fishes in San Francisco Bay and the Delta, and are still increasing their range. What effect this population explosion will have on native freshwater and estuarine fishes is not known, but freshwater populations of the small tidewater goby *[Eucyclogobius newberryi]* might be in some danger of being eliminated through competition."

In Australia, the yellowfin goby was first recorded from Dawes Point in Sydney Harbor in June 1971, though by 1973 it was reported to be "common throughout Sydney Harbor" (Hoese 1973). Hoese suggested that this species "appears to be undergoing a similar radiation (to that observed in the San Francisco area) in Sydney Harbor and is expected to spread to adjacent areas." He also suggested that it may compete with *Arenigobius bifrenatus* or juvenile whiting (*Sillago* spp.) of similar size in this area.

During the eight years following Hoese's (1973) initial report, over 100 additional specimens of yellowfin goby were collected from two major port estuaries in the Sydney metropolitan area. The majority of these specimens were obtained by New South Wales (NSW) Fisheries staff during surveys carried out in both Sydney Harbor (between 1973 and 1981) and Botany Bay, about 20 km to the south (between 1978 and 1980). Specimens were obtained over muddy (mainly) and sandy substrates at depths of 0-14 m, where salinities ranged from 27 to 35 ppt and temperatures from 12 to 27°C (Middleton 1982). These fish ranged from ~40 mm total length (TL) (0+ age class fish) to 240 mm (2+ fish), with the modal length group being around 130 mm (1+ fish). Although the numbers of fish caught fluctuated widely during this period, the occurrence in the samples of both reproductively maturing females (particularly between June and August) and juveniles suggested successful breeding, with good recruitment in 1977 leading to a strong year class in 1978 (Middleton 1982).

In comparison with the San Francisco Bay area, the numbers of yellowfin gobies collected in the Sydney area up to 1981 were relatively small and Middleton (1982) concluded that there had been no similar population "explosion" in the Sydney area. She attributed this to the inhibition of reproduction due to the relatively warm water temperatures in this latter area combined with possible potential competition with native species such as other gobiids, sillaginids, bothids and platycephalids in these estuaries.

Other recent records from upper Sydney Harbor include the collection there by trawling of running ripe fish by P. Gibbs (pers. comm.; in Bell et al. 1987), and the collection and underwater observation of many adult fish in Rozelle Bay in 1986 and 1987 by M. Lincoln-Smith (pers. comm.). A single specimen has also been recorded from Port Kembla Harbor, about 90 km to the south of Sydney (R. Talbot, pers. comm.), and two specimens reported from the Hunter River near the major port city of Newcastle, 120 km to the north of Sydney, in response to a poster circulated to NSW commercial fishermen (Middleton 1982).

More recently, numerous juvenile and adult fish have also been collected from the Hawkesbury River (which is not a port for oceangoing vessels), located 30 km to the north of Sydney (Bell et al. 1987). Adult fish have also been collected in freshwater up to the limits of tidal influence in this system (J. Harris, pers. comm.). These data, taken together, indicate that *A. flavimanus* is now reproducing successfully in the Hawkesbury River system.

Although *A. flavimanus* probably arrived in the ports of Sydney Harbor, Botany Bay, the Hunter River and Port Kembla in the ballast water of ships from Japan, its spread to the Hawkesbury River system may have been by larval dispersal from Sydney Harbor and or in the outlet pipes of pleasure craft which regularly move between these two estuaries (Bell et al. 1987).

The striped goby Tridentiger trigonocephalus

A second species of oriental goby, the striped goby *Tridentiger trigonocephalus*, has also colonized restricted areas in the coastal waters of both California and Australia. This species, also known as the chameleon goby and in Japan as "shimahaze", generally inhabits the rocky shores of bays, not only throughout Japan but also in eastern China, the Korean peninsula and southeastern USSR (Fowler 1961). Aspects of the reproductive biology and life history of the striped goby in Japan have been described by Dotu (1958) and Hirose and Kubo (1983).

The first record of this species occurring in California was from Los Angeles Harbor in 1960 (Hubbs and Miller 1965). It was later recorded from San Francisco Bay in 1966, several years after the first records of *A. flavimanus* from the same area. Although it was only recorded from two localities in this latter area, Brittan et al. (1970) assumed it to be "firmly established". Numerous mature adult striped gobies, together with clutches of their eggs, were also collected from Los Angeles Harbor in 1977 (Haaker 1979).

The first specimen of this species collected in Australian waters was found among seagrass growing on a silty-sand substrate in Sydney Harbor in May 1973. This, and a second specimen taken from this area soon after, were collected together with a variety of common native gobiids from the same habitat (Friese 1973). Specimens were subsequently collected from the Swan River estuary near Perth and the port of Fremantle (Chubb et al. 1979), as well as from Cockburn Sound to the south (both localities in southwestern Western Australia), and also from two localities in Port Philip Bay near Melbourne, Victoria (Paxton and Hoese 1985).

More recent collections of this species have been made in Rozelle Bay (Sydney Harbor) by M. Lincoln-Smith (pers. comm.), who observed densities on a rocky substrate among the piles along the length of a timber berth to be 2-3 individuals per 10 m^2 during visual diving surveys. This same area was subsequently sampled, using rotenone ichthyocide, by R. Talbot (pers. comm.), who found actual densities on this rocky substrate to be over an order of magnitude higher than the above visual estimates. Sampling of a similar habitat under a coal loader berth in Port Kembla Harbor revealed similar densities of this species, which made up the highest biomasses in the fish samples collected from both of the above localities (R. Talbot, pers. comm.). As in the case of *A. flavimanus,* the most likely origin of *T. trigonocephalus* in Australian waters is via ballast water carried by ships from Japan, though Hubbs and Miller (1965) suggested that its initial introduction into San Francisco Bay may have been as fertilized eggs on the introduced Japanese oyster *Crassostrea gigas*.

Percichthyiids and Sparids

The Japanese sea bass Lateolabrax japonicus

The Japanese sea bass, or "suzuki", is a percichthyid fish found in the inshore coastal waters of Japan, Korea, Taiwan and China as far south as Hong Kong (Katayama 1960; Chan 1968). This species is a valuable food fish in both Japan and China and grows to a length of approximately one meter (Okada 1955, 1960).

It is catadromous, undergoing a spawning migration to brackishwater during autumn and winter. The young fish ascend rivers and remain upstream during spring and summer, after which they move downstream to saltwater habitats in autumn, where they remain during winter. Adults mature at lengths of around 60 cm and ages of 3 to 4 years (Okada 1960; Chan 1968). The Japanese sea bass is fished commercially using gill nets and hook and line, and is also raised in ponds after being captured near estuaries during its spring migration back to freshwater (Okada 1960).

Two adult Japanese sea bass have been collected to date from estuaries in the vicinity of Sydney. The first (of standard length (SL) 370 mm) was captured in Pittwater (Broken Bay - Hawkesbury River system, 30 km to the north of Sydney) in April 1982, and the second (397 mm SL) in Botany Bay in October 1983. Both specimens were from commercial catches delivered to the Sydney fish markets. The lengths of these two specimens and the probable growth rates for the species (Chan 1968; Hayashi 1972) suggested that if they arrived in Sydney as larvae via ships' ballast water from Japan, which was considered their most likely origin, this may have occurred as early as 1980, and perhaps at the same time (Paxton and Hoese 1985).

The stomachs of both specimens contained fish remains, but their gonads were undeveloped. Paxton and Hoese (1985) suggested that if this species did manage to establish a self-reproducing population around Sydney, it could spread both further north and south along the coastline, considering its broad latitudinal distribution in the northern hemisphere (≈23-43°N).

Paxton and Hoese (1985) concluded that "the establishment of such a large carnivore as the Japanese sea bass could have a major influence on a large number of native species, perhaps even some economically important species," and "while some may applaud the introduction of a potentially important commercial fish, such introductions should only be considered after exhaustive experiments to test the ecological results."

The Sobaity sea bream Sparidentex hasta

The sobaity sea bream is a sparid fish found in inshore waters of the Arabian Sea, from the west coast of India and north-westwards into the Persian Gulf. To date only a single specimen has been reported from Australia, caught by an angler in the Swan River near Perth, Western Australia. Although this fish weighed about 3 kg, which was near the maximum size recorded for the species, it was suggested that it most probably arrived in Fremantle Harbor at a very small size in the ballast water of a freighter carrying live sheep to the Persian Gulf (Harvey and Beard 1985).

Salmonids

Although most members of the family Salmonidae are popularly considered to be "freshwater" fishes, a number of species (notably in the genera *Salmo* and *Oncorhynchus*) are either primarily anadromous, or at least include sea-run populations, within their cool-temperate northern hemisphere distributions (McDowall 1978).

Four species belonging to the above two genera have been deliberately introduced into Australian waters for recreational angling purposes.

Of these, the brown trout *(Salmo trutta),* which occurs naturally in Europe and western Asia, was introduced from the UK to Tasmania in 1864 (as fertilized ova) and from there to both mainland Australia and New Zealand. The rainbow trout *(Oncorhynchus mykiss),* which occurs naturally in western North America, was introduced to both Tasmania and several mainland states from New Zealand, where it had previously been introduced, in 1894 (Roughley 1957). After several early attempts to introduce it (e.g., from the UK to Tasmania in 1866 and 1884), the Atlantic salmon *(Salmo salar),* which occurs naturally on both sides of the North Atlantic Ocean, in both Europe and northeastern North America, was introduced to NSW from North America in 1963 (Merrick and Schmida 1984). The quinnat salmon *(Oncorhynchus tshawytscha),* which occurs naturally in northwestern North America, was introduced to Victoria from Oregon, USA, in 1966 (Hames 1988).

Although the two trout species have formed self-reproducing populations in a number of suitable areas, many populations of these two, and all existing populations of the two salmon species, must be artificially replenished by means of hatchery production and stocking (Merrick and Schmida 1984).

Of the above four, the only species which includes significant naturally reproducing sea-run populations in Australian waters is the brown trout, which occurs commonly in inshore coastal and estuarine waters in Tasmania (Sloane 1983), and occasionally also in Victoria. Although Australian stocks of rainbow trout and Atlantic salmon have been previously restricted to freshwater habitats, in recent years both of these species have been successfully farmed in the sea around the coastline of Tasmania.

Sea-farm production of Atlantic salmon from Tasmania is projected to reach about 3,000 t per annum by 1990 and that of rainbow trout around 2,000 t (Gjovik 1988). Salmon farming operations are now also commencing in Western Australia and Victoria (O'Sullivan 1988) and experiments with on-land circulating saltwater tank culture are currently being carried out in southern Queensland (Ahnlund 1988).

Although the culture of the Pacific quinnat salmon in Australia so far has been restricted to freshwater hatchery-stocking operations, and no sea-run populations currently exist, saltwater farming experiments using this species are currently being carried out (initially in on-land tanks) in Victoria (Hames 1988). In New Zealand, however, where this species includes substantial sea-run populations, it is not only farmed in both freshwater ponds and sea pens, but the sea-run stocks are also "ranched" (i.e., harvested on their return to their place of artificial spawning and initial release) off the east coast of the South Island. These sea-run fish have also provided a significant by-catch (about 20,000 fish in 1986/87) during ocean trawling operations aimed at red cod and barracouta in this area (Field-Dodgson 1988).

The environmental impacts of sea-cage salmonid farming (e.g., eutrophication problems and algal blooms resulting from excess nutrient inputs in the vicinity of sea farms) are currently being studied in New Zealand (Kaspar 1988), and also presently being considered in relation to the developing industry in Tasmania (Woodward 1989). The latter author notes that the experience of overseas fish farms can serve as a guide to the many problems that we might expect in Australia in the absence of effective management, and quotes Warrer-Hansen (1982) as listing some of the problems which have occurred in Denmark.

Discussion

Deliberate Introductions

Within the literature there are numerous well documented cases of deliberate introductions of exotic organisms into the marine environment in various parts of the world, many of these being of commercially important species.

With specific regard to fish, apart from the four species of salmonids discussed in some detail above, all of which, from overseas evidence, have at least the potential to form significant sea-run populations, each of the remaining exotic marine and estuarine fish species discussed appear to have been accidentally introduced into Australian waters. Although unsuccessful attempts were made by E. Dannevig to introduce several species of commercially important marine flatfishes (Pleuronectiformes) from Europe to NSW in the early 1900s, it would appear that such deliberate introductions of truly marine fishes have been relatively rare, even on a worldwide basis.

One area, however, where a number of such attempts have been made (some successfully) is Hawaii. Introductions of exotic marine fishes judged at the time to be of potential economic value to fisheries in the relatively "depauperate" coastal waters around Hawaii have been discussed by Brock (1960), Randall (1960), Kanayama (1968), Randall and Kanayama (1972), Maciolek (1984), and most recently by Randall (1987).

Randall (1987) records 21 species of saltwater and brackishwater fishes (of the families Cyprinodontidae, Poeciliidae, Percichthyidae, Plecoglossidae, Salmonidae, Engraulidae, Cichlidae, Clupeidae, Serranidae, Lutjanidae, Kuhliidae and Lethrinidae) which have been introduced into Hawaiian waters for either mosquito control, tuna bait or commercial and sport fishing purposes. An additional three species (a mugilid, a mullid and a clupeid), which have since become established, were also introduced inadvertently together with the above. Of those deliberately introduced, Randall (1987) noted that only seven species (of the families Poeciliidae, Cichlidae, Clupeidae, Serranidae and Lutjanidae) have established breeding populations.

Randall concludes as follows: "None of these introduced fishes have fully attained what was expected of them, and all have been criticized for one negative attribute or another.

"Of the seven exotic species deliberately established and the six species which arrived in Hawaii unplanned, four, *Lutjanus kasmira, Valamugil engeli,* and the two tilapias, are regarded as unfortunate introductions".

"This should serve as a warning that further introductions of fishes to the Hawaiian Islands should, in general, be discouraged. Fortunately, since 1952, there has been an Advisory Committee on Aquatic Biota (on which the author serves) which carefully screens all applications to import live exotic fishes and other aquatic animals to Hawaii for the State's Department of Agriculture. Some of the applications have been denied to safeguard against potential ecological disasters in Hawaii's aquatic environment" (Randall 1987).

Also fortunately, Australia has its own Advisory Committee on Live Fish (answerable to the Standing Committee on Fisheries), which performs a similar function in screening and advising on all proposed introductions of aquatic organisms to Australian waters (O'Connor 1990). Although a number of applications have been made (and refused) for the importation of commercially important marine invertebrates (particularly molluscs and crustaceans), no applications have yet been considered for the introduction of marine fishes for sport or food purposes.

In contrast to the position with marine food and sport fishes, a wide variety of marine aquarium fishes is regularly imported into this country, and the above Advisory Committee is currently reviewing the possible threats to Australian native species and the natural environment which might be posed by this trade.

The marine aquarium fish trade in Australia has been recently reviewed and discussed by Kailola (1985). Fish for this trade are obtained from northern Australia (mainly Queensland), from other tropical Indo-West Pacific waters, or (rarely) from Hawaii, the Caribbean Sea or the Red Sea and Mediterranean Sea areas. Most of the marine aquarium fish sold in Australia are collected in Australian waters, and overall about 90% are collected from the Indo-West Pacific area in general. As pointed out by Kailola (1985), except for a handful of species, identical varieties of marine aquarium fish can be collected in Australian waters as in other Indo-West Pacific seas. Kailola (1985) also noted that: "It seems that a fish is much more likely to die in its aquarium before its owner tires of it to the point where he will willingly dump it (rarely "them") in the sea! Hardy well-kept fishes have a capable owner who probably paid high prices (if imported/transhipped) for these living ornaments and from him also, the dumping risk is negligible."

The Advisory Committee on Live Fish, in considering the whole question of marine aquarium fish imports, is currently aiming at identifying criteria on which an acceptable list of species posing minimal environmental risks can be based.

On the advice of the above Advisory Committee, the Australian National Parks and Wildlife Service regulates and controls the importation to Australia of all living aquatic organisms, including marine fishes, through the Wildlife Protection (Regulation of Exports and Imports) Act 1982 (Michaelis 1990).

Accidental Introductions

Apart from deliberate introductions, and accidental ones known or thought to be associated with them (e.g., Randall 1987), rumors of deliberate "plantings" and other quarantine improprieties can also be found in the literature, e.g., in Springer and Gomon (1975, p. 61) for marine, and McKay (1984, p. 181 and 190) and McDowall (1984, p. 206) for freshwater species.

More recently, ballast water has been frequently suggested as a probable vector of introduced marine organisms. Studies both in Australia and overseas have shown that ballast water contains live marine organisms, often represented by larval or juvenile stages (Williams et al. 1988). It has been suggested that these organisms may survive after being discharged with the ballast water and then settle, reach maturity, breed and establish populations near the discharge point. These populations may subsequently colonize nearby areas and gradually extend their distributions. It is very difficult, however, to prove conclusively that a species has been introduced in this way, for it may be several years before a population becomes large enough to be recognized and reported in the literature.

With specific regard to fish, however, in addition to the four exotic species discussed in some detail above as apparently having arrived in Australia (and two of them also in California) by means of ships' ballast water, seven additional species are listed by Carlton (1985) as probably having been transported by this means to other parts of the world. Williams et al. (1988) have also since found two additional fish species (a cosmopolitan tropical Indo-Pacific theraponid and a tropical Indo-Pacific eleotrid) in the ballast water of a Japanese woodchip vessel in the port of Eden (southern NSW).

In Australia, Hoese (1973) and Friese (1973) were probably the first to warn of the dangers of such fish introductions via ballast water, though Grainger (1973) also reported on this subject. The study by Williams et al. (1982), however, increased the awareness in the scientific community of the potential problems associated with the discharge of ballast water into Australian ports. This study also recommended the treatment of ballast water to reduce this problem of introducing exotic species. Further public and scientific interest was aroused with the discovery of more marine fish introductions, and this has been reflected in the popular articles of Parr (1984, 1985), Anon. (1985), Bodeker (1985) and Harvey and Beard (1985). Paxton and Hoese (1985) have also subsequently echoed the call of Williams et al. (1982) for sterilization of ballast waters to ensure that future harmful introductions do not occur.

Further discussion of ballast water as a significant vector for marine introductions, and also possible future control measures, is included in the second paper in this series (Pollard and Hutchings, this vol.) which reviews the occurrence of exotic marine invertebrates and algae in Australian waters.

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References

Ahnlund, H. 1988. Salmon farming in the tropics. Austasia Aquacult. 2(7): 8.

Anon. 1985. Ballast water hides unwanted immigrants. Aust. Fish. 44(9): 38.

Arthington, A.H. 1989. Impacts of introduced and translocated freshwater fishes in Australia, p. 7-20. *In* S.S. De Silva (ed.) Proceedings of the workshop on introduction of exotic aquatic organisms in Asia. Asian Fisheries Society, Manila, Special Publication No. 3.

Baker, J.C. 1975. A contribution to the life history of the yellowfin goby *(Acanthogobius flavimanus)* in the San Francisco Bay - Delta area. California State University, Sacramento, California. M.Sc. thesis. 37 p.

Bell, J.D., A.S. Steffe and R.B. Talbot. 1987. The oriental goby, *Acanthogobius flavimanus,* colonizes a third estuary in New Couth Wales. Japan. J. Ichthyol. 34(2): 227-230.

Bodeker, P. 1985. Fishy story that could keep growing. Daily News (Perth, Western Australia), 30 April, p. 14.

Brittan, M.R., A.B. Albrecht and J.D. Hopkirk. 1963. An oriental goby collected in the San Joaquin River Delta near Stockton, California. Calif. Fish Game 40(4): 302-304.

Brittan, M.R., J.D. Hopkirk, J.D. Connors and M. Martin. 1970. Explosive spread of the oriental goby *Acanthogobius flavimanus* in the San Francisco Bay - Delta region of California. Proc. Calif. Acad. Sci. 38(11): 207-214.

Brock, V.E. 1960. The introduction of aquatic animals into Hawaiian waters. Int. Rev. Ges. Hydrobiol. 45: 463-480.

Carlton, J.T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Ann. Rev. Oceanogr. Mar. Biol. 23: 313-371.

Carlton, J.T. 1987. Patterns of transoceanic marine biological invasions in the Pacific Ocean. Bull. Mar. Sci. 41(2): 452-465.

Chan, W.L. 1968. Marine fishes of Hong Kong, Part 1. Government Press, Hong Kong, 129 p.

Chubb, C.F., J.B. Hutchins, R.C.J. Lenanton and I.C. Potter. 1979. An annotated checklist of the fishes of the Swan-Avon River System, Western Australia. Rec. Western Aust. Mus. 8: 1-55.

Courtenay, W.R., Jr., D.A. Hensley, J.N. Taylor and J.A. McCann. 1984. Distribution of exotic fishes in the Continental United States, p. 41-77. *In* W.A. Courtenay, Jr. and J.R. Stauffer, Jr. (eds.) Distribution, biology and management of exotic fishes. Johns Hopkins University Press, Baltimore.

Dotu, Y. and S. Mito. 1955. On the breeding habits, larvae and young of a goby *Acanthogobius flavimanus* (Temminck and Schlegel). Japan. J. Ichthyol. 4(4-6): 153-161.

Dotu, Y. 1958. The bionomics and life history of two gobiid fishes *Tridentiger undicervicus* Tomiyama and *Tridentiger trigonocephalus* (Gill) in the innermost part of Ariake Sound. Sci. Bull. Fac. Agric. Kyushu Univ. 16(3): 343-358.

Field-Dodgson, M.S. 1988. Development of salmon fishing in New Zealand. Austasia Aquacult. 2(7): 9-10, 13.

Fletcher, A.R. 1986. Effects of introduced fish in Australia, p. 231-238. *In* P. De Deckker and W.D. Williams (eds.) Limnology in Australia. C.S.I.R.O. Melbourne, and Junk, Dordrecht.

Fowler, H.W. 1961. A synopsis of the fishes of China. Part IX. The gobioid fishes. Q. J. Taiwan Mus. 14: 203-250.

Friese, U. 1973. Another Japanese goby in Australian waters: what next? Koolewong 2(3): 5-7.

Gjovik, J. 1988. Marine farming of salmon and trout in Tasmania. Austasia Aquacult. 2(7): 4-5.

Grainger, R. 1973. The problem of the stowaway organisms. Fisherman 4(7): 13.

Haaker, P.C. 1979. Two Asiatic gobiid fishes, *Tridentiger trigonocephalus* and *Acanthogobius flavimanus*, in southern California. Bull. South. Calif. Acad. Sci. 78(1): 56-61.

Hames, F. 1988. Chinook salmon developments in Victoria. Austasia Aquacult. 2(7): 5-6.

Harvey, H. and I. Beard. 1985. Bilgewater bream breaks quarantine. Modern Fishing, June, p. 28.

Hayashi, I. 1972. On the ovarian maturation of the Japanese sea bass *Lateolabrax japonicus*. Jap. J. Ichthyol. 19(4): 243-254.

Hirose, K. and T. Kubo. 1983. Gonadal maturation and spawning of striped tripletooth goby, *Tridentiger trigonocephalus*. Bull. Tokai Reg. Fish. Res. Lab. 112 : 49-65.

Hoese, D.F. 1973. The introduction of the gobiid fishes *Acanthogobius flavimanus* and *Tridentiger trigonocephalus* into Australia. Koolewong 2(3): 3-5.

Hubbs, C.L. and R.R. Miller. 1965. Studies of cyprinodont fishes. Part 22. Variation in *Lucania parva*, its establishment in western United States, and a description of a new species from an interior basin in Coahuila, Mexico. Misc. Publ. Mus. Zool. Univ. Mich. 127 : 1-111.

Hutchings, P.A., J.T. van der, Velde and S.J. Keable. 1987. Guidelines for the conduct of surveys for detecting introductions of non-indigenous marine species by ballast water and other vectors, and a review of marine introductions to Australia. Occas. Rep. Aust. Mus. Sydney No. 3. 147 p.

Kailola, P.J. 1985. The marine aquarium fish industry in Australia. Report to Australian National Parks and Wildlife Service, Canberra.

Kanayama, R.K. 1968 Hawaii's aquatic animal introductions, p. 123-131. *In* Proceedings of the annual conference of the Western Association of State Game and Fish Commissions No. 47.

Katayama, M. 1960. Fauna Japonica, Serranidae (Pisces). Biogeographical Society of Japan, Tokyo. 189 p.

Kaspar, H. 1988. Environmental impacts of sea cage salmon farming. Catch (M.A.F., New Zealand) 15(5): 17-18.

Lake, J.S. 1971. Freshwater fishes and rivers of Australia. Nelson, Sydney. 61 p.

Leidy, R.A. 1984. Distribution and ecology of stream fishes in the San Francisco Bay drainage. Hildgardia 52(8): 1-175.

Maciolek, J.A. 1984. Exotic fishes in Hawaii and other islands of Oceania, p. 131-161. *In* W.R. Courtenay, Jr. and J.R. Stauffer, Jr. (eds.) Distribution, biology and management of exotic fishes. Johns Hopkins University Press, Baltimore.

Matsuda, H., K. Amaoka, C. Araga, T. Uyena and T. Yashimo, editors. 1984. The fishes of the Japanese archipelago. Tokai University Press, Tokyo. 437 p.

McDowall, R.M. 1968. Interactions of the native and alien faunas of New Zealand and the problem of fish introductions. Trans. Am. Fish. Soc. 97(1): 1-11.

McDowall, R.M. 1978. New Zealand freshwater fishes - a guide and natural history. Heinemann, Auckland. 230 p.

McDowall, R.M. 1984. Exotic fishes: the New Zealand experience, p. 200-214. *In* W.R. Courtenay, Jr. and J.R. Stauffer, Jr. (eds.) Distribution, biology and management of exotic fishes. Johns Hopkins University Press, Baltimore.

McKay, R.J. 1984. Introductions of exotic fishes in Australia, p. 177-199. *In* W.R. Courtenay, Jr. and J.R. Stauffer, Jr. (eds.) Distribution, biology and management of exotic fishes. Johns Hopkins University Press, Baltimore.

McKay, R.J. 1989. Exotic and translocated freshwater fishes in Australia, p. 21-34. *In* S.S. De Silva (ed.) Proceedings of the workshop on Introduction of Exotic Aquatic Organisms in Asia. Asian Fisheries Society, Manila. Special Publication No. 3.

Merrick, J.R. and G.E. Schmida. 1984. Australian freshwater fishes - biology and management. Griffin Press, Sydney. 409 p.

Michaelis, F.B. 1990. Introduction of exotic aquatic organisms in Asia - workshop convened by the Asian Fisheries Society, Darwin, N.T., June 1988. Part 2. Recommendations of the workshop and the Australian Government Position. *In* D.A. Pollard (ed.) Proceedings of the Australian Society for Fish Biology's Pre-conference Workshop on Introduced and Translocated Fishes and their Ecological Effects. Bureau of Rural Resources, Canberra. 3 p.

Middleton, M.J. 1982. The oriental goby, *Acanthogobius flavimanus* (Temminck and Schlegel), an introduced fish in the coastal waters of New South Wales, Australia. J. Fish Biol. 21(5): 513-523.

Miller, D.L. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game Fish. Bull. (157): 1-235.

Miyazaki, I. 1940. Studies on the Japanese common goby, *Acanthogobius flavimanus* (Temminck et Schlegel). Bull. Japan. Soc. Sci. Fish. 9(4): 159-180.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley. 405 p.

Okada, Y. 1955. Fishes of Japan. Maruzen, Tokyo. 462 p.

Okada, Y. 1960. Studies on the freshwater fishes of Japan. Prefectural University of Mie, Tsu. 874 p.

O'Connor, P.F. 1990. Introduced Fish - the Role of the Advisory Committee on Live Fish. *In* D.A. Pollard (ed.) Proceedings of the Australian Society for Fish Biology's Pre-conference Workshop on Introduced and Translocated Fishes and their Ecological Effects. Bureau of Rural Resources, Canberra. 3 p.

O'Sullivan, D. 1988. Selected notes on salmon and trout. Austasia Aquacult 2(7): 3.

Parr, L. 1984. Fish populations threatened by inadequate quarantine laws. Aust. Nat. Hist. 21(5): 19.

Parr, L. 1985. Fish populations threatened by inadequate quarantine laws. Australian Fish. 44(2): 30-31.

Paxton, J.R. and D.F. Hoese. 1985. The Japanese sea bass, *Lateolabrax japonicus* (Pisces, Percichthyidae), an apparent marine introduction into eastern Australia. Jap. J. Ichthyol. 31(4): 369-372.

Pollard, D.A. and J.J. Burchmore. 1986. A possible scenario for the future of Australia's freshwater fish fauna, p. 615-636. *In* P. De Deckker and W.D. Williams (eds.) Limnology in Australia. CSIRO, Melbourne and Junk, Dordrecht.

Pollard, D.A. and T.D. Scott. 1966. River and reef, p. 95-115. *In* A.J. Marshall (eds.) The great extermination. Heinemann, London.

Randall, J.E. 1960. New fishes for Hawaii. Sea Frontiers 6: 33-43.

Randall, J.E. 1987. Introductions of marine fishes to the Hawaiian Islands. Bull. Mar. Sci. 41(2): 490-502.

Randall, J.E. and R.K. Kanayama. 1972. Hawaiian fish immigrants. Sea Frontiers 18: 144-153.

Roughley, T.C. 1957. Fish and fisheries of Australia. Angus and Robertson, Sydney. 343 p.

Sloane, R.D. 1983. The truth about trout. Tas-Trout Publications, Rosny Park, Tasmania. 178 p.

Springer, V.G. and M.F. Gomon. 1975. Revision of the blenniid fish genus *Omobranchus* with descriptions of three new species and notes on other species of the tribe Omobranchini. Smithson. Contrib. Zool. 177: 1-135.

Tilzey, R.D.J. 1980. Introduced fish, p. 271-279. *In* W.D. Williams (ed.) An ecological basis for water resource management. Australian National University Press, Canberra.

Warrer-Hansen, I. 1982. Evaluation of the matter discharged from trout farming in Denmark. *In* J.S. Alabaster (ed.) Report of the EIFAC workshop on fish-farm effluents, Silkeborg, Denmark, May 1981. EIFAC Technical Paper No. 41, 166 p.

Weatherley, A.H. and J.S. Lake. 1967. Introduced fish species in Australian waters, p. 217-239. *In* A.H. Weatherley (ed.) Australian inland waters and their fauna. Australian National University Press, Canberra.

West, G.J. and J. Glucksman. 1976. Introduction and distribution of exotic fish in Papua New Guinea. Papua New Guinea Agric. J. 27: 19-48.

Whitley, G.P. 1951. Introduced fishes. Parts 1 and 2. Aust. Mus. Mag. 10: 189-200, 234-238.

Williams, R.J., E.G. van der Wal and J. Kelly. 1982. Ballast water as a dispersal vector for non-indigenous marine animals. Unpublished report to the Fishing Industry Research Committee. FIRTA 76/18, 58 p.

Williams, R.J., E.J. van der Wal and J. Story. 1978. Draft inventory of introduced marine organisms. Aust. Mar. Sci. Bull. (61): 12.

Williams, R.J., F.B. Griffiths, E.J. van der Wal and J. Kelly. 1988. Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. Estuar. Coast. Mar. Sci. 26: 409-420.

Woodward, I. 1989. Finfish farming and the environment - review. Department of Sea Fisheries, Tasmania. Technical Report No. 35. 43 p.

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