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# PERSPECTIVES IN AQUATIC EXOTIC SPECIES MANAGEMENT IN THE PACIFIC ISLANDS

VOLUME I

INTRODUCTIONS OF COMMERCIALY SIGNIFICANT  
AQUATIC ORGANISMS TO THE PACIFIC ISLANDS

by

L.G. Eldredge  
Pacific Science Association  
Honolulu, Hawaii, USA

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South Pacific Commission  
Noumea, New Caledonia

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## PREFACE

It comes as a shock to realise that over half the fish caught in some of the rivers in the larger South Pacific Islands are actually introduced, exotic species. By comparison, the overall impact of introduced species on marine ecosystems appears to be much less, but since we know so little about what is going on in that area beneath high water mark, it is difficult to tell. What we do know, is that the vast majority of these exotic species were introduced without any form of quarantine and with little consideration of their possible long-term impact on aquatic ecologies.

The impetus for this review came from a discussion amongst the countries of the region at the South Pacific Commission's 23rd Regional Technical Meeting on Fisheries in 1991. At the 17th Regional Technical Meeting on Fisheries in 1985, SPC members had already adopted a set of interim guidelines for the international transfer and quarantine of giant clams, and the 1991 meeting asked the SPC Fisheries Programme to work on recommendations for extending these guidelines to aquatic species in general. The meeting envisaged that, eventually, there might ultimately be a need for a regional convention laying down basic aquatic introduction risk-assessment and quarantine procedures for the region as a whole.

This review, of the aquatic species introductions that have already occurred, is one part of a multi-step exercise. A companion report suggesting detailed guidelines for aquatic quarantine for the South Pacific will shortly be discussed by the fisheries departments of the region, and work is hoped to start thereafter on the compilation of guidelines for assessment of the ecological risks associated with the introduction of fish and aquatic invertebrates.

The author of this review is well known for his work on introduced and exotic species in the Pacific Islands and has drawn on all of his extension network of contacts to make this review as exhaustive as possible. It has not been an easy job. As well as a review of the available literature, it has required correspondence with all of the fisheries departments, all the academic institutions, and all of the relevant organisations and experts in the region, and the manuscript itself has gone through several drafts, being both added-to and narrowed-down by a multitude of willing reviewers. Our grateful thanks go to Lu Eldredge of the Pacific Science Association for masterminding the whole exercise.

The thanks of the South Pacific Commission are also due to the South Pacific Regional Environment Programme (SPREP) for co-sponsoring this exercise. Projects which cut across the work-programmes of more than one organisation are usually difficult to implement, but the unique relationship that developed between SPC and SPREP during the many years in which we shared a single roof continues to help us in appreciating each other's goals.

Mafaituuga Vaasatia Poloma Komiti

Director of Programmes  
South Pacific Commission

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# INTRODUCTION

Documentation of animals introduced to Pacific Islands since European contact is for the most part anecdotal. Long-term, quantitative studies have not been conducted in the marine environment as they have in other areas. The purpose of this review is to record the intentional and accidental introduction of aquatic plants and animals to the Pacific Islands (the area encompassed by the South Pacific Commission). Plants and animals are distributed either intentionally or accidentally. Five periods of introductions for aquatic and terrestrial animals have been proposed (Eldredge, 1992). A sixth period is added herein.

In summary these periods are:

1. The early period of settlement of islands by traditional voyagers when traditional life styles were maintained. This continuation of life style has been interpreted as 'transported landscapes' by anthropologists (Kirch, 1982a and 1982b). Roberts (1991) described voyager-related rat dispersal among the islands as early as 3100 to 2500 B.P. It was during this time that chickens, dogs, pigs, etc. were intentionally carried around. At the same time rats, geckos, skinks, snails, insects, etc. were also accidentally transported.
2. The exploration period, beginning in the early 1500s with the Spanish and extending until nearly the end of the nineteenth century, saw numerous importations. Trans-Pacific galleon trade had great impact in both directions (Guzman-Rivas, 1960). A number of anecdotal reports appear in early Spanish documents. It was during this time (in the 1770s) that the catfish and the sambar deer were introduced to Guam from the Philippines.
3. The late 1800s, when Western influence and political colonization expanded throughout the Pacific and continued into the mid-1900s. Development included the transplantation of oysters to Fiji and Hawaii and non-indigenous pearl oysters (*Pinctada maxima*) to Christmas Island and Suvarrow and throughout Micronesia.
4. Post World War II, with subsequent political changes, saw the establishment of numerous development projects, especially in agriculture. Noteworthy in the aquatic environment were the transfers of trochus.
5. The past 20 years, when emphasis has been placed on the development and expansion of terrestrial agriculture and marine and freshwater aquaculture, resulting in a new wave of intentional and accidental introductions including giant clams, green snails, penaeid shrimps, and others. It is during this period that most former colonial islands achieved self governance and independence.

To these is added a newly recognized period:

6. The past decade, when greater westernization and more affluence allowed for the development of the aquarium-ornamental aquatic plant and animal industry. Presently, this is seen in only a few islands—Guam, Saipan, and Oahu (Hawaii)—but should be a warning for other developing areas. During this period numerous aquarium organisms have 'escaped' into ponds and streams, becoming established. At least 16 fish species are known to have been released into the environment at Guam; 9 becoming established. Slightly more are known from Fiji. In Hawaii, a total of around 40 freshwater fish species have been introduced. Between 1982 and 1990, alone, more than 20 species have become established (Devick, 1991). More than 30 piranhas have been surrendered or discovered on Oahu since the beginning of 1992! Freshwater turtles have also become established at Guam, Saipan, and in Hawaii. Several species of freshwater snails have also been found originally imported as aquarium ornamentals or they may have accidentally arrived on aquatic plants.

The first major review of introduced aquatic organisms to mention the Pacific Islands was that of Walford and Wicklund (1973) who discussed world-wide situations but with an emphasis on the European coasts. The only mention of the Pacific is a short case-history study of the Hawaiian Islands drawn from the review by Brock (1960). Brock's list also formed the background for most more recent reports. In 1984, Maciolek reviewed the fishes introduced to the Pacific, with emphasis on those transported to Hawaii. Randall (1987) added new information on Hawaiian fishes.

A wide range of aquatic animals were reported as having been introduced to Fiji (Andrews, 1985). For Papua New Guinea, West and Glucksman (1976) described a number of fish introductions; Allen (1991) has brought this information up to date.

Introductions to coral reefs were reported by Eldredge (1987). This included broadly based information, covering primarily Pacific Island examples. Specifically, examples from the U.S.-affiliated islands were additionally reviewed (Eldredge, 1988). One very important and extensively introduced group of animals—the tilapia—were the topic of a single review (Nelson and Eldredge, 1991). Long-term observations have been conducted in Australia and recently reported (Pollard and Hutchings, 1990a and 1990b).

In his historical review of the introduction of inland aquatic species, primarily fishes, Welcomme (1992) analyzed 1673 records of 291 species in 148 countries (very few of these records include information on the Pacific Islands). Nearly 50% of all introductions analyzed took place between 1950 and 1989. In a list of countries and numbers of species received Hawaii (47), Fiji (28), and Guam (14) are the only Pacific Islands with ten or more species introduced. For aquaculture purposes *Cyprinus carpio* has been introduced to 50 countries, *Oncorhynchus mykiss* to 48, *Ctenopharyngodon idella* to 39, and *Oreochromis mossambicus* to 34. Nine other species have been taken to ten or more countries. The percentages of introductions are given for the following purposes (Welcomme, 1992):

Aquaculture	36.1%
Sport	11.8%
Improvement of wild stock	10.8%
Accident	9.0%
Ornament (Aquarium trade)	8.4%
Control of unwanted organisms	5.4%
Unknown	18.5%

Welcomme concluded that further introductions will occur and that there was a need for a code of practice to be internationally recognized. The International Council for the Exploration of the Sea (ICES) has developed a code setting out requirements for species and for quarantine. In the Pacific region this has been slightly modified and adopted by the Indo-Pacific Fisheries Council for the formulating of national legislation.

Aquatic organisms intended for aquaculture are transported intentionally to a new island site. Some aquaculture trials have been carried out directly in the aquatic environment, others in experimental, and supposedly, self contained tanks. Unfortunately, there are numerous examples of escapes from tanks into the natural environment. To date, it appears that these escapees have not been overly detrimental. At present, commercial aquaculture is more or less confined to red algae, pearl oysters, and penaeid shrimps (Munro, 1993). Munro further reviewed the status of aquaculture and warned against 'careless transfers and unthinkable introductions'.

In contrast, the release of aquarium or ornamental plants and animals provides numerous examples with destructive results—decline in native (endemic) animals, alteration of the natural environment, and introduction of 'new' diseases and parasites. Most freshwater aquarium organisms, by definition, are originally intentionally introduced. This problem has been reviewed in depth for the contiguous U.S. states only (Courtenay and Stauffer, 1990). Legislation controlling importation exists in many islands but is not enforced in all situations.

At least eight communicable diseases of fish are known in Europe. Many of them have been transported with introduced fish stocks (Rosenthal, 1980). Six lethal viral diseases of shrimp have been

identified and are found in cultured and wild penaeid shrimps. IHHNV (infectious hypodermal and hematopoietic necrosis virus) has been introduced to Tahiti, Guam, and Hawaii (Sindermann, 1993). Nine obligate pathogens and parasites have been identified from penaeid stock imported to Hawaii (Brock, 1992). Five pathogens are known from the oyster *Crassostrea gigas*, and the protozoan *Perkinsus* has been reported from bay scallops (Sindermann, 1993) and giant clams (Braley, 1992). Disease interactions with exotic organisms fall into four categories (Williams and Sindermann, 1992, p. 71):

1. effects of exotic diseases on local organisms,
2. effects of local diseases on exotic organisms,
3. increased susceptibility to diseases of exotic organisms cultured in unsuitable or marginal environmental conditions, and
4. predisposition of the environment to pathogen problems.

These authors provide examples of each of the above and show specific concern about giant clams (and possibly *Perkinsus*) being introduced into the Caribbean.

The introduction of exotic organisms through fouling on ship's hulls and through ship ballast water tanks is another distribution mechanism. Recently Carlton (1987) reviewed animal invasions in the Pacific area and suggested 14 routes of transoceanic dispersal. The Hawaiian Islands, Pacific coast of North America, and Australasia are the major receiving areas; the major donor area is the extended Pacific coast of Asia. The routes do not define intra-Pacific interactions.

Fouling results from the growth of plants and animals on submerged man-made objects. As long as there have been maritime movements, plants and animals have been redistributed. Several species have been reported in Hawaiian waters, arriving on the hulls of ships (Doty, 1961). In 1992, a drydock towed to Guam carried biota from Subic Bay, Philippines (Myers and Paulay, pers. comm.); another towed to Hawaii may also have transported non-indigenous species.

Ballast-water transport is the movement of living organisms, particularly larvae, in the ballast tanks of ships. Carlton (1985) outlined the problem and detailed much evidence in the first complete review of ballast-water transport. Recently, Carlton and Geller (1993) further described ballast-water transport by identifying 367 distinct taxa carried in ballast tanks and sampled at Oregon (U.S.A.). Additionally, he listed 45 species from eight phyla which have most likely been transported in ballast water and have become locally established.

Unfortunately, little data are available for the Pacific Islands. The recent expansion of toxic dinoflagellates (and paralytic shellfish poisoning) may be explained by transport in ballast water (Hallegraeff, 1992). In Australia, a long-term study (Hutchings et al., 1987) has resulted in a definite policy position on ballast-water transport (Jones, 1991).

With extensive introductions into the aquatic environments of the Pacific Islands, local legislation and enforcement mechanisms are imperative. This review attempts to document and detail the commercially significant aquatic introductions to the Pacific Islands, exclusive of the Hawaiian Islands, although there are extensive references to Hawaii since it has been a source of much of this introduced material and a place from which many lessons may be learned.

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## INTRODUCTION

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# **BIVALVES**

## GIANT CLAMS (Family Tridacnidae)

Giant clams have played a major role in islander life for thousands of years. There are nine species in two genera—*Tridacna* and *Hippopus*—in the family Tridacnidae. The confused taxonomy of these species was revised by Rosewater (1965) and recently reviewed by Lucas (1988). Since Rosewater's 1965 revision, *Tridacna tevoroa* and *T. rosewateri* have been described by Lucas et al. (1990, 1991) and Sirenko and Scarlato (1990), respectively; *Hippopus procellanus* was added by Rosewater (1982). A workshop on giant clams was held in April 1988 at James Cook University, Townsville, Australia. The results, which include 54 separate contributions, contain the most current information on the biology and culture of giant clams (Copland and Lucas, 1988).

The currently described species are:

- Tridacna gigas* (Linnaeus, 1758)
- Tridacna derasa* (Roding, 1798)
- Tridacna squamosa* (Lamarck, 1819)
- Tridacna maxima* (Roding, 1798)
- Tridacna crocea* (Lamarck, 1819)
- Tridacna tevoroa* (Lucas, Ledua and Braley, 1990)
- Tridacna rosewateri* (Sirenko and Scarlato, 1990)
- Hippopus hippopus* (Linnaeus, 1758)
- Hippopus porcellanus* (Rosewater, 1982)

All living tridacnid clams live in the Indo-west Pacific; none in the Hawaiian Islands. The larger members of the family have been listed as threatened by IUCN (1983).

Local overharvesting has greatly reduced wild stocks. *Tridacna gigas* is extinct at Guam and the Mariana Islands, the Federated States of Micronesia (Yap, Chuuk, Pohnpei, and Kosrae) Fiji, New Caledonia, Taiwan, the Ryukyu Islands and Vanuatu; *T. derasa*, at Vanuatu; and *H. hippopus*, at Fiji, Tonga, Western and American Samoa, Guam and the Mariana Islands, and Taiwan (Munro, 1989). Munro (1989) reviews information on the status and utilization of seven species in 32 countries.

Several hatcheries have been established, the larger ones being at Palau [Micronesian Mariculture Demonstration Center (MMDC)], Solomon Islands [Coastal Aquaculture Centre of ICLARM (CAC)], and Australia (Orpheus Island Research Station of James Cook University, Townsville). All of the larger species have been successfully reared. Hatchery-reared individuals have been distributed throughout the Pacific to reseed and to establish population in lagoons and coastal areas (see list below).

In June 1992, ICLARM held a workshop on 'Genetic aspects of conservation and cultivation of giant clams' in Manila. This workshop was convened to 'to promote regional cooperation in breeding giant clams, and provide a forum for discussion of the re-establishment of stocks in a genetically sound way' (Munro, 1993, p. iv). Along with discussion papers, there were six country reports. Recent studies have shown that there is significant genetic structuring among the Pacific giant clam populations. Care must be taken that restocking does not eliminate local diversity; transfers should not be made, for example, between Australia or the Solomon Islands and Micronesia, since appropriate material already exists in the Marshall Islands (Benzie, 1993).

Transport of adults or juveniles also allows the transport of potential diseases, parasites, or predators. The diseases and parasites identified from giant clams include seven bacteria and bacterial diseases; a nematode, a trematode, and a turbellarian; Rickettsial infections, and three protozoans and protozoan diseases (Humphrey, 1988). No virus or viral diseases have yet been reported.

The snail predator *Cymatium muricinum* is most well known (Perron et al., 1985). This species is widely distributed and preys on a variety of bivalves. The larvae of *C. muricinum* settle from the plankton and although they are not known to occur in high densities, large numbers have been found feeding

on juvenile giant clams in land-based nurseries (Heslinga and Watson, 1985). Caution should be taken when transporting giant clams that *C. muricinum* not also be transported. Itano and Buckley (1988) reported that *C. muricinum* began appearing at the Alofau (American Samoa) nursery site about four months after the introduction of *T. derasa* from Palau. The snail *Chicoreus ramosus* is another giant clam predator (Heslinga et al., 1984).

The pyramidellid snail *Tathrella iredalei* is an ectoparasite on giant clams. At Palau (MMDC) infestations occur in land-based tanks which have been in culture for more than 3 months (Heslinga et al., 1990). Eggs or juveniles enter through the seawater system. At MMDC, *T. iredalei* lay egg masses on the undersides of the clams. The nonplanktonic, nonfeeding larvae hatch as juveniles in about 15 days. Isolated infestations develop and spread throughout the tanks as more juveniles are produced (Heslinga et al., 1990). Smith (pers. comm.) reported that *T. derasa* received at Guam in 1989 probably carried egg masses with them, since *T. iredalei*, previously unknown at Guam, is now probably established. Further, (Govan, 1992) pointed out that undetermined species of pyramidellid snails have been reported on giant clams imported to Fiji, Guam, Hawaii, the Philippines (Negros), as well as to Florida and Bonaire. At Orpheus Island Research Station, a pyramidellid, *Turbonilla* sp. (identified as *Pyrgiscus*) (Cumming, 1988), is found in seawater tanks, is an ectoparasite of juvenile *T. gigas*, and appears to be the same one found in the Solomon Islands (Cumming, 1993). At Palau, *T. iredalei* is controlled by periodically emptying the tanks and changing the gravel (Heslinga et al., 1990). Information on numerous predators, primarily gastropods, has been compiled by Govan (1990).

Numerous transplantations of at least four species have taken place throughout the Pacific Islands. In the Solomon Islands *T. gigas* broodstock has been transported to Guadalcanal and thousands of cultured juveniles from the CAC have been taken to other islands within the Solomons; however, such movements are all within the drifting range of a larval clam (Munro, pers. comm.).

Below, giant clam transfers are listed by species and island group. Additional transfers of species continue to take place in the aquarium trade. In 1984, test marketing of 100–120mm *T. derasa* was initiated at aquarium stores at Guam (Heslinga, 1989). Specimens from Palau (MMDC) for the aquarium trade began being sent to/through Hawaii in 1987. Between then and January 1991, approximately 13,000 clams of varying sizes were transshipped (Heslinga, pers. comm.).

Chronological list of giant clam transfers and introductions by species and country:

#### *Tridacna derasa* [Smooth Giant Clam]

##### American Samoa

1986: Palau (MMDC) to Tutuila

1,000 16-month old specimens (71.69 mm average size) (transported through Honolulu, 894 survived); 671 to Alofau, 201 to remain at Office of Marine and Wildlife Resources, predation by *Cymatium muricinum* (Anon., 1986; Itano and Buckley, 1988); of juveniles imported in 1986, now 450 mature broodstock (Anon., 1992)

1991: Palau (MMDC) to American Samoa

18 clams (238.8 mm); 2,000 yearlings to workshop participants (MMDC, 1991)

##### Chuuk

1991: Palau (MMDC) to Chuuk

2,000 yearlings to workshop participants (MMDC, 1991); 2,000 additional (Heslinga, n.d.)

1992: Kosrae to Chuuk

3,000 1.4 year-old clams (Lindsay, 1993)

## Cook Islands

1986: Palau (MMDC) to Aitutaki

1,000 juveniles; heavy predation by *Cymatium muricinum*; cyclones (January 1987) disturbed trays and scattered specimens; [Note: this is first introduction of *T. derasa* outside its native ranges in Polynesia] (Sims and Howard, 1988)

## Federated States of Micronesia and Marshall Islands

1988: Palau (MMDC) to Kosrae, Yap, Pohnpei, Chuuk, and Majuro

1,000 juveniles to each FSM state marine resource divisions for culture; at Kosrae, 60% survival by June 1987, predation by *Cymatium muricinum* (Riley, 1992)

## Fiji

1985: Palau (MMDC) to Fiji

500 juvenile clams, all died shortly after arrival (Adams, pers. comm.) [Note: this was MMDC's first shipment to the South Pacific]

## Guam

1984: Palau (MMDC) to Guam

100 3-year old clams (3.75 pounds each) planted at Cocos Island (PFDF, 1985)

1989: Palau (MMDC) to Guam

test marketing (100–120 mm) specimens to aquarium stores (Heslinga, 1989)

1989: Palau (MMDC) to Guam

100 5-year olds to Guam, 87 transplanted to Apra Harbor during September 1989 and January 1990, survival not too successful; another ship of 6-month old and 2-year old clams held at GADTC, no releases (FitzGerald, pers. comm.)

## Kosrae

1988/91: Palau (MMDC) to Kosrae

20,000 (3–5 mm) clams, cultured for 15 months, half distributed summer 1992 to Yap, Pohnpei, Chuuk; 50,000 (1–2 mm) maintained in pools; in 1991 2,000 (80 mm), in 1990 2,000 (52 mm), in 1989 2,000 (62 mm) and 1,000 (54 mm), 1988 1,000 (74 mm) (Riley, 1992)

1991: Palau (MMDC) to Kosrae

2,000 yearlings to workshop participants (MMDC, 1991)

## Mariana Islands

1986/88: Palau (MMDC) to Saipan

in 1986: 500 (65.7); in 1987 100 (160 mm), 200 (161 mm); 1988 200 (163 mm); another 2,000 (Heslinga, pers. comm.)

1991: Palau (MMDC) to Saipan

2,000 yearlings to workshop participants (MMDC, 1991); 2,000 additional (Heslinga, n.d.)

## Marshall Islands

1985/90: Palau (MMDC) to Marshall Islands

in 1985 3,000 clams of various sizes to Majuro, ranging between 73.2 and 97.2 mm; in 1989 1,000 (64 mm) to Enewetak; in 1990 16,000 clams, various sizes, ranging between 31 and 65.7 mm (Heslinga, pers. comm.) (to lagoons at Mili, Likiep, and Majuro)

## Pohnpei

1985/90: Palau (MMDC) to Pohnpei

in 1985 1,250 (23.6–93.2 mm); in 1989 1,000 (73.8 mm); in 1990 1,000 (10–20 mm) (Heslinga, pers. comm.) 1992 Kosrae to Pohnpei 3,000 1.4-year old clams (Lindsay, 1993)

## Tuvalu

1989: Palau (MMDC) to Tuvalu  
1,000 clams (145 mortalities); predation by *Cymatium muricinum* and *C. aquatile* (ACIAR, 1992)

## Western Samoa

?: Palau (MMDC) to Western Samoa  
specimens under cultivation by Samoa Marine (Anon. 1990)

## Yap

1984: Palau (MMDC) to Yap  
1,014 clams (84 mm) held 3 months, 18-month clams transported to four other sites at Yap; January 1986 distributed to 28 villages, three other sites added, totaling 31 plant sites; predation by *Cymatium muricinum* and *Chicoreus ramosus* (Heslinga and Watson, 1985; Price and Fagolimul, 1988)

1985: Palau (MMDC) to Yap  
1,000 reared at Yap proper for 9–12 months, 658 clams transported to outer islands, each inhabited outer island received 30 clams for the lagoon (Price, 1988; Lindsay, 1991)

1986/87: Palau (MMDC) to Yap  
6,000 clams to ocean nursery in Rumung; 6 months later 50 clams each distributed to 53 villages, remaining specimens transplanted to outer islands in 1988 (Price, 1988; Lindsay, 1991)

1991: Palau (MMDC) to Yap  
2,000 yearlings to workshop participants (MMDC, 1991); 2000 additional (Heslinga, n.d.)

1992: Kosrae to Yap  
100 clams (Riley, 1992); 3000 1.4-year old clams (Lindsay, 1993)

1993: Palau (MMDC) to Yap  
10,000 seedlings to ocean nursery

*Tridacna gigas* [Giant Clam]

## American Samoa

1991: Palau (MMDC) to American Samoa  
2,000 yearlings to workshop participants (MMDC, 1991)

## Chuuk

1991: Palau (MMDC) to Chuuk  
2,000 yearlings to workshop participants (MMDC, 1991)

## Cook Islands

1991: Australia (JCU) to Aitutaki  
11,000 clams, quarantined at Aitutaki hatchery/nursery (ACIAR, 1992)

## Fiji

1986: Australia (JCU) to Fiji  
2,000 juveniles from Orpheus Island to quarantine tanks at Makogai Island for reintroduction (Ledua and Adams, 1988; ACIAR, 1992)

1987: Australia (JCU) to Fiji  
475 juveniles, 419 survived quarantine (Ledua and Adams, 1988)

1990: Australia (JCU) to Fiji  
7,000 clams (ACIAR, 1992) including 5,000 tested in shipping trials, to go to quarantine at Makogai Island (Braley, 1992)

## Guam

1982: Palau (MMDC) to Guam  
500 juveniles released, unprotected, heavy predation, unsuccessful (Munro and Heslinga, 1983; Heslinga, 1989) (Heslinga and Watson, 1985)

## Kosrae

1991: Palau (MMDC) to Kosrae  
8,000 1–2 year-old [4,000 (29 mm), 2,000 (unknown size), 2,000 (45 mm)] specimens (Riley, 1992)  
1991: Marshall Islands (Reimers Enterprises) to Kosrae  
56 3–4 year-old specimens (Riley, 1992)  
1991: Palau (MMDC) to Kosrae  
2,000 yearlings to workshop participants (MMDC, 1991)

## Pohnpei

1990: Palau (MMDC) to Pohnpei  
10,000 clams (10–20 mm) (Heslinga, pers. comm.)

## Saipan

1991: Palau (MMDC) to Saipan  
2,000 yearlings to workshop participants (MMDC, 1991)

## Tonga

1991: Australia (JCU) to Tonga  
11,000 11-month old, October 1991, 2,800 to Vava'u, 1,000 to Ha'apai, remaining 3,600 remained at Tongatapu (ACIAR, 1992; Fa'anunu, pers. comm.)

## Western Samoa

1990: Australia ('Great Barrier Reef') to Western Samoa  
1,300 juveniles by Samoa Marine after quarantine at Fisheries Division transferred to farm at Aleipata (Anon., 1990)  
1991: Australia (JCU) to Western Samoa  
11,000 clams in May; 6,000 in July (ACIAR, 1992)

## Yap

1991: Palau (MMDC) to Yap  
2,000 yearlings to workshop participants (MMDC, 1991)

*Tridacna squamosa* [Fluted Clam]

## Guam

1982: Palau (MMDC) to Guam  
500 juveniles released, unprotected, heavy predation, unsuccessful (Heslinga, 1985, 1989)

## Western Samoa

1990: ? to Western Samoa  
under cultivation by Samoa Marine (Anon., 1990)

*Tridacna tevoroa*

## Fiji

?: Tonga to Fiji  
500 juveniles to Makogai Island, 2% mortality (Ledua, 1993)

*Hippopus hippopus* [Horse's Hoof, Bear Paw, or Strawberry Clam]

## Chuuk

1991: Palau (MMDC) to Chuuk  
2,000 yearlings to collaborators (Heslinga, n.d.)

## Cook Islands

1991: Australia (JCU) to Aitutaki  
20,000 clams quarantined at Aitutaki hatchery/nursery (ACIAR, 1992)

## Fiji

1991: Australia (JCU) to Fiji  
20,000 clams quarantined at Makogai Island (ACIAR, 1992)

## Kosrae

1990/91: Palau (MMDC) to Kosrae  
in 1990 3,000 (53 mm), 1,000 (62 mm) in 1991, 1-2 year old clams (Riley, 1992)  
1991: Pohnpei to Kosrae  
50 specimens, approximately 5 years old; spawned in September 1991, all veligers died (Riley, 1992)  
1991: Palau (MMDC) to Kosrae  
2,000 yearlings to collaborators (Heslinga, n.d.)  
1992: Marshall Islands (Reimers Enterprises) to Kosrae  
40 individuals (Riley, 1992)

## Saipan

1991: Palau (MMDC) to Saipan  
2,000 yearlings to collaborators (Heslinga, n.d.)

## Tonga

1991: Australia (JCU) to Tonga  
20,000 11-month old specimens, transferred to ocean nursery at Tongatapu (February 1992) (Fa'anunu, pers. comm.)

## Western Samoa

1991: Australia (JCU) to Western Samoa  
20,000 specimens (ACIAR, 1992)  
1990 and 1992: Solomon Islands (ICLARM/CAC) to Western Samoa  
216,000 larvae (18-day) and 43,000 larvae (25-day), all died (Bell and Munro, pers. comm.)

## Yap

1991: Palau (MMDC) to Yap  
2,000 yearlings to collaborators (Heslinga, n.d.)

The first giant clam introduction to Hawaii was in March 1951 when 60 individuals of *T. crocea* from Rose Island were placed in holding ponds at Coconut Island, Kaneohe Bay, Oahu (Brock, 1952). A few were still alive in 1959 but there was no evidence of reproduction (Brock, 1960). At some time later, the remaining specimens were collected and sent to the Steinhart Aquarium in San Francisco (Jokiel, pers. comm.). *Tridacna gigas* and *T. squamosa* were shipped to Hawaii from Palau (MMDC) beginning in 1985 (Heslinga, 1989, pers. comm.; Heslinga et al., 1984).

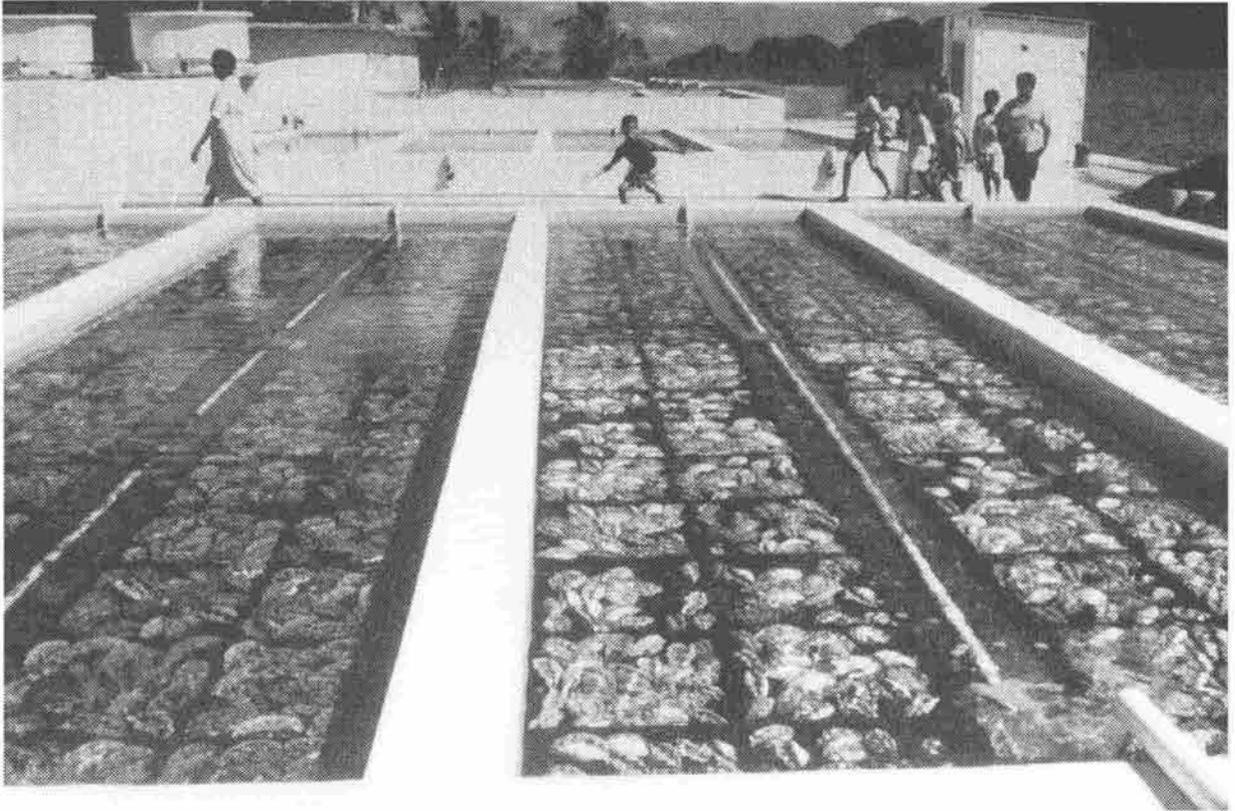
Giant clams have also been shipped to the Caribbean where an estimated 600 clams from Palau were reportedly being cultured in Bonaire, Guadeloupe, and south Florida (Williams and Bunkley-Williams, 1990; Williams and Sindermann, 1992). The Fundashon Marcultura at Bonaire (Netherlands Antilles) is presently (mid-1993) growing *T. derasa* (originally from MMDC, Palau, in 1988) and *T. maxima* and *T. crocea* (from wholesalers in Miami, Florida). Spawning has been observed in home aquariums with lowered salinity but not at the major facility (Berkers, pers. comm.)

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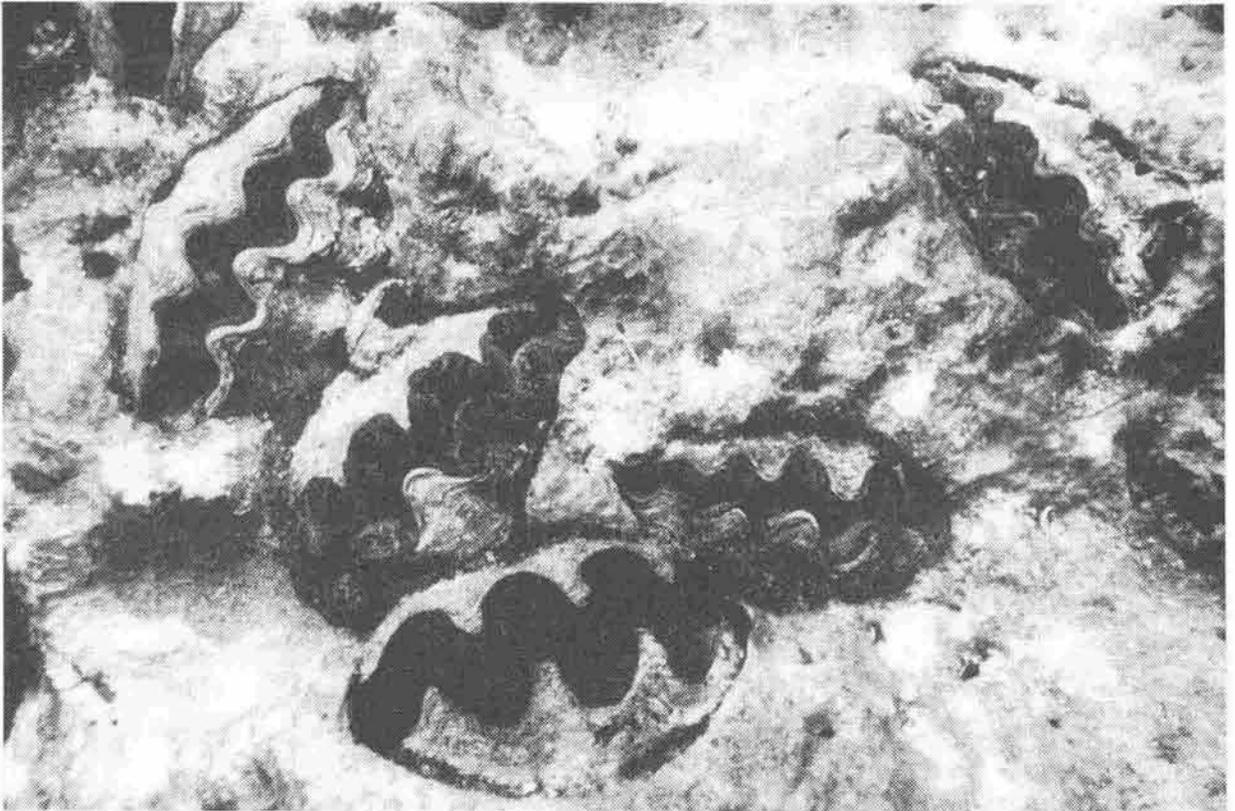
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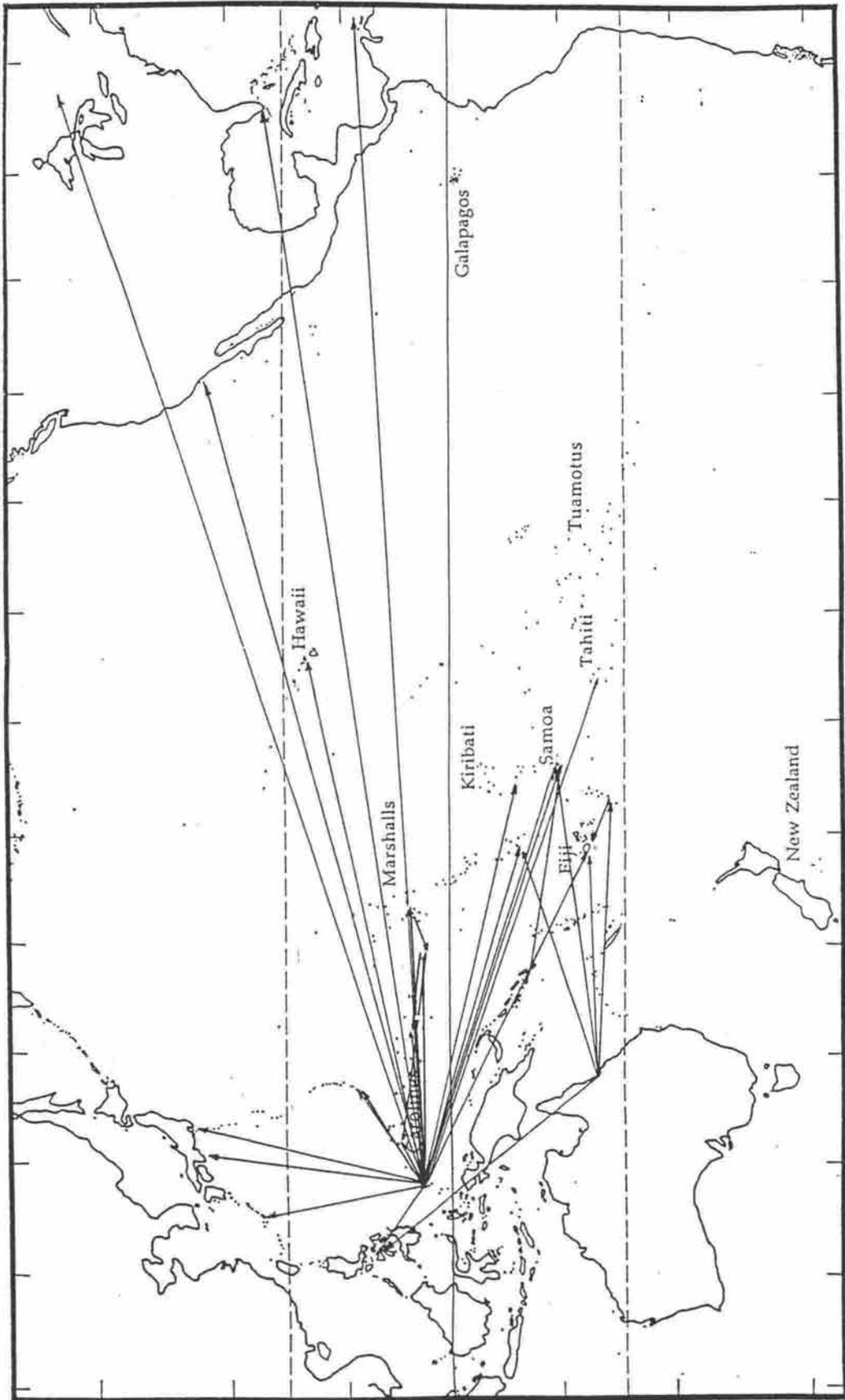
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*Tridacna* grow-out tanks at Micronesian Mariculture Demonstration Center, Koror, Palau



*Tridacna derasa* on reef flat [Photos: R. H. Richmond]



Tridacnid clams – generalized map of tridacnid clam transfers among the Pacific Islands, all species included; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.

## OYSTERS (Family Ostreidae)

Oysters are found worldwide throughout temperate, subtropical, and tropical waters. Many are harvested from local stock for local consumption. Numerous species have been transported throughout the tropics—most such introductions have not been successful. The biology and culture of tropical oysters have been reviewed (Angell, 1986).

Species belonging to the genera *Crassostrea*, *Ostrea*, and *Saccostrea* are the most widely utilized. Historically, the taxonomy of these has been confused (Torigoe, 1981; Arakawa, 1990a). Features of the shell are used to differentiate the genera. Individuals of *Saccostrea* have denticles (chomata) at the hinge, a deep umbonal cavity, and a tendency to grow in a cornucopia (rudistiform) shape; those of *Ostrea* have denticles but no umbonal cavity, and grow in a subcircular, flat shape; and those of *Crassostrea* have no denticles, a moderate umbonal cavity, and grow in a somewhat elongated and cupped shape (Angell, 1986).

Below is a chronological summary of oyster introductions to south Pacific Islands [it should be noted that information from different sources vary slightly as to number of individuals introduced and date of introduction] (modified from Uwate et al., 1984, with additions and modifications):

### *Crassostrea belcheri*

#### Tonga

1977: specimens from Sabah evaluated in intertidal racks in the Nukunukumotu Channel, some sent to Vava'u

1978: 100,000 individuals (mixed with *Perna viridis*) from Sabah attached to strips in intertidal racks between Nukunukumotu Island and Tongatapu

1981: culture trials terminated, since being poorly monitored

### *Crassostrea echinata* [Australian oyster]

#### Fiji

1910: individuals from Australia [by the grandfather of a Mr. Borron, owner of Mago Island in the Lau Group (Glude, 1972)] planted in Mago Island lagoon. 1971: one shell found in the Namuka area, west of Suva

1981: 2,280 seeds from CNEXO (Tahiti) planted at Laucala and Namarai Bays; high mortality because of siltation and abundant brown algae, project suspended at end of 1981 (Vereivalu, 1990)

#### French Polynesia [see also Coeroli et al., 1984]

1972: SPIFDA-supplied individuals from New Caledonia

1978: additional specimens from New Caledonia; 2 million spat produced at COP (CNEXO), thought to be less sensitive to *Polydora*

1983: additional specimens from New Caledonia

#### Guam [see also Braley, 1984]

1979: approximately 700 specimens from Koror, Palau, planted at 4 sites in Sasa Bay, Apra Harbor (Braley, pers. comm.)

#### New Caledonia

1979–1980: 1,650,000 eggs imported from Tahiti, survival good, 20,000 still cultivated in 1983

*Crassostrea gigas* [Pacific oyster, Japanese oyster] [see also Glude, 1984]

## Fiji

1968: individuals from Japan in raft culture, theft in 1969 terminated experiments  
 1969: seed oysters from Japan planted at Bay of Islands near Lami, good growth and survival; second introduction from Japan planted at Namarai Bay, harvested  
 1970: shipment from Japan planted in Namarai Bay again, most died  
 1971: 5,000 seed from California cultured at Cave Island in Bay of Islands (hurricane damage in 1973)  
 1972: 200,000 cultchless seed from California, erratic growth, some survival; receipt of a shipment of 45 kg of cultched spat, 25% survival reported  
 1973: 2 mt cultched spat from Japan, considerable mortality because of Nadi Airport strike; 20,000 spat from Australia, high mortality at Bay of Islands; one million cultchless spat from California  
 1974: 2 mt (900,000) spat from Japan put in raft culture; one million spat from U.S., cultured at Rewa Delta, heavy predation by *Scylla serrata*  
 1975: unidentified introductions  
 1976: specimens imported from Philippines, cultured but no growth in 14 months  
 1977: additional introductions; 100,000 from an American supplier, 100% mortality (Bourne, 1979)

## French Polynesia

1972: unspecified introductions received from a Mr. T. Lenai; in August seed introduced from California, individuals (to Tahiti, Raiatea, Tahaa) had little growth because of heavy *Polydora* infestation  
 1976: seed stock from California, 90% mortality, *Polydora* infestation and *Scylla serrata* predation

## Guam

1975: 11,550 spat (431 collector shells) from Taiwan (photo of raft culture at mouth of Talofoto River) (FitzGerald, 1982), considered unsuccessful

## New Caledonia

1967: few specimens from Japan  
 1971: spat to Noumea (from Australia?)  
 1970–1977: numerous unspecified introductions from Japan and California  
 1976–1977: about 40,000 eggs (probably *C. gigas*) imported from COP hatchery in Tahiti

## Palau

1972: approximately 100,000 spat from California, initial mortality 27% (Pflum, 1972), 40% dead by January 1973  
 1973: additional 100,000 cultchless spat from California, 40% mortality within 6 weeks (Tufts, 1973); 6,500 cultched from Washington State (September 1973)  
 1975: 25,000 imported (unspecified locality) planted at Ngetpang Bay

## Tonga

1974: unspecified introduction, poor growth rate in 1975  
 1975: cultched spat imported from Tasmania and Japan, heavy mortality, predation by drill (*Cymatium*)

## Vanuatu

1972: 20,000 unattached spat from California to Espiritu Santo (following recovery in New Caledonia)  
 1973: approximately 600,000 spat imported from California to Mounparap Bay; additional 100,000 from California to Port Sandwich, Malekula; some additional trials at Efate near Pt. Vila

Western Samoa

?: no information other than arrow on map showing recent transfer from U.S. north-west (Chew, 1990)

*Crassostrea iredalei* [Philippine oyster]

Fiji

1975: about 300 specimens from Cavite, Philippines, transported, all killed in flood six months later

1976: additional specimens from Philippines, quarantined in New Caledonia, 22% mortality

Tonga

1976: under cultivation, source unknown

*Crassostrea virginica* [American oyster]

Fiji

1970: specimens from Hawaii planted at Bilo Bay

Tonga

1973: 10,000 spat mixed with *C. commercialis* from California through Fiji

*Ostrea edulis* [Flat oyster, European native oyster]

Fiji

1977: spat introduced [from undisclosed locality; from Japan (Andrews, 1985)] by private farm which closed after growth to marketable size

Tonga

1975: several shipments from Japan and California, high mortality

*Saccostrea commercialis* [= *Crassostrea commercialis*, includes *S. glomerata*] [Sydney rock oyster, Australian rock oyster]

Fiji

1880s: specimens thought to have been introduced from Australia, planted near Savusavu, Vanua Levu (Glude, 1972)

1968: introduction from Australia, spatfall in 1969

1970: from Australia, planted at Bilo Bay

1973: introductions from California, cultured at Taveuni, Savusavu, and Labasa; growth stopped January 1974 (Ritchie, 1974)

New Caledonia

around 1971: adult specimens from Australia to Ouenghi area of Baie St. Vincent, kept in trays, sold locally

Tonga

1973: 10,000 (?*C. glomerata*) from New Zealand to Fanga'uta Lagoon, Tongatapu; 10,000 spat (mixed with *C. virginica*) from California

*Saccostrea cucullata tuberculata* [Solomon Island mangrove oyster]

Guam [see also Braley, 1984]

1978: 45 specimens from Solomon Islands arrived (4/12/78), held, and planted (4/11/79) in Sasa Bay, Apra Harbor (Braley, pers. comm.)

## Unidentified Oysters

## Fiji

1973: 200,000 cultchless spat imported from California

Hawaii has had a long history of oyster introductions. *Crassostrea virginica* seed was first planted in Pearl Harbor in 1866. Additional introductions to Oahu were in 1877 to Honolulu, 1883 to Kaneohe Bay, 1890 to Moanalua, and 1893 and 1895 to Pearl Harbor. Systematic introductions were begun in the 1920s to Kaneohe Bay and Pearl Harbor (Kay, 1979). *Crassostrea gigas* was brought from Japan and planted at Kalihi, Oahu, in 1926, and in 1938 and 1939 shipments were set out at Pearl Harbor and Kaneohe Bay, Oahu (Brock, 1960). Individuals have also been received from the northwest U.S. (Chew, 1990). Kay (1979) indicated that both species on Oahu as well as in fishponds on Molokai, have commercially valuable populations. In addition, *C. amasa*, *C. commercialis*, *C. virginica*, and *Ostrea lurida* have been introduced but not successfully established (Brock, 1960; Kay, 1979). Hawaii was the source of specimens of *C. virginica* introduced to Fiji in 1970 (Andrews, 1985).

Oyster introductions into the south Pacific have, for the most part, not been successful. The Pacific oyster (*C. gigas*), originally from Japan and introduced in the early 1900s to north America, is the most often transported species. No commercial production has resulted (Angell, 1986). Bourne (1979, p. 45) noted, 'one can only conclude that *C. gigas* does not appear to be a suitable oyster for culture in the tropical islands of the South Pacific.' Glude (1984) noted that *C. gigas* introductions 'failed because of high mortalities during the second year' (p. 37). He added that there was little interest in continuing to culture it. High temperatures and predation may account, in part, for the lack of success.

Oyster shells provide an ideal substrate for a variety of attached (sessile) and sedentary plants and animals. Most often these are just nuisance organisms which cause no problems but may cause mortality by growing over the animals themselves. However, disease-producing organisms, predators, parasites, and other obnoxious organisms might be associated. This may be referred to as fouling or biofouling. Some examples of these are: sponges, especially *Cliona* which can bore into shells, forming a series of tunnels; sea anemones and corals; erect or encrusting bryozoans; tube worms, especially *Polydora* (mud blister worms) whose burrows fill with mud and occasionally break through, causing the oyster to secrete a new layer of shell; and barnacles and tunicates. Algae and bacteria can also be found on oyster shells. Fouling may be controlled by the following methods: physical (air drying in sun), chemical (placing in freshwater, applying chemicals such as copper sulfate or brine), and biological (becoming familiar with the life history and ecology of fouling organisms to take advantage of natural systems) (Quayle and Newkirk, 1989).

In the Pacific area at Palau, observations at the Micronesian Mariculture Demonstration Center showed that in oyster pens which also contained the siganid fish *Siganus canaliculatus*, another maricultured animal, fouling organisms were not found. In empty pens without the fish, there was extensive growth of algae and other animals (Hasse, 1974).

In his review of *C. gigas* in the Pacific islands, Bourne (1979) specifically noted that with best information available no other exotic species were introduced with *C. gigas* seed to Palau, Vanuatu, New Caledonia, Fiji, Tonga, and Tahiti. He further added that this may have resulted because the seed originated at hatcheries and relatively small numbers of seed were introduced for only short periods of time.

Information concerning parasites and diseases among the islands is virtually nonexistent. No viral or bacterial diseases have been reported (Angell, 1986). A list of known parasites of *C. gigas* and *C. virginica* has been prepared (Cheng, 1967). A thorough review of competitors and fouling organisms associated with *C. gigas* details species which grow on the shells and some prevention and eradication measures (Arakawa, 1990b).

*Hartmannella tahitiensis* is an amoeba associated with a mass mortality of *C. commercialis* at Vahi tarua, Port Phaeton, Tahiti, in 1968 (Cheng, 1970). Specimens were alive but moribund when examined. Since *H. tahitiensis* is a soil animal, Cheng hypothesized that with the freshwater runoff and erosion individuals were washed into the estuary where they entered the oysters. He further added that the

amoeba 'should be considered as a facultative parasite of moribund oysters or, more appropriately, as a secondary invader of necrotic tissues rather than as a true parasite' (Cheng, 1970, p. 418). The species may not cause a problem if transported, since it does not attack healthy oysters.

Information on marine fungi is scarce; however, Lee et al. (1982) reported a mass mortality in Pearl Harbor, Oahu, in 1972 in which 99% was thought to be caused by fungal infection. Pearl Harbor might otherwise be considered a source of seed oyster. A mycelial disease (*Perkinsus*) is known from *C. gigas* and *C. virginica* in the U.S. (Quayle and Newkirk, 1989).

Flatworms of the genera *Stylochus* and *Pseudostylochus* are known to feed on oysters. In Hawaii, Brick (1970) reported heavy predation by an undescribed species of *Stylochus* on *C. gigas* and *C. virginica*. He reported 100% mortality after suspending two oyster racks in Kaneohe Bay, Oahu. Dead oyster shells contained one to five flatworms. In a second trial two week later, 40% mortality occurred within ten days. Hallier (1977) reported high mortality in *C. gigas* caused by a *Pseudostylochus* in 1975 and early 1976 at Lamap, Port Sandwich Bay, Malekula Island, Vanuatu.

Mud blister worms, *Polydora* spp., are closely associated with oysters. Individual worms bore into mollusk shells, forming a small mud-filled cavity. The blisters which form on the inner surface of the shell lower the marketability of the oyster and can cause public health problems. The best documented cases of *Polydora* infestation are in Hawaii. *Polydora websteri* was introduced into land-locked oyster runways either from individuals transferred from Kaneohe Bay or from oyster spat imported from the U.S. mainland. The infestation was so extreme that the oyster culture operation was eventually abandoned (Bailey-Brock and Ringwood, 1982).

*Polydora nuchalis* was introduced to Oahu (possibly with penaeid shrimp from western Mexico). This species of worm forms masses of mud tubes, accumulating large amounts of sediment, and may completely block drains and pipes. Transfer from one site to another is carried out easily when oysters are transported (Bailey-Brock, 1990)

*Polydora* infestations have been reported from French Polynesia in *C. gigas* which appeared not to be very resistant. An experimental hatchery for *C. gigas* closed after three years because *C. gigas* did not appear to be commercially culturable (Uwate et al., 1984). *Crassostrea echinata* appears to be less sensitive to *Polydora* (Uwate et al., 1984).

Several different snail species are predators on oysters. Among the more important are the oyster drills (family Cymatidae) but little is known about them among the Pacific islands. In Tonga, unexplained mortality reduced stocks of *C. gigas*, and the remaining individuals were killed by the drill, *Cymatium* (Uwate et al., 1984). The mud crab *Scylla serrata* also preys on oysters.

Any or all of the above organisms can be transported either as juveniles or adults on oyster shells or in contained water when they are transferred from culture area to culture area or from island to island. Caution is of utmost importance in order to avoid disaster.

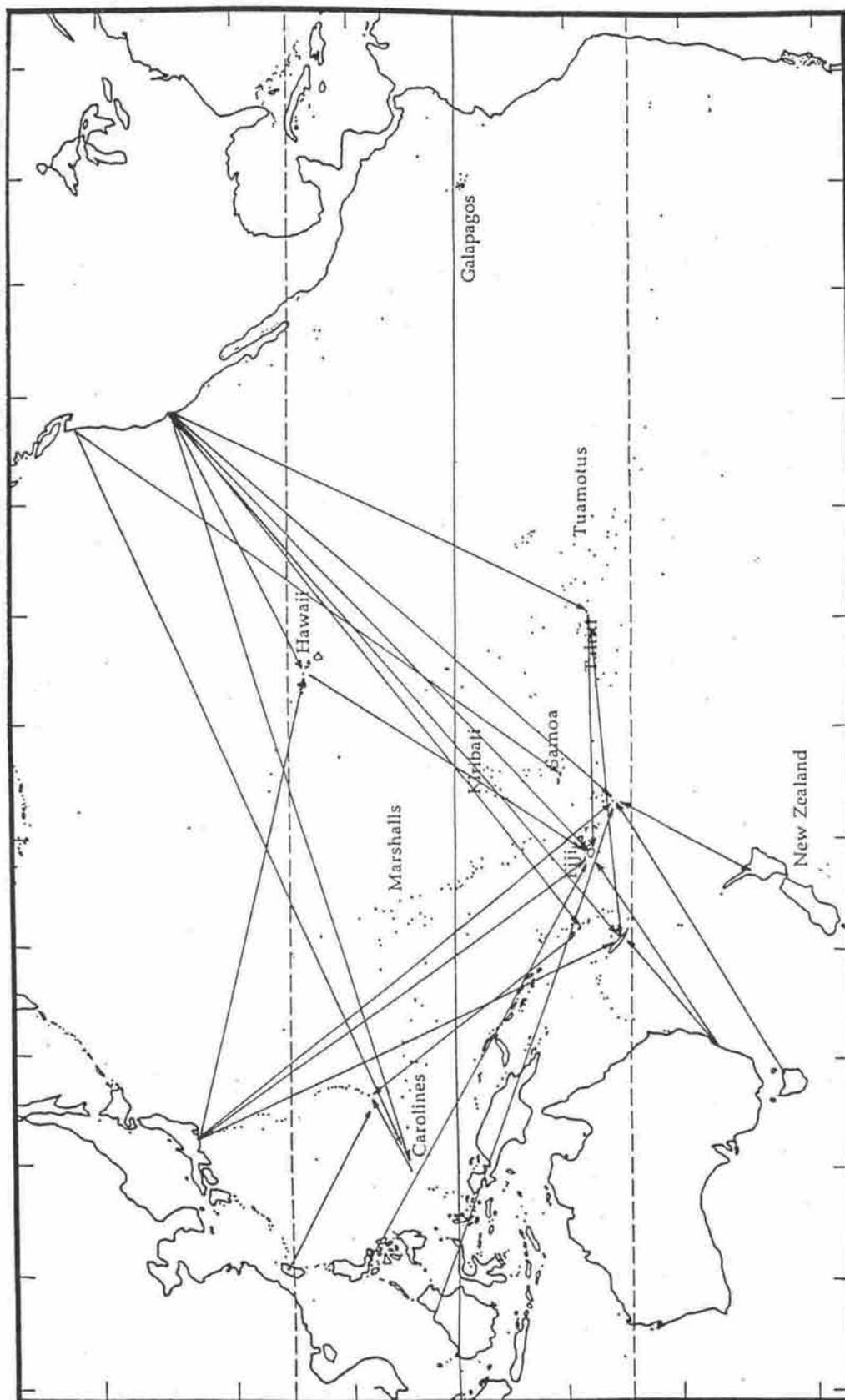
Some public health problems can arise from transporting oysters. Red tides caused by the dinoflagellate *Pyrodinium bahamense* are known to produce paralytic shellfish poisoning or PSP. This is the result of eating bivalves (oysters, mussels, etc.) which have been harvested during red tides. Deaths may occur as a result of respiratory failure within 12 hours. PSP has been around Papua New Guinea for many years and has been spreading rapidly to Palau, Guam, Tuvalu, Fiji, and the Solomon Islands (Macleay, 1984).

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Oysters – generalized map of oyster transfers among the Pacific Islands, all species included; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.

## GREEN MUSSEL [*Perna viridis*]

Green mussels, *Perna viridis* (formerly known as *Mytilus viridis* and *Mytilus smaragdinus*), are marine bivalves with thin green shells which live attached to rocks and hard substrate in shallow waters. The biology and culture of three species of *Perna* have been reviewed by Vakily (1989). The taxonomy of the genus and the three species has been discussed by Siddal (1980).

Below is a chronological summary of green mussel introductions to south Pacific islands (modified from Uwate et al., 1984, with additions).

### Cook Islands

1984: small collections from Tahiti informally introduced; unsuccessful (Sims, pers. comm.)

### Fiji

1975: (April) 800 specimens brought from the Philippines, initial mortality high; individuals surviving showed excellent growth; spawning twice a year

1976: (January) additional specimens from the Philippines; 99% survival during first two months

1976: (October) additional imports

1981: grow-out trials at Namarai Bay, Laucala Bay, and Rewa delta at Suva; predation heavy; no evidence of natural spatfall; commercial production potential (Navakalomona, 1982), no projects implemented; trials terminated

1987: 1,500 surviving individuals cleaned, quarantined, and moved to Naqara for observation (Anon., 1987) [Fiji mussel project closed in 1989 (Adams, pers. comm.)]

### French Polynesia

1978: green mussel introduced from New Caledonia to Tatutu Bay and Uturoto Bay; spat production found viable (AQUACOP, 1979; AQUACOP, 1982)

1979: culture studies initiated; successful larval development and settlement (AQUACOP and de Gaillande, 1979); culture area caged to exclude principal predator (*Scylla serrata*)

1990: spat production continues, estimated 3 million annual production (Preston, 1990)

### New Caledonia

1972: green mussels introduced from Manila Bay, Philippines, to Baie de Saint-Vincent (SPIFDA, 1972)

1976: second introduction from the Philippines; initially grown at private farm until 1978

1978: eggs to St. Vincent Station and 3 private farms

1979-1980: more than 3 million eggs successfully fertilized at one farm, others less successful

1983: mussel farming program initiated, mangroves and stream bed appeared adequate

### Tonga

1975: transport from the Philippines attempted, no survival

1976: specimens imported from Singapore, survival rates encouraging; seeded in lagoons at Tongatapu, Pangaimotu, and Vava'u

1976: specimens from the Philippines, 40-50% mortality; also some raft culture, most died

1977: green mussels from Sabah cultured in Umisi area of Fanga'uta Lagoon, growth rates encouraging

1978: two shipments (100,000 individuals, including *Crassostrea belcheri*) from Sabah, good growth but trial culture did not provide meaningful results

1983: no further studies planned

## Western Samoa

1981: study initiated

1982: (June) importation from Tahiti (40,000 81-day old spat), planted close to Apia

1983: (February) 70,000 spat, to remote areas of Savai'i and Upolu islands (Bell and Albert, 1983); 10% mortality

Western Samoa status reports are the most thorough (Bell and Albert, 1983; Bell, et al., 1983; Bell and Albert, 1984). In June 1982, 40,000 spat were received. Of these 3,000 were planted at Fisheries Harbour and 10,000 at Mulinu'u which had high mortality during the first month. Of those planted at Fisheries Harbour, only 220 remained in June 1983 when the rafts were dismantled. In the second phase of the culture, 40,000 spat were planted in Safata Bay (30,000 attached to rafts and 10,000 placed in trays) in February 1983. Of these, 3,500 remained in June 1983. Siltation and predation by crabs appeared to be a problem. At Asau on Savai'i, 30,000 spat were attached to two rafts in February 1983. In June of that year between 20,000 and 25,000 mussels remained, and in September 1983 the rafts were densely populated but no spatfall had been observed. One raft was completely harvested.

As with other mollusks, little is known about diseases, parasites, or predators of mussels. Vakily (1989) reported on earlier investigations and noted that in India potentially pathogenic bacteria were part of the normal flora of both the mussel and the surrounding seawater. Further, Vakily (1989) added that the crab *Scylla serrata* was also a predator in Brunei, Malaysia, and the Philippines. He also noted that in India and off the South African coast fish (Family Sparidae) prey on raft-cultured mussels.

*Perna canaliculus*, the New Zealand mussel, has been reported from Australia. Specimens from Tasmania are held in the Australian Museum. Individuals may have arrived through ship fouling but have apparently not become well established (Pollard and Hutchings, 1990).

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## PEARL OYSTERS [*Pinctada* and *Pteria* species]

Marine species of pearl oysters (family Pteriidae) belong to two genera – *Pinctada* and *Pteria*. Specimens of *Pinctada* have subquadrate shells and a short hinge line; those of *Pteria* have extended hinge lines which form wing-like shells (Kay, 1979). The biology and culture of pearl oysters have recently been reviewed (Gervis and Sims, 1992).

Three species of *Pinctada* have been transported and cultivated among the Pacific islands. *Pinctada fucata martensi* (Japanese pearl oyster) occurs naturally in Japanese waters and was taken to Palau in the mid 1930s. The other two species – *P. margaritifera* (black-lip pearl oyster) and *P. maxima* (gold-lip pearl oyster) – occur more widely throughout the Indo-west Pacific region. *P. margaritifera* is found from the Red Sea and Persian Gulf to Hawaii and southeastern Polynesia, as well as in the Gulf of California and the Pacific coast of central America. *P. maxima* is restricted to the Indo-Malayan region from Burma eastward to the Solomon Islands and northward to south of Japan, including all of Malaysia, Indonesia, and the Philippines (Doumenge et al., 1991; Gervis and Sims, 1992).

The taxonomy of pearl oysters has a confusing history. More than 100 names have been proposed for what are now thought to be about a dozen species (Ranson, 1961; Doumenge et al., 1991). *Pinctada fucata martensi* has teeth on the hinge; the other two species do not. The shell of *P. margaritifera* is dark and slightly more convex than that of *P. maxima*. Adults of the latter species remain unattached; those of the former are attached by a byssus to solid substrate.

Pearl oysters have been transplanted since the beginning of the century (Saville-Kent, 1905). In the 1930s, Japanese interests introduced *P. maxima* to Micronesia, and in the 1970s there were several additional transfers. Since the species are widely spread, note is made here only of known introductions of individuals transported from one island to another (modified from Uwate et al., 1984, with additions).

### *Pinctada fucata martensi* [Japanese pearl oyster or akoya]

#### Marshall Islands

1935–1936: specimens to Ebon from Japan for Mikimoto pearl farm(s); planting and operations abandoned in 1942

#### Palau

1935–1936: specimens from Japan for Mikimoto pearl farm(s); before World War II, eight separate farms were known in Palau; plantings and operations were abandoned in 1942 (Smith, 1947)

#### Tonga

1975–1977: 1,979 specimens to Vava'u from Tasaki Pearl Co., Amani, Japan along with *P. margaritifera*, *P. maxima*, and *Pteria penguin* (Tanaka, 1990)

### *Pinctada maxima* [gold-lip pearl oyster]

#### Cook Islands

1904: Lever Brothers transplanted 1,500 specimens to Suwarrow Island from Cape York Peninsula in the Torres Straits (Saville-Kent, 1905)

#### Kiribati

1904: Lever's Pacific Plantation Ltd., transported pearl oyster to Christmas Island lagoon from the Torres Strait; unsuccessful

## Palau

1935–1942: 77,460 shells transported from northwestern Australia and Indonesia (by the Arafura pearling fleet); 43,185 implanted, yielding 11,460 pearls 1942 pearl operations terminated

## Tonga

1977: introductions from Tasaki Pearl Co., Amani, Japan

*Pinctada margaritifera* [black-lip pearl oyster]

## Cook Islands

1955: individual shells from Manihiki to Rakahanga; later to Pukapuka (1956) and Palmerston (1957); successful (Noakes, 1959)

1980s: Department of Fisheries working with commercial company on spat collection to be distributed to grow-out facilities

1980s: several transfers to Rakahanga from Manihiki (4520 in 1982); two shipments in 1985

## French Polynesia

ongoing: spat collection at Hikueru, Takapoto, and Takaroa seeded in lagoons of various islands

1979: spat from Okinawa to Takapoto (Millous, 1980)

## Kiribati

1977: natural stocks transferred to Christmas Island, planted at sites east of Cook Island and northeast of Wood Island; specifics unknown [possibly remnants of the original native stock (Sims, pers. comm.)]

## Tonga

mid-1970s: introductions from Tasaki Pearl Co., Amani, Japan

Unidentified pearl shell introductions, probably *P. maxima*

## Papua New Guinea

1977: 7,000 live 'mother-of-pearl' shells collected at Kuri Bay, Western Australia, to be planted in Fairfax Harbor, Port Moresby; promising, but polychaete infestation caused high mortality; farm closed because of economic considerations

Although native (but rare) throughout the Hawaiian Islands, 300 *Pinctada margaritifera* (formerly known as *P. galtsoffi*) from Pearl and Hermes Reef were taken to Coconut Island in Kaneohe Bay in September 1930, and in August 1950, 6 were added (Brock, 1952). Individuals of *Pinctada fucata martensi* were brought to Hawaii in 1956 (Kanayama, 1967).

Braley (1991) investigated the introduction of *P. margaritifera* to Tokelau and suggested that broodstock be obtained from the northern Cook Islands, since there would be probably less chance of transporting new parasites and diseases from a neighboring lagoon.

In 1975, individuals of the mabe shell or blister pearl (winged pearl shell) *Pteria penguin* were imported to Tonga from Japan. Growth was excellent. Additional specimens were received from the Tasaki Pearl Co., but prior to Hurricane Issac (March 1982) all mabe pearls were harvested; however, in 1983 some pearl shells were still being cultivated at other sites. In 1990, several specimens of *Pteria* were reported on FAD lines at Vava'u; there was no way of determining whether or not they originated from this earlier introduction (Tanaka, 1990).

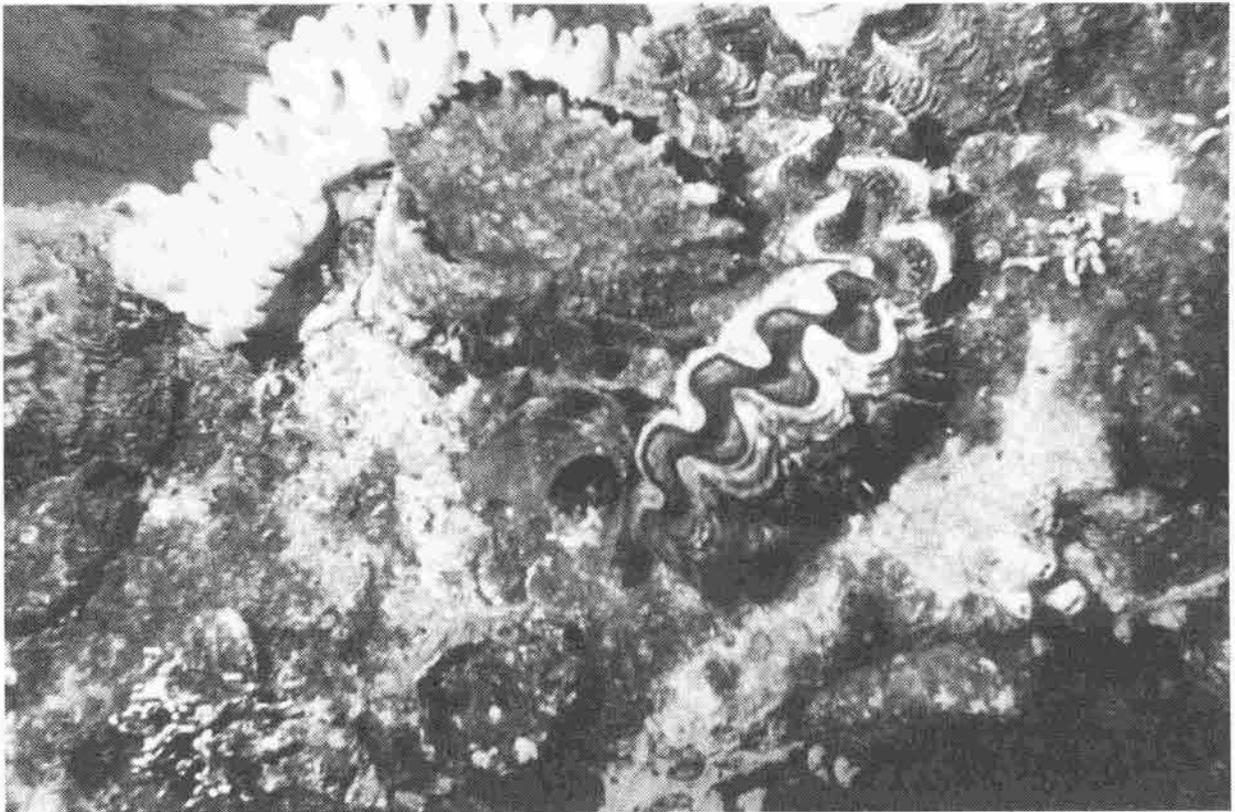
Inter-island transfer of shells provides an opportunity for diseases and parasites to be further transmitted. Gervis and Sims (1992) reviewed fouling and boring organisms and parasites and pathogens. An additional associate is a mud-blister worm *Polydora pacifica* which forms bore-holes and produces tumor-like growths on the inner surfaces of the shells at Palau (Takahashi, 1937).

A virus, which first appeared at atolls in the Gambiers, is suspected to have caused the deaths of as many as one million shells at Takapoto in the Tuamotu Archipelago, and a ban on transfers was initiated (Anon., 1985). Additional mortalities have occurred. In 1985, 50% to 80% of the stock died, in 1988 mortalities were still high (Cabral, 1989). These deaths apparently resulted from a variety of factors, including transfer of shells from one lagoon to another. The French Polynesian Ministry of the Sea authorizes transfers in an attempt to control the spread of diseases (Cabral, 1992). Diseases of cultured *P. margaritifera* in French Polynesia have appeared in wild stocks and other bivalves (Gervis and Sims, 1992).

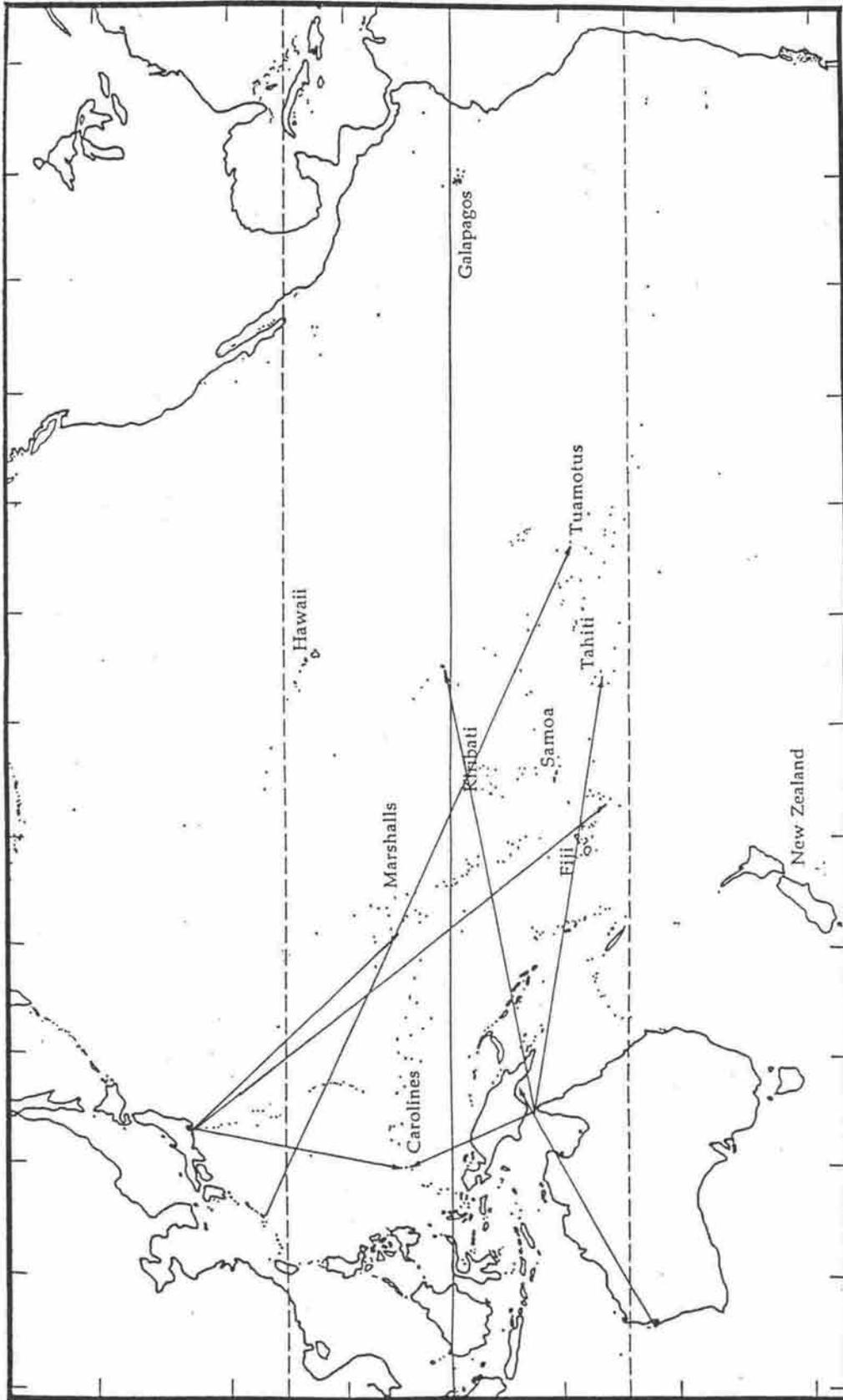
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*Pinctada margaritifera* (upper middle) on reef flat with *Tridacna* [Photo: N. Sims]



*Pinctada* species – generalized map of pearl oyster transfers among the Pacific Islands, all species included; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.

## FRESHWATER CLAMS [*Corbicula fluminea*]

The Asiatic clam *Corbicula fluminea* was widely introduced into North America in the early 1900s from south-east Asia. The species presently occurs from the U.S. west coast and southern states, throughout drainage east of the Mississippi River and into northern Mexico (McMahon, 1991).

In Hawaii, living Asiatic clams were first observed at an 'open market' in Kailua (Oahu) in August 1977, having been illegally imported through a Los Angeles exporter (Burch, 1978). Additionally, it was noted that previously confiscated *C. fluminea* had arrived from the Orient.

In 1982, *C. fluminea* was first discovered on Kauai (Devick, 1991a) where it had spread to at least 14 reservoirs and irrigation ditches and to five rivers and streams in eight watersheds (Heacock, 1991). In March 1988 the Asiatic clam was also found in a major irrigation system in central Maui but none had been found in streams (Hau, 1991). These clams have also been seen at local 'swap meet' markets on the Big Island of Hawaii. Specimens were found on Oahu in 1988, in Manoa Stream (Oahu) in 1990 (Devick, 1991a), and at Kaneohe in 1992 (Burch, pers. comm.).

Asiatic clams were probably introduced by Asian immigrants for food, even though the first seen in Hawaii were from California. These clams grow rapidly and can completely block irrigation pipes and create large amounts of sediment in ditches. In California reservoir fishes are known to have declined because of competition for bottom-living food (Devick, 1991a). For the Pacific islands, all possible means to avoid introduction should be pursued.

In addition, individuals of a species of the clam *Musculium* had become established in reservoirs on Oahu and Maui by 1990 (Devick, 1991b).

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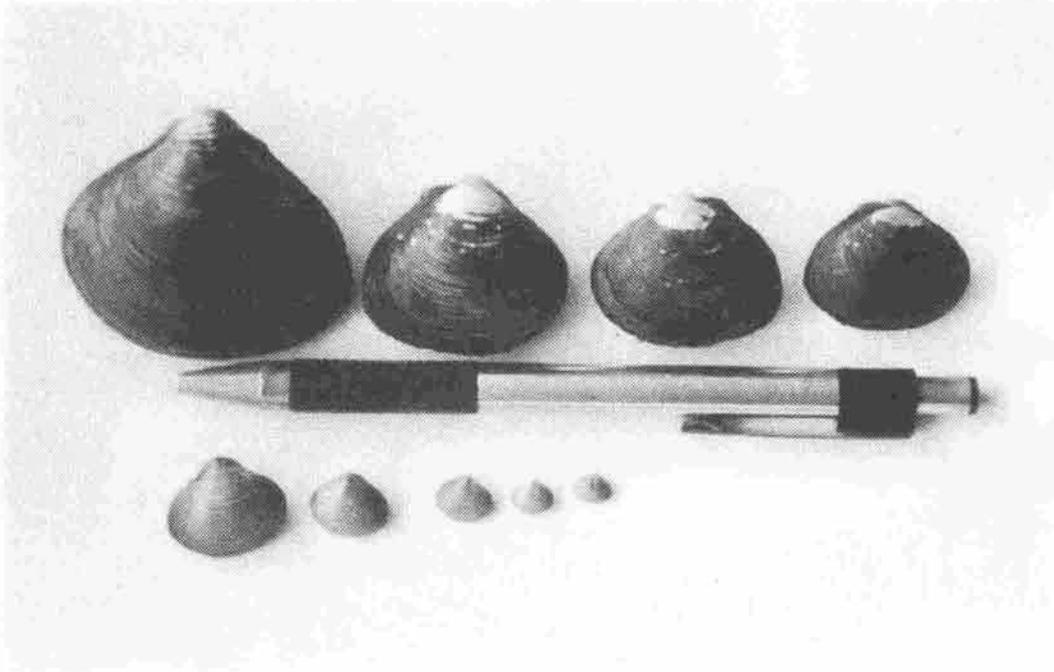
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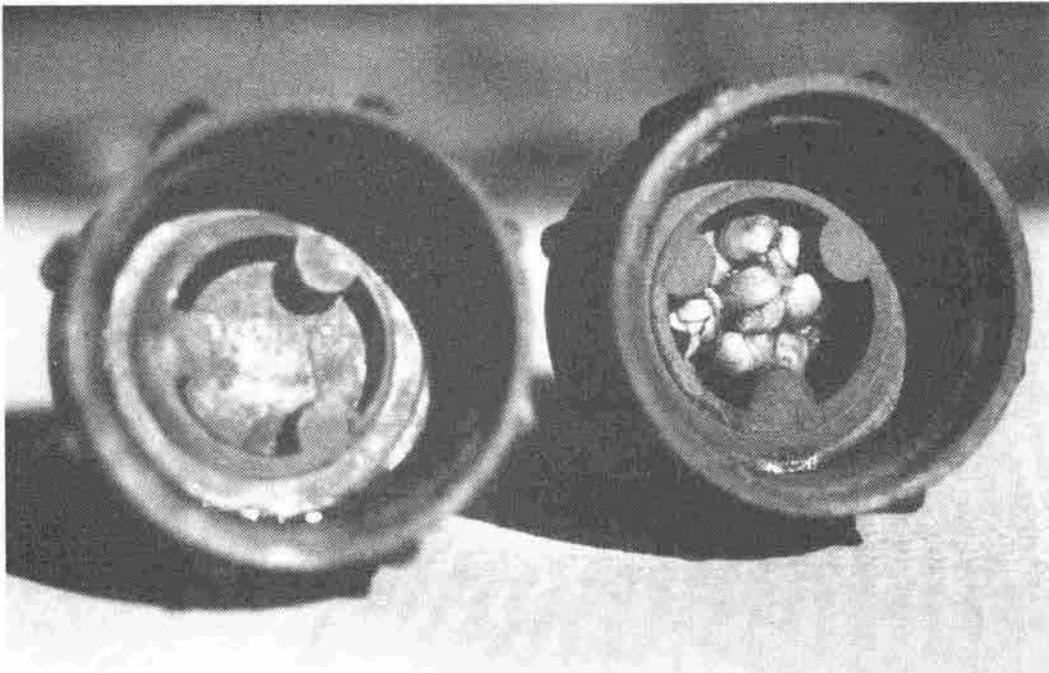
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*Corbicula fluminea*, size series, Maui (Hawaii) [Photo: S. Hau]



*Corbicula fluminea* blocking irrigation pipes, Maui (Hawaii) [Photo: S. Hau]

## OTHER BIVALVES

The first introduction of *Tapes japonica* [= *Venerupis semidecussatus*, *V. philippinarum*] [Japanese clam, Manila clam] occurred at the turn of the century (Kay, 1979). In 1920, 10 barrels of clams were brought from Japan and planted at Pearl Harbor, Kaneohe Bay, and Waialae Bay, Oahu, Hawaii (Brock, 1960) where they became well established. Open harvesting began in 1965, but over-collecting caused such a population decline that all harvesting was officially stopped in 1969 (Yap, 1977). About 3000 to 5000 very small clams were sent to Fiji in 1971 from California along with a shipment of seed oysters (Glude, 1972). They arrived in excellent condition and were placed in trays at Cave Island in Bay of Islands near Suva. The present status of these clams is unknown (Andrews, 1985). Known as 'palourde' in France, individuals were transported to French Polynesia in 1980 (AQUACOP, 1982). Initial results appear good; they attained commercial size in less than a year.

Another Japanese clam, *Cytherea meretrix*, was introduced to Hawaii from Japan in 1929 when some 10 gallons were planted at Kaneohe Bay and Kalihi, Oahu. In 1939, a second shipment of 20,000 young individuals was planted at Kaneohe Bay (Edmondson and Wilson, 1940; Brock, 1960). Introduction of the Pismo clam *Tivela stultorum* to Hawaii in 1927 and 1928 was unsuccessful (Brock, 1960).

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# **GASTROPODS**

## TROCHUS [*Trochus niloticus*]

The large trochus, *Trochus niloticus*, is a member of the topshell family Trochidae. Its natural distribution ranges from the Andaman Islands in the Indian Ocean to the Pacific Islands of Fiji and Wallis, including Palau, Yap, Papua New Guinea, the Solomon Islands, Vanuatu, and New Caledonia, and the north and north-eastern coasts of Australia (Bour, 1990). Individuals have been introduced to all other islands where they are presently found (see list below).

Individuals live in shallow-water reef flats. In general, smaller individuals (<20 mm) are found in the shallowest water and larger ones (30–90 mm) seaward on the reef flat. Larger animals are found less commonly at depths as great as 7 m, and individuals have been reported at depths to 24 m (McGowan, 1956; Smith, 1987). Trochus feed on the low algal turf growing over the coral rubble substrate. The biology of trochus has been reviewed by Nash (1985) and Bour (1990).

Trochus shell has been harvested since the beginning of the 1900s. World production is currently estimated to be between 3000 and 6000 tons, making this species one of the most valuable gastropods in the world market both for shell and for meat.

In Palau and Yap, trochus was commercially collected between 1898 and 1914 by the Germans; however, data were not maintained until 1915. Between 1920 and 1930, the catch ranged between 100 tons and nearly 400 tons (McGowan, 1958). In 1918 at Yap alone, the catch reached more than 65 tons because of the introduction of Okinawan fishermen; the catch then greatly declined because of overharvesting (Asano, 1939b). For New Caledonia, figures have been recorded since 1907, and between 1918 and 1940 varied between 200 and 1000 tons (Bour, 1990). In Fiji, 561 tons were exported in 1925; the catch then steadily declined to 183 tons in 1939 (Burrows, 1941). Trochus catch increased after a slump in the 1950s and 1960s; more than 588 tons were exported in 1973. Total catches averaged around 400 tons per year during most of the 1980s (Adams, pers. comm.).

In the Torres Straits of eastern Australia, trochus harvesting began in 1912 and grew steadily. The fishery increased sporadically to 966 tons in 1915, 1097 tons in 1927, and other peaks in 1946, 1950, and 1953 (Nash, 1985). By 1927, the fishery had expanded to Swains Reefs at the southern end of the Great Barrier Reef.

Experimental introduction to Chuuk (Truk) was begun in 1927. More than 6000 individuals had been transplanted by 1931. Since the Chuuk project was successful, introductions were initiated to several other Caroline islands between 1930 and 1940, to Saipan in 1938 and to Jaluit in 1939. Further introductions were interrupted by World War II.

In the 1950s, the introduction of trochus was reinitiated. During this time the South Pacific Commission began encouraging transplantation (van Pel, 1957), and the Administration of the Trust Territory of the Pacific Islands supported extensive surveys in Micronesia (McGowan, 1957, 1958). Somewhat later specimens were unofficially carried from Saipan to Guam and have become very successfully established (Smith, 1987). The FAO/UNDP Fishery Support Programme further supported this and began an ambitious transplant program in the mid-1980s (Gillett, 1992).

Little is known about the ecology of trochus other than its general distribution, growth rates, and food preferences. Large shells are the habitats for several other invertebrates and algae. Boring sponges and worms are commonly found. The hipponicid snail *Sabia conica* is also often found on trochus, where it usually forms a scar in the shape of its shell (Smith, pers. comm.) For the Andaman and Nicobar Islands, Rao (1937) described some aspects of trochus ecology and biology. He noted that bivalves (*Lithophga nasuta*, *L. laevigata*, *Parapholas quadrizonata* and *Roccellaria* sp.) bore into shells. Gastropods (*Saptadanta nasika*, *Patella tara* and *Vermetus andamanicus*) cause damage to the periostracal and nacreous layers of the shell (also Prashad, 1933, 1934).

Parasites are apparently unknown. A commensal copepod (*Panaietis incamerata*) has been found in the buccal cavity and esophagus of *T. niloticus* at the Andaman Islands (Monod, 1934).

Impacts of trochus introduction have not been systematically investigated. Anecdotal reports include the apparent decrease of the small turbinid snails (*Turbo setosus* and *T. argyrostomus*) following the rapid increase and spread of trochus at Aitutaki (Sims, 1984a, 1985b).

**Chronological list of trochus introductions to Pacific islands:**

[from Gillett, 1992, with modifications and additions]

Before 1927: Palau to Chuuk (=Truk) and Pohnpei

Unsuccessful attempts (South Seas Government, 1937; McGowan, 1957)

1927–1931: Palau to Chuuk

Total of 6724 shells transferred in bait wells of skipjack boats; 5 years elapsed before judged successful; first harvest in 1939, greatest annual harvest 230 tons in 1952 (Asano, 1937, South Seas Government, 1937; McGowan, 1957, 1958)

1930: Palau and Yap to various sites in Caroline Islands

Japanese government and private companies transferred shells among islands, including Ngulu, Ngatik, Mokil, Puluwat, Ulithi; unsuccessful at Kapingamarangi, Nukuoro, Satawan (McGowan, 1957)

1937: Palau to Puluwat

9,740 shells planted on reef at Enderby (=Puluwat) [map arrow to Phoenix in Bour et al. (1982) probably mistake for Enderby; arrow not in Bour (1990)] (South Seas Government, 1938)

1938: Palau to Saipan

2,974 individuals released (Asano, 1938, 1939a; South Seas Government, 1939)

1939: Chuuk to Pohnpei

Two trips, skipjack vessel transported 6,745 shells (South Seas Government, 1938; Asano and Inenami, 1939)

1939: Chuuk to Jaluit

6,143-ton cargo ship carried 1,740 shells in four water tanks (South Seas Government, 1938; Asano and Inenami, 1939)

1939: Palau to Pohnpei

6,745 shells transferred, greatest harvest 180 tons in 1951 (McGowan, 1957)

1939: Palau to Satawal

5,000 shells transferred, success not known (McGowan, 1958)

1939 or 1940: Yap to Ulithi

Very successful (McGowan, 1957; McCoy, pers. comm.)

1939: Palau to Jaluit

Shells transferred to other atolls of the Marshall Islands, including Majuro and Ailinglaplap; transfer to Ebon not successful (McGowan, 1957; Bour et al., 1982)

1940s or early 1950s: Pohnpei to Kosrae

Unsuccessful (McGowan, 1958)

Early 1950s: Saipan to Guam

Shells transplanted by two fishermen, very successful (Smith, 1986; Stojkovich and Smith, 1978)

1952: Guam to Hawaii

27 shells released in Coconut Island ponds, Kaneohe Bay (Brock, 1952)

- 1954 :? to Kili Atoll  
Unsuccessful (McGowan, 1958)
- 1957: Fiji (Viti Levu) to Aitutaki  
Two transfers made – one in seawater, other (40 shells) in damp crates; trochus plentiful in 1965, first harvest of 200 tons in 1981 (Van Pel, 1957; Devambe, 1960; Sims, 1984a, 1984b; Powell, pers. comm.)
- 1957: Vanuatu to Tahiti  
1,200 shells shipped in circulating water tanks; 40 survived the 15-day trip (Yen, 1985 and pers. comm.)
- 1958: Fiji to American Samoa  
No details available (Bour et al., 1982); no specimens observed (as of 4/92) during several invertebrate surveys (B. Smith, pers. comm.)
- 1958: New Caledonia to Tahiti  
40 shells transferred by aircraft in damp sacks; first harvest 1971, greatest annual harvest 261 tons in 1973 (Van Pel, 1957; Powell, 1960, Anon., 1972)
- 1959: Pohnpei to Kosrae  
500 live trochus released at 13 locations, large numbers observed in August 1973 (Wass, 1973; Gawel, 1982)
- 1963: Guam to Hawaii  
750 trochus released in Kaneohe Bay; 1967 survey showed survival but no indication of reproduction observed, some specimens observed in 1970, one dead and eroded shell found in 1977, one large live specimen collected in 1978 kept at Coconut Island for about one year (Kanayama, 1967; Katekaru, pers. comm.; R. Brock, pers. comm.)
- 1963: Tahiti to Moorea and Bora Bora  
800 shells to Moorea; 660 to Bora Bora (Anon., 1972; Yen, 1988)
- 1964: Tahiti to Raiatea  
400 shells transferred (Anon., 1972; Yen, 1988)
- 1968: Tahiti to Tuamotu  
120 shells to Manihi (Yen, 1988)
- 1968: Tahiti to Australs  
83 shells transferred to Tubuai and Rurutu (Yen, 1988)
- 1968: Tahiti to Gambier  
100 specimens transferred (Yen, 1988)
- 1969: Tahiti to Tuamotu  
60 specimens to Tikehau, 170 to Fakarava, 64 to Takarua, 60 to Anaa, 100 to Pukapuka, 355 to Rangiroa (Yen, 1988)
- 1972: Tahiti to Australs  
500 specimens to Tubuai (Yen, 1988)
- 1972: Tahiti to Tuamotu  
160 specimens to Arutua, 100 to Apataki (Yen, 1988)
- 1972: Tahiti to Gambier  
300 specimens transferred to Aukena and Akamaru (Yen, 1988)

- 1973/1981–1982: Aitutaki to Palmerston  
Several unsuccessful transplants; 2,000 in 1981, 1,000 in 1982 (Powell, pers. comm.; Sims, 1984a)
- 1981–1983: Aitutaki to Southern Cook Islands  
500 shells to Manuae, uncommon in 1985; 300 to Mitiaro, rare or extinct; 300 to Mauke; 300 to Atiu, rare or extinct; 300 to Mangaia, rare; 200 to Rarotonga, rare or extinct (Sims, 1984a, 1984b); estimated (unexploited) population (1993) 154,735 (Adams, pers. comm.)
- 1982: Aitutaki to Rakahanga and Manihiki  
Shells transported on ship deck in wet sacks, unsuccessful, all dead before arrival (Anon., 1983; Sims, 1985a)
- 1983: Yap to Woleai  
2,000 specimens transplanted, all died in transit (Fagolimul and Price, 1987)
- 1984: Yap to Woleai and Fachaulap (=Faraulep)  
4,708 to Woleai (12 died); 2,200 to Fachaulap (Fagolimul and Price, 1987)
- 1984: Somewhere in Marshall Islands to Ebon, Aur, and Maloelap  
Conducted in conjunction with trolling resource survey (Elanzo, pers. comm.)
- 1985: Yap to Ifalik and Eaurpik  
924 to Ifalik (541 died); 875 to Eaurpik (359 died) (Fagolimul and Price, 1987)
- 1985: Aitutaki to Northern Cook Islands  
439 specimens to Penryhn, 6 days in bait tank; 398 to Manihiki, 9 days in bait tank; 693 to Rakahanga, 10 days in bait tank; to Pukapuka, 13 days in bait tank, all died (Sims, 1985a)
- 1985: Aitutaki to Suwarrow  
460 specimens carried for 3 days in flooded skiff, very low mortality (Sims, pers. comm.)
- 1985: Fiji (Viti Levu) to Tuvalu (Funafuti)  
181 specimens transferred in three air shipments, successful (Parkinson, 1984; Pita, 1985; Adams, pers. comm.; Batty, pers. comm.)
- 1986: Aitutaki to Northern Cook Islands  
1,200 trochus shipped, carried in flooded skiff, very good survival rate (Dashwood, pers. comm.)
- 1986: Fiji (Viti Levu) to Tokelau  
1,029 specimens transferred (584 by ship via Western Samoa, 161 flown to Western Samoa, 284 flown directly to Fakaofu and parachuted); one juvenile found in December 1987 (Gillett, 1986; Vola, 1987; Gillett 1988a)
- 1986: Yap to Eaurpik, Elato, Lamotrek, and West Fayu  
3,125 specimens transferred, 22 died en route (Fagolimul and Price, 1987)
- 1987: Aitutaki to Suwarrow  
1,000 specimens transferred via flooded skiff, no mortality (Sims, pers. comm.)
- 1987: Fiji to Funafuti  
200 specimens transported on commercial aircraft, 20 died en route (Petaia, pers. comm.)
- 1987: Yap to Fais, Ifalik, and West Fayu  
2,504 specimens transferred, 77 died en route (Fagolimul, pers. comm.)
- 1988: Aitutaki to Tokelau  
578 specimens transferred to Fakaofu using aircraft and parachute (Gillett, 1988b)

- 1988: Aitutaki to Tuvalu  
1,336 specimens to Nukulaelae, 2,674 to Funafuti, and 844 to Nukufetau, using military aircraft and parachutes (Gillett, 1988c)
- 1989: Aitutaki to Tokelau and Tuvalu  
1,000 specimens to Nui, 600 to Nanumea (a second drop of 600 fell from the harness after the parachute opened, survival unknown), 1200 to Atafu, and 1,080 to Nukunonu, using military aircraft and parachutes (Gillett, 1990)
- 1989: New Caledonia (Mainland) to Loyalty Islands  
5,709 juveniles transplanted from the mainland to Lifou Island may have spawned early in 1990 (Hoffschir, 1990; Hoffschir et al., 1990)
- 1989: Pohnpei to Nukuoro and Kapingamarangi  
500 specimens to each island, using flooded skiff on deck, about 6 died in transit (Curren, pers. comm.; Gawel, pers. comm.)
- 1989: Guam to Pingelap  
300 hatchery-reared juveniles transplanted via Pohnpei, placed at south-east end of atoll (B. Smith, pers. comm.)
- 1990: Fiji to Western Samoa  
40 specimens transported in September using commercial aircraft and released at Namu'a Island in Aleipata area, some large shells kept at Fisheries Division (Zann, pers. comm.)
- 1991: Woleai to Elato and Lamotrek  
500 seedlings to Elato (no mortality); 304 seedlings to Lamotrek (MRMD, 1993; Iou, pers. comm.)
- 1991: Ulithi to Sorol  
514 shells transported, 3 died en route (A. Smith, pers. comm.)
- 1992: Fiji (Lakeba) to Tonga and Niue  
Approximately 250 shells planted at Tapania Island, Vava'u; 213 specimens transplanted to Niue (99 at Uani near Hakapu Village, 77 at Matalave and Makatutuaha near Namukulu Village, 47 at Patuoto near Tamakautoga Village; 35 retained at Tongatapu (Gillett, 1992)
- 1992: Ulithi to Sorol and Eaurpik  
500 adults (3–5 inch) to Sorol (no mortality); 3 to Eaurpik (MRMD, 1993; Iou, pers. comm.)
- 1992: Woleai to Fachaulap  
200 seedlings to Fachaulap (MRMD, 1993; Iou, pers. comm.)

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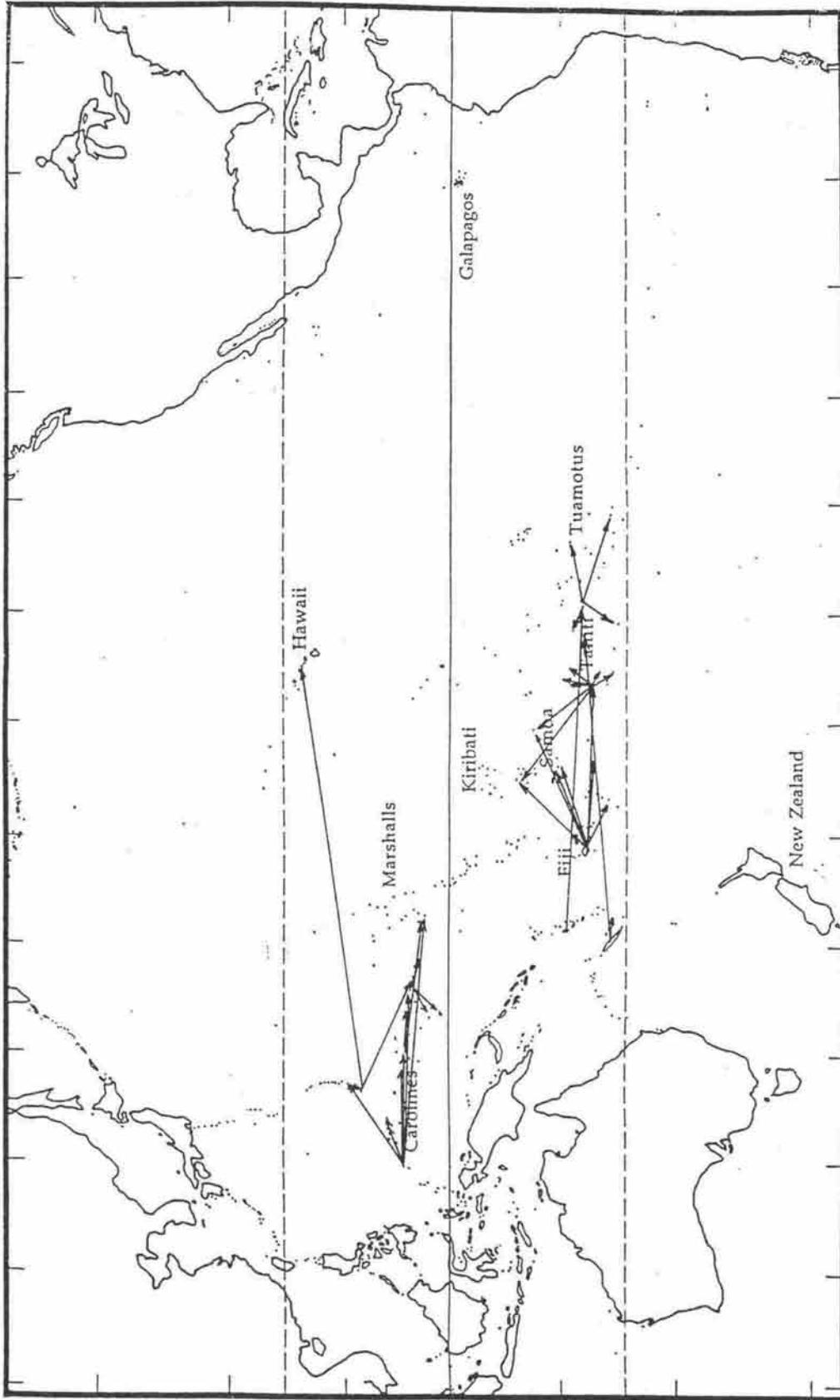
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*Trochus niloticus* on reef flat at Guam [Photo: B. D. Smith]



*Trochus niloticus* – generalized map of trochus transfers among the Pacific Islands; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.

## GREEN SNAIL [*Turbo marmoratus*]

The green snail *Turbo marmoratus* is a large gastropod which is found naturally west of Fiji and considered to be limited to continental islands such as Papua New Guinea, Solomon Islands and Vanuatu (Yamaguchi, 1989) (but not New Caledonia). The biology of the green snail, based primarily on studies conducted in the Ryukyu Islands, has been described by Yamaguchi (1988). Shells of these snails are highly prized for jewelry and other ornamental artwork, such as wood inlay. As more needs arose for mother-of-pearl shell, consideration was given to green snail culture.

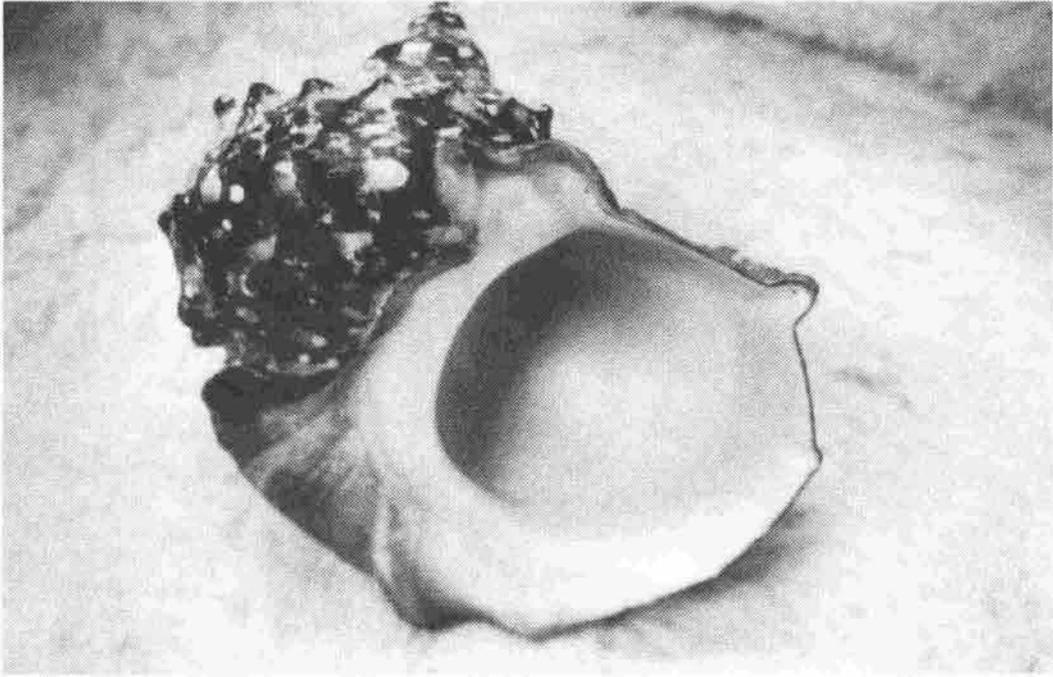
In 1967, 300 green snails were collected at Efate, Vanuatu, for shipment to Tahiti. Forty-two survived the trip and were immediately planted on the outer slopes of the reef at Tautira along the east coast of Tahiti (Yen, 1991). During a 1971 survey, seven adult green snails were observed. Several months later in October 1972 two juveniles were collected at Faaone, thus confirming the success of the introduction. Between September 1979 and January 1980, a general survey was conducted, showing that the green snail had naturally spread along the entire east coast of Tahiti and was found only at depths of 1 to 15 m. This success led to additional transplanting around Tahiti, beginning in 1976. [Yen (1991) provides a table of all introductions.] Between 1980 and 1981, green snails were further transplanted to Moorea, Huahine, Raiatea, Tahaa, Bora Bora and Maupiti in the Society Islands and to islands in the Tuamotu Archipelago where new introductions were also made between 1985 and 1990. A stock assessment study was conducted at Pointe Venus, Tahiti, where populations were found to be most dense at 2.5 m and a size/weight curve was determined (Gauducheau et al., 1991).

In November 1981, 12 specimens were sent to the Cook Islands for planting at Aitutaki [some escaped at Rarotonga (Sims, pers. comm.)], and during May 1982, green snails were taken to the Gambier Islands (Yen, 1991). At Aitutaki no green snails were observed during a month-long trochus survey (Adams, pers. comm.) The status of other introductions (to New Caledonia) is unknown (Yamaguchi and Kikutani, 1989). A feasibility study was conducted to introduce green snails to the Federated States of Micronesia (Yamaguchi and Kikutani, 1989). In 1993, the Ministry of Fisheries at Tonga requested that some green snails be transplanted from Vanuatu (Adams, pers. comm.). [The status of these requests is unknown.]

Unfortunately, virtually nothing is known about potential problems of introductions of this nature.

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*Turbo marmoratus* (about 20 cm) [Photo: M. Yamaguchi]

## FRESHWATER GASTROPODS

In recent years the introduction of members of the snail family Ampullariidae (sometimes known as Pilidae) has caused considerable alarm. Commonly known as apple snails or golden snails, these snails are known to cause much damage to rice and a number of other plants in Taiwan, Japan, the Philippines and elsewhere in south-east Asia (Acosta and Pullin, 1991; Mochida, 1991; Cowie, pers. comm.) and to taro in Hawaii (Cowie, 1992, in press). Members of the genus *Pomacea* are native to Central and South America; *P. paludosa* is native to the southern United States, especially Florida. *Pomacea canaliculata* was introduced to Taiwan from Argentina in 1979–1980, from Taiwan to Japan in 1981, and to Luzon, Philippines in 1982 (Mochida, 1991). This species was first recorded from Guam in 1989, having been brought from Taiwan without authorization. Government officials ordered their eradication, since they were illegally introduced. Subsequent surveys did not locate specimens; however, in 1991 dense populations were found at a wetland in Mangilao, some 20 miles away (Smith, 1992). Laup (1991) reported *Pomacea lineata* (probably *P. canaliculata* [Cowie, pers. comm.]) from Papua New Guinea — Morobe, Eastern Highlands and possibly East New Britain Province — having been brought in by Filipino agricultural officers. *Pomacea canaliculata* is the most abundant and widespread ampullariid in the Hawaiian Islands, being first reported from Maui (1989), subsequently on Oahu (1990), Kauai (1991), and Hawaii (1992) (Cowie, 1992, in press).

Apple snails and other species have apparently been introduced into various islands as a food item or possibly with the aquarium trade. Artificial culture has been attempted in Hawaii (Cowie, in press). Live snails can be purchased at Oahu (Hawaii) markets. Individuals have escaped and have been intentionally released in wetland and marsh areas and into taro patches. *Pomacea canaliculata* may be identified, in part, by its pink to reddish eggs which are deposited on grass or aquatic plants, above the surface of the water.

Other species of *Pomacea* introduced are *Pomacea gigas* to the Bio-Research Institute, Manila from Florida, U.S.A. (where is not native, either), in 1983 and *Pomacea bridgesi* (reported as *Pomacea cuprina*) to Manila around 1983 (Mochida, 1991). *Pomacea bridgesi* was first collected from an unidentified site in the Hawaiian Islands in 1962, later from the island of Hawaii in 1965, Oahu in 1990, and Kauai in 1992 (Cowie, in press). In Hawaii *Pomacea paludosa* is known only from Maui, having been collected in 1990 (Cowie, 1992, in press).

Another ampullariid, *Pila conica*, a native of Asia, has also been introduced to Guam by unknown means. Specimens were first found among water hyacinth roots in Agana Spring in 1984 and dispersed to Agana Swamp by the end of 1984. In 1986, specimens were found at Laguas River and by 1992 in the Namu River watershed. Searches at streams between these sites did not yield specimens (Smith, 1992). *Pila conica* was taken to Palau by an agricultural worker around 1984–1985 and thought to have been completely eradicated by 1987 (Smith, pers. comm.). Specimens of *Pila conica* were first collected in the Hawaiian Islands at Maui in 1966; first records from Oahu and Molokai were in 1991 (Cowie, in press).

Snails belonging to the related family Viviparidae have also been introduced. In Hawaii *Cipangopaludina chinensis*, an Asian species, was introduced probably as food by 1900; Bishop Museum collections contain specimens from the early 1920s at Oahu and Hawaii. Individuals have also been found at Maui, Kauai and Molokai (Cowie, in press). Additional viviparid specimens were intercepted at Honolulu upon arrival from the Philippines in 1970 or 1971 (Cowie, in press). One viviparid species and two planorbid species are known to have become established at Guam, probably originating through the aquarium trade (Smith, pers. comm.). Several additional freshwater gastropod species are known from the Hawaiian Islands, including at least two high-spired thiarids which are usually available in the local food markets.

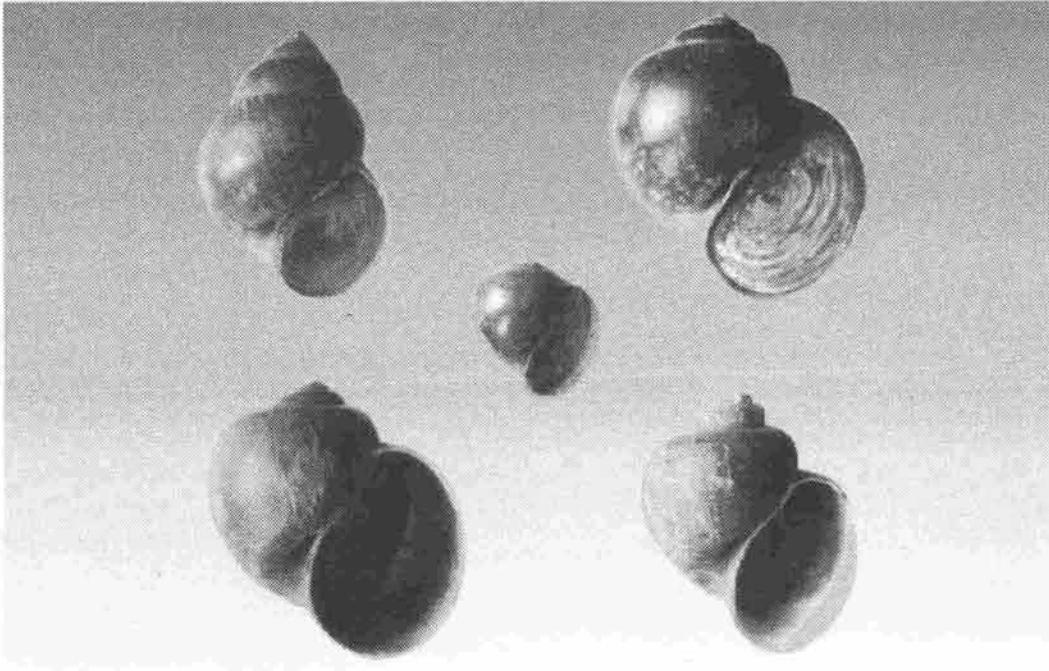
In general, freshwater snails have been introduced through aquaculture for food or through the commercial ornamental aquarium trade (Cowie, 1992). In both cases individuals have escaped or been released into the natural environment. Some species appear to cause considerable damage to agricultural products. A workshop on the impact of ampullariids on rice farming was held in the

Philippines in 1989 (Acosta and Pullin, 1991). In Hawaii, ampullariids cause damage to taro (Cowie, in press). *Pomacea canaliculata* has been confirmed as an intermediate host for the rat lungworm *Angiostrongylus cantonensis* in Taiwan and Japan (Mochida, 1991). Smith (1992) pointed out that at Guam seven deaths had been caused by eosinophilic meningoencephalitis during the past 20 years, although there is no direct evidence of a relationship with ampullariids and that there had not been an increase since the establishment of apullariids. In the Philippines it has been reported that ampullariids have displaced native snails. One native species has become extinct in Cagayan Valley since the arrival and spread of golden snails (Acosta and Pullin, 1991).

Several species of the freshwater gastropod genus *Lymnaea* have been introduced to tropical areas. *Lymnaea viridis* is now established at Guam (Asan River) (B. Smith, pers. comm.) and in Papua New Guinea (Boray, 1978). Further, Boray (1978) found that *L. viridis* was a relatively efficient host for the liver fluke *Fasciola hepatica*. Circumstantial evidence suggests that these snails were introduced with aquatic plants, either as adults or as eggs attached to the plants. Boray (1978) urged stricter quarantine regulations to prevent the spread of these snails and others which could introduce such additional parasites as the more pathogenic *Fasciola gigantica*, not now known from Papua New Guinea (or Australia and New Zealand), or several *Schistosoma* species. These potential public health problems need further study.

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**Ampullariid and viviparid snails from the Hawaiian Islands; *Cipangopaludina chinensis* (top left); *Pila conica* (top right); juvenile *Pomacea paludosa* (center); *Pomacea canaliculata* (bottom left); *Pomacea bridgesi* (bottom right). [Photo R. H. Cowie]**

## OTHER GASTROPODS

About 200 individuals of the limpet *Cellana mazatlandica* were transported from Chichi Jima, Bonin Islands, and released at Guam in May 1966 (Eldredge, 1987). They arrived in weakened condition, and successful establishment was doubtful.

Two species of abalone have been transported to Hawaiian waters. Thirty-five red abalone, *Haliotis rufescens*, were brought from California in 1927 and 1928, but there was no survival. In 1958 and 1959, nearly 900 black abalone, *Haliotis cracherodii*, from southern California were planted at Rabbit Islands and Pyramid Rock, Oahu, respectively (Brock, 1960). During recent coastal surveys no abalone has been observed (Henderson, pers. comm.). Abalone [*Haliotis diversicolor* and *H. fulgens*] have been transported at various times since 1989 to the Hawaii Natural Energy Laboratory for closed-system research and experimental culture.

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# FISHES

## MARINE FISHES

Among the islands of the Pacific there are only a few documented reports of introduced marine fishes; however, at least 33 marine species have been introduced into Hawaiian waters [see **The Hawaiian Example I**, below]. Reports of *Oreochromis mossambicus* are among the best known (Nelson and Eldredge, 1991). As a result of their wide tolerance to salinity (Stickney, 1986), individuals have been able to become established in brackish and marine habitats—in the estuaries of Papua New Guinea (Glucksman et al., 1976), the brackish waters of the Sopo area of Tongatapu, Tonga, and at Tuvalu (Uwate et al., 1984), in the mangroves of Yap in the Caroline Islands (Nelson, 1987), and at Fanning Atoll, Line Islands (Lobel, 1980).

Impacts of tilapia introductions are thought to be numerous and difficult to quantify. However, it is believed that the presence of tilapia in shallow nearshore areas may have replaced some of the more highly valued species (Nelson and Eldredge, 1991). Lobel (1980) reported that fishermen at Fanning Atoll claimed that there had been a decrease of mullet, bonefish, and milkfish with the establishment of tilapia. At both Nauru and Kiribati, the presence of tilapia has interfered with the traditional and contemporary aspects of milkfish culture (Ranoemihardjo, 1981; Teroroko, 1982).

Unintentional records of fish introductions are related to shipping activities. The blenny *Petroscirtes breviceps* was collected in September 1972 from continuous-flow bilge water on a ship from north-western Australia arriving at Port Moresby, Papua New Guinea (Springer and Gomon, 1975). At Guam, the pomacentrid *Neopomacentrus violascens* was recently collected at Apra Harbor. This fish was most likely introduced by means of fouling or Navy barge hulls towed from the Philippines (Myers, 1989) or possibly from ballast water. Two individuals of an unidentified *Parioglossus* and one *Omobranchius elongatus*, neither previously known from Guam, were collected at Guam in June 1992 from the hull of a drydock which had been towed from Subic Bay, Philippines (Myers, pers. comm.)

Additionally, in Hawaii, *Mugiligobius parvus* was first noted in 1987 and has been collected at Pearl Harbor, Ala Moana drainage canals, at Coconut Island, and at the north end of Kaneohe. This species is thought to have arrived from Japan in ballast water tanks (Randall et al., 1993). Hoese (1973) reported on two species of Japanese gobies—*Acanthogobius flavimanus* and *Tridentiger trigonocephalus*—found in Sydney Harbor, Australia. It is believed that these fish were transferred from Japan by means of ships' ballast water tanks.

Live baitfish are needed for the pole-and-line skipjack fishery. Since many native stocks are not abundant, a small-scale pilot project on the development of a livebait culture project was initiated at a small mangrove marsh in Vaitoloa, Vaiusu Bay, near Apia, Western Samoa, in July 1978 (Popper, 1982). The project was designed to culture Mexican mollies (*Poecilia mexicana*) because individuals are extremely hardy, resistant to environmental fluctuations, and are easy to breed and rear. Specimens were already present in Western Samoa, having been introduced for mosquito control several decades earlier. Experimental ponds were completed in early 1979. A broodstock of 5,000 large females was established, and fry were collected periodically, being transferred to fry stock ponds to grow. When individuals reached 1 g (more than 5 cm total length), they were harvested and transported to the wharf for sea trials. The use of mollies was not as conclusive as had been expected and the effort did not prove to be economically sound (Popper, 1982).

In 1973, the office of Marine Resources, Government of American Samoa, initiated a pilot project on the culture of two species of mollies (Poeciliidae)—*Poecilia mexicana* and *P. vittata*. Local populations of *P. mexicana* had been introduced there earlier. During a one-year period nearly 1.3 million fish, weighing 7,180 lbs., were delivered for sea trials. Even with relatively good results, it was calculated that costs were too high to support a commercial pole-and-line fishery based in American Samoa (Vergne et al., 1978). The relocation of pond sites caused further delays (Crossland, 1978).

Since trolling from small boats has been a traditional method of fishing, the Government of American Samoa embarked on a test to use mollies in combination fishing trials during 1978 (Lambert and

Bryan, 1979). The results were inconclusive, although in every case it was noted that the cultured baitfish was very hardy and would remain alive for long periods of time. In June 1979, approximately 12,000 baitfish escaped from the airport ponds into the lagoon after the ponds were vandalized (Sesepesara, pers. comm.).

In September 1989, 543 mullet (*Mugil cephalus*) fry were imported to Guam from the Oceanic Institute in Hawaii to be stocked in a commercial farm. Additional shipments of 37,400 fry were made between April and June 1990. Fifty 2- and 3-year old individuals were sent to establish a brood stock at the Guam Aquaculture Development and Training Center and have not been released into ponds or the wild (FitzGerald, pers. comm.). A faster-growing variety of mullet was introduced from Taiwan to Guam in 1991–1992 (Crisostomo, pers. comm.) The status of these is unknown.

Also in June 1990, 10,000 mullet fry were imported to Tonga from the Oceanic Institute and were released in Lake Ano. Thirty individuals were measured 16 months later; the average fork length was 28.07 cm and weight 302.3 gm (Anon., 1992).

### The Hawaiian Example I:

Of a total of 60 species of fish introduced to Hawaiian waters (Maciolek, 1984), 33 live in salt water or can tolerate saltwater to varying degrees (Randall, 1987; Randall et al., 1993). Individuals representing 13 of these species have not become established, and at least 6 of these appear to have been unintentional introductions.

The Marquesan sardine *Sardinella marquesensis* (originally reported as *Harengula vittata*) was the first truly marine fish introduced into Hawaiian waters. Approximately 150,000 individuals were released around Oahu between 1955 and 1959 (Murphy, 1960). By 1958, individuals were collected around Kauai and Maui, indicating successful establishment, but their abundance was never great enough to become the major baitfish as anticipated (Randall, 1987a). A fisherman on Kauai died of clupeoid poisoning in 1987, having eaten three of these fish (Melton et al., 1984). Another introduced clupeid, the goldspot herring (*Herklotsichthys quadrimaculatus*), appeared in Hawaiian waters in 1975 and has since become more abundant than *S. marquesensis* (Randall, 1987a).

Three species of jacks (*Caranx* spp.), a bonefish (*Albula* sp.), a goatfish (*Upeneus vittatus*), and a mullet (*Valamugil engeli*) were accidentally introduced along with the Marquesan sardine in 1955 (Randall and Katayama, 1972). All were collected at Nuku Hiva in the Marquesas. The bonefish and the jacks occurred naturally in Hawaiian waters. The goatfish appears to have become established and has caused no obvious disturbance (Randall, 1981). The mullet *Valamugil engeli* was first reported in 1966. It has little economic value because of its small size. However, it may be competing with the commercially important mullet *Mugil cephalus*. Maciolek (1984) reported that *V. engeli* comprised about 80% of the mullets collected in Kauai estuaries between 1975 and 1978. Juvenile *V. engeli* are difficult to differentiate from those of *M. cephalus* and are often mistakenly reared in ponds (Randall, 1987).

Nine species of groupers (Serranidae) and snappers (Lutjanidae) originally from the Marquesas and the Society Islands (specifically Moorea) and one snapper (*Lutjanus guttatus*) species from Manzanillo Bay, Mexico, were released at various sites around Oahu and Molokai between 1956 and 1961. Individuals of four species have become established (Oda and Parrish, 1982; Randall, 1987; Randall et al., 1993). *Lutjanus fulvus* (*toau*, the Tahitian name, has become adopted as the local name) (Fig. 1) have become established at Oahu and spread to the other islands but are not common. *L. kasmira* (*taape*, the Tahitian name) has been very successful and spread throughout the islands to Laysan. Oda and Parrish (1982) studied *taape* feeding habits in an attempt to explain its effects on local fishes. *Taape* appear to be generalized carnivores, consuming fish and some crustaceans. There is little overlap with the squirrelfish *Myripristes kuntzei* found in the same habitats (Oda and Parrish, 1982). Specimens readily enter traps, take baited hooks, and are quite unpopular with local fishermen because it is thought that *taape* have caused the decrease in the other more popular fishes (Randall, 1987). *Cephalopholis argus* (*roi* in Tahitian) (Fig. 2) has become established and is abundant along the Kona coast of Hawaii (Hobson, 1974). *Lutjanus gibbus* was long thought to be an unsuccessful introduction, but recent catches have demonstrated that *L. gibbus* is established off Hawaii, Oahu, and Kauai (Randall et al., 1993).

Information on aquarium introductions is sketchy. The origin of *Poecilia mexicana* and *P. vittata* is unknown, and both were established by 1950 (Randall, 1987b). *Poecilia mexicana* may have been released from home aquariums (Maciolek, 1984). *Cromileptes altivelis*, known from one specimen and sightings of three individuals, may also have been released from aquariums (Randall, 1981; Randall and Heemstra, 1991), but there is no evidence of its being established. Individuals of *Centropyge flavissimus* (lemon peel angelfish) and *Pomacanthus imperator* (emperor angelfish) have been sighted and, from unconfirmed reports, may have also originated from the aquarium trade (Randall, 1987b; Pyle, pers. comm.).

Two tilapia species have become established in coastal waters, being able to live successfully in saltwater (Randall, 1987). *Oreochromis mossambicus* was introduced to control aquatic plants, and as a food fish and baitfish. It is suspected of competing aggressively with the mullet *Mugil cephalus*. *Sarotherodon melanotheron* escaped from experimental baitfish tanks and became very abundant around Oahu, where it is often mistakenly identified as *O. mossambicus*. *Sarotherodon melanotheron* is thought to feed on the native baitfish (*nehu*), and specimens are often caught in *nehu* seines.

Specimens of the blennioid *Omobranchus elongatus* were found in holding tanks at Coconut Island, Kaneohe Bay, Oahu, and were thought to have been introduced with *Tridacna* substrate brought from American Samoa in 1951. However, after one specimen was collected at Pearl Harbor, the species may be considered native (Strasburg, 1956, 1966).

Specimens of an unidentified blennioid fish were first collected in Kaneohe Bay, Oahu, in 1974. Larvae of this species had been abundant in Kaneohe Bay since 1971-1974. By 1990, individuals were common on buoys and wharf pilings and were also known from Pearl Harbor. This habitat and the identification of the species as *Parablennius thysanius*, known from the Philippines to the Indian Ocean, suggest that individuals were transported on ship bottoms among fouling organisms (Springer, 1991).

*Mugiligobius parvus* is thought to have been accidentally introduced to Hawaii via ship ballast water. The first individuals recorded from Hawaii were collected in Pearl Harbor in 1987. By 1989 they were common in the Ala Moana drainage canal and in 1990 were collected at the north end of Kaneohe Bay. *Mugiligobius parvus* appears to have become well established on Oahu and is unknown from the other islands (Randall et al., 1993).

#### Fishes introduced to the marine waters (or occasionally found in coastal waters) surrounding the Hawaiian Islands

[modified from Maciolek (1984) and Randall (1987a); \* not established; ? status unknown]

Species	Date	Source
Clupeidae		
<i>Dorosoma petenense</i>	1958(1959)	California, USA
<i>Herklotsichthys quadrimaculatus</i>	1970?	Jaluit, Marshall Is.
<i>Sardinella marquesensis</i>	1955-1958	Nuku Hiva, Marquesas
Engraulidae		
* <i>Anchoa compressa</i>	1932	California, USA
Plectoglossidae		
* <i>Plectoglossus altivelis</i>	1925	Japan
Salmonidae		
* <i>Oncorhynchus tshawytscha</i>	1925-1929	Pacific Northwest
Cyprinodontidae		
* <i>Fundulus grandis</i>	1905	Texas, USA

## MARINE FISHES

Species	Date	Source
Poeciliidae		
<i>Poecilia latipinna</i>	1905+	Texas, USA
<i>P. mexicana</i>	1950?	?
<i>P. vittata</i>	1950?	?
Percichthyidae		
* <i>Morone saxatilis</i>	1920	California, USA
Serranidae		
<i>Cephalopholis argus</i>	1956	Moorea
* <i>C. urodeta</i>	1958	South Pacific
? <i>Cromileptes altivelis</i>	1978+	?
* <i>Epinephalus fasciatus</i>	1958	Marquesas
* <i>E. hexagonatus</i>	1956	Moorea
* <i>E. merra</i>	1956+	Moorea
* <i>E. spiniger</i>	1958	Marquesas
Kuhliidae		
* <i>Kuhlia rupestris</i>	1958	Guam
Lutjanidae		
<i>Lutjanus fulvus</i>	1955(1958)	Marquesas – Moorea
<i>L. gibbus</i>	1958(1961)	Marquesas – Moorea
* <i>L. guttatus</i>	1960	Mexico
<i>L. kasmira</i>	1955+	South Pacific
Lethrinidae		
* <i>Lethrinus</i> sp.	1958	Marquesas
Pomacanthidae		
? <i>Centropyge flavissimus</i>	?	?
? <i>Pomacanthus imperator</i>	?	?
Mullidae		
<i>Upeneus vittatus</i>	1955	Nuku Hiva, Marquesas
Cichlidae		
<i>Oreochromus mossambicus</i>	1951–1952	Singapore
<i>Sarotherodon melanotheron</i>	1962	New York, USA
Mugilidae		
<i>Valamugil engeli</i>	1955	Nuku Hiva, Marquesas
Blenniidae		
? <i>Omobranchus elongatus</i>	1951	?American Samoa
<i>Parablennius thysanius</i>	1971–1972	?Philippines
Gobiidae		
<i>Mugiligobius parvus</i>	1987	?

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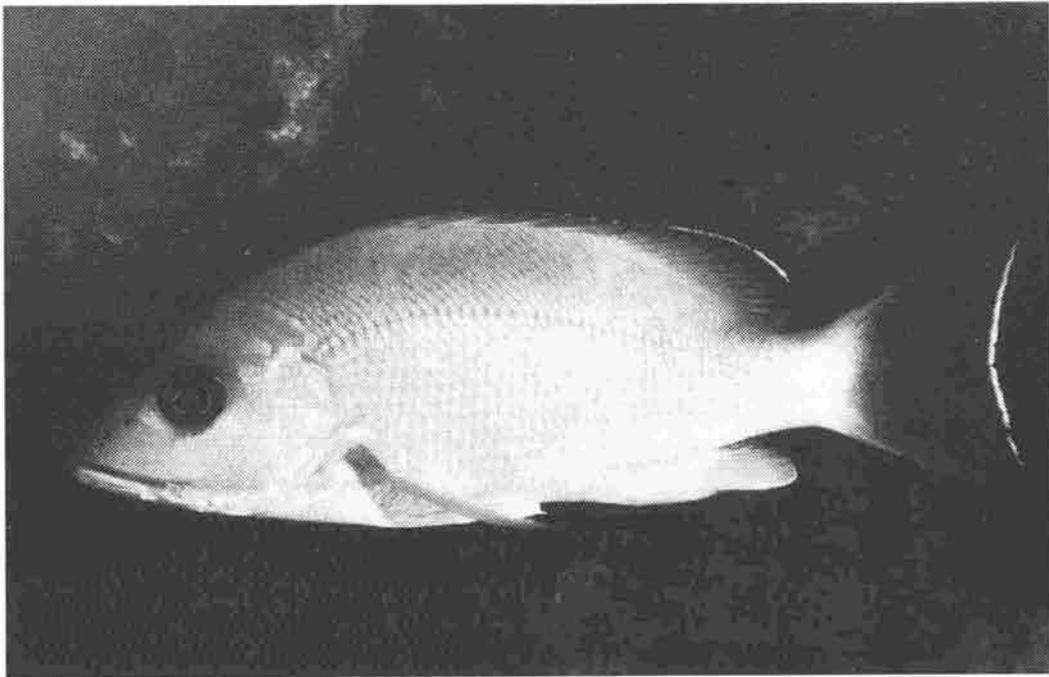


Figure 1. *Lutjanus fulvus*, Kona, Hawaii (21 cm) [Photo: J. E. Randall]

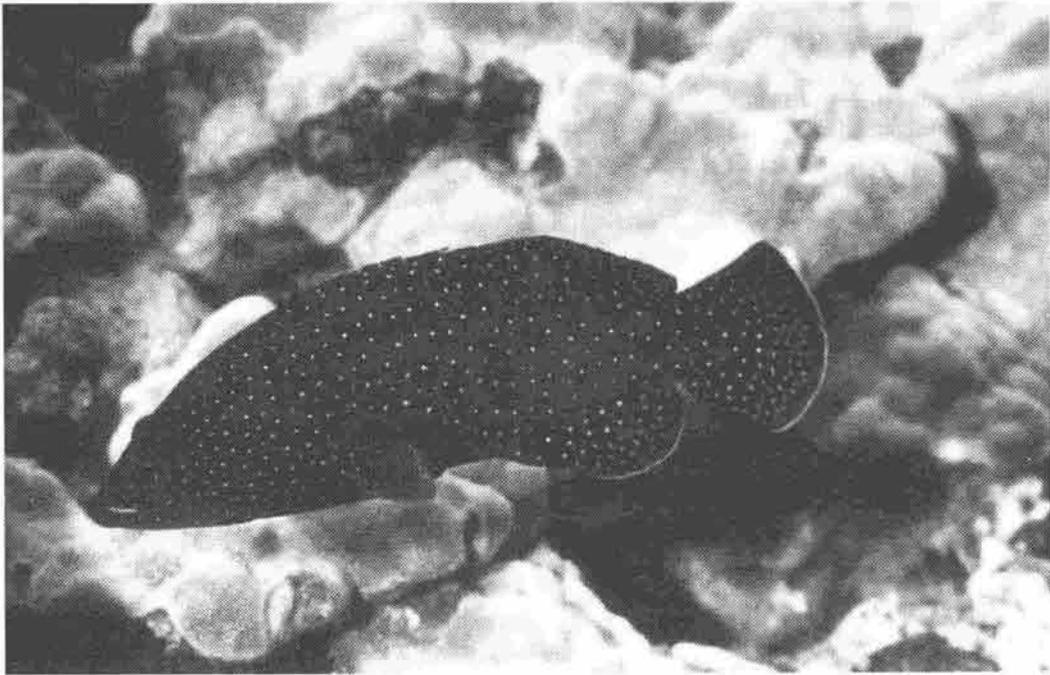


Figure 2. *Cephalopholus argus*, Kona, Hawaii (21 cm) [Photo: J. E. Randall]

# FRESHWATER FISHES

More than 291 inland aquatic species, mostly freshwater fishes, have been introduced into 148 countries (Welcomme, 1988, 1992). Freshwater fishes in the Pacific area have been introduced to enhance local stocks, for (commercial and subsistence) aquaculture, and for mosquito and aquatic weed control. More recently, aquarium (ornamental) fishes have been either released or escaped. At least 56 species of freshwater fishes have been introduced to the Pacific islands [see list below], exclusive of the Hawaiian Islands. More than 40 species are known to have been introduced into Hawaiian fresh waters (Maciolek, 1984) and are not discussed here except for aquarium fish which were introduced between 1982 and 1992 [see list below]. During this time, nearly 20 species have become established. Approximately 40 piranhas have been surrendered or discovered on Oahu in 1992. In early 1993, two separate spawning events occurred with quarantined piranhas, resulting in more than 300 young. Courtenay and Stauffer (1990) reviewed the aquarium fish industry in the contiguous United States and discussed concerns and environmental responsibilities.

Five different species of tilapia have been transplanted throughout the islands (Nelson and Eldredge, 1991), *Oreochromis mossambicus* most commonly. The impacts of tilapia are varied. Gillett (1989) speculated that tilapia was introduced through projects designed to bolster fisheries. Local fishermen at Fanning Atoll reported fewer mullet, bonefish, and milkfish following the introduction of *O. mossambicus* (Lobel, 1980). Subsistence and traditional aquaculture practices have been disturbed. The traditional milkfish culture on Nauru has been virtually destroyed (Ranoemihardjo, 1981). Eradication attempts at Nauru and Kiribati have been unsuccessful (Ranoemihardjo, 1980; Teroroko, 1982). [See *Tilapia Introductions to Pacific Islands*, below, for revised list.]

Subsistence fisheries have developed with tilapia. At Tonga, *O. mossambicus* has become established in Lake Vailahi, Niuafu'ou, and at Vava'u and Nomuka. In Papua New Guinea, this species constitutes more than half of the local catch (Coates, 1985). Osborne (1993b) further noted that *O. mossambicus* provides a major subsistence source of protein to villagers living along the Sepik River. He agrees with Allen (1991) that such introductions have negative impacts on the environment and on native species and create turbid conditions in formerly clear lakes.

At Saipan, the decline of the common moorhen (*Gallinula chloropus guami*) is thought to be caused, in part, by competition with the tilapia in Lake Susupe (Stinson et al., 1991). At Rennell Island, the extinction of two duck species (*Anas superciliosa* and *A. gibberifrons*) is speculatively attributed to the introduction of *O. mossambicus*; however, the osprey (*Pandion haliaetus melvillensis*) which was always found along the seashore began to be seen at Lake Tegano after the introduction of tilapia (Diamond, 1984). The originally algal-colored green crater at Niuafu'ou Crater Lake, Tonga, lost its color after the introduction of tilapia, and the duck population decreased markedly during the five years following this introduction (Scott, 1993).

The common carp *Cyprinus carpio* was introduced to Papua New Guinea in the early 1960s (Devambe, 1964) and escaped into the Sepik River drainage system. Individuals are spreading 40 to 60 km per year, both upstream and downstream along the lower floodplain regions (Ulaiwi, 1990) where significant fisheries have developed.

Milkfish fry were transported to the northern Cook Islands to Lake Te Rotonui on Mitiaro (Cook Islands) in 1990 and supplemented in 1991 by milkfish from Oceanic Institute (Hawaii) (Adams, pers. comm.).

## Systematic list of freshwater fishes introduced to Pacific islands

[based on Maciolek (1984) with numerous additions of more recent information; this paper should be consulted for extensive first-record notes; Papua New Guinea was not included in Maciolek's review. Family order based on Berra (1981); scientific and common names from Robins et al., 1991a, 1991b; \* species not established or information not reliable].

## Anguillidae [Freshwater eels]

American eel [*Anguilla rostrata* (Lesueur)]

\*Guam [FitzGerald, 1982 (failed)]

Japanese eel [*Anguilla japonica* Temminck and Schlegel]

Guam [FitzGerald, 1982 (discontinued)]

## Clupeidae [Herring]

Freshwater herring [*Potamalosa richmondia* (Macleay)]

\*Fiji [Andrews, 1985]

## Salmonidae [Trout]

Rainbow trout [*Oncorhynchus mykiss* (Walbaum); formerly known as *Salmo gairdneri*] (Fig. 3)

PNG [Devambe, 1964; Glucksman et al., 1976; Allen, 1991]

\*French Polynesia (Tahiti) [Maciolek, 1984]

Brown trout [*Salmo trutta* Linnaeus] (Fig. 4)

PNG [Glucksman et al., 1976; Allen, 1991]

\*Fiji [Andrews, 1985]

Brook trout [*Salvelinus fontinalis* (Mitchell)]

\*PNG [Glucksman et al., 1976]

## Retropinnidae [Southern Hemisphere Smelts]

Australian smelt [*Retropinna semoni* (Weber)]

\*PNG [Glucksman et al., 1976]

## Chanidae [Milkfish]

Milkfish [*Chanos chanos* (Forsk.)]

Guam [FitzGerald, 1982]

Cook Islands (Mitiaro) [Adams, pers. comm.]

## Cyprinidae [Carps]

Goldfish [*Carassius auratus* Linnaeus]

PNG [Allen, 1991 as *Crassius auratus*]

Western Samoa [Maciolek, 1984; Schuster, 1993]

Fiji [Adams, pers. comm.]

Common carp [*Cyprinus carpio* Linnaeus] (Fig. 5)

PNG [Devambe, 1964; Glucksman et al., 1976; Allen, 1991]

\*Fiji [Andrews, 1985]

Guam [Maciolek, 1984]

\*New Caledonia [Maciolek, 1984]

\*French Polynesia (Tahiti) [Maciolek, 1984]

Bighead carp [*Aristichthys nobilis* (Richardson)]

\*Guam [FitzGerald, 1982]

\*Fiji [Andrews, 1985]

Grass carp [*Ctenopharyngodon idella* (Cuvier & Valenciennes)]

\*Guam [FitzGerald, 1982]

\*PNG [Glucksman et al., 1976 (DASF ponds, not released, 1961)]

\*Fiji [Andrews, 1985; Vereivalu, 1990]

Silver carp [*Hypophthalmichthys molitrix* Cuvier & Valenciennes]

\*PNG [Glucksman et al., 1976 (DASF ponds, not released, 1961)]

Fiji [Andrews, 1985 as *Hypothamichthys molitrix* (Valenciennes)]

- Javanese carp [*Puntius gonionotus* (Bleeker)]  
 \*PNG [Glucksman et al., 1976 (DASF ponds, not released, about 1967–1970)]  
 Fiji [Andrews, 1985; Ryan, 1980]
- Green barb [*Puntius semifasciolatus* (Gunther)]  
 \*PNG [West & Glucksman, 1976, single specimen, Waigani Swamp, January 1966]
- Barb [*Puntius sealei* (Herre)]  
 Palau (Babelthuap) [Bright and June, 1981]
- Chinese barb [*Barbus semifasciolatus* Gunther]  
 \*PNG [Glucksman et al., 1976 – one specimen from Waigani Swamp]
- Cobitidae [Loaches]  
 Oriental weatherfish [*Misgurnus anguillicaudatus* Cantor]  
 Palau (Babelthuap) [Bright and June, 1981]
- Ictaluridae [Catfishes]  
 Channel catfish [*Ictalurus punctatus* Rafinesque]  
 \*Guam [Maciolek, 1984]  
 \*French Polynesia (Tahiti) [Maciolek, 1984]
- Clariidae [Airbreathing catfishes]  
 Walking catfish [*Clarias batrachus* (Linnaeus)] (Fig. 6)  
 PNG [Allen, 1991]  
 Guam [Myers, pers. comm.; Crisostomo, pers. comm.]
- Catfish [*Clarias macrocephalus*]  
 Guam [Anon., 1910; Maciolek, 1984, as *C. batrachus*]
- Schilbidae [Schilbids]  
 Swai [*Pangasius sutchi* Fowler]  
 \*Guam [FitzGerald, 1982]
- Ariidae  
*Arius* sp.  
 \*Guam [Anon., 1910; Maciolek, 1984]
- Plotosidae [Plotosids]  
 Freshwater catfish [*Tandanus tandanus* Mitchell]  
 \*PNG [Glucksman et al., 1976 (DASF ponds, stocks destroyed)]
- Poeciliidae [Livebearers, Mollies]  
 Mosquitofish [*Gambusia affinis* (Baird and Girard)] (Fig. 10)  
 PNG [Glucksman, 1976; Allen, 1991]  
 Fiji [Ryan, 1980; Andrews, 1985]  
 Guam [Brock and Yamaguchi, 1955; Maciolek, 1984]  
 Line Islands [Maciolek, 1984]  
 Marshall Islands (Jaluit) [Maciolek, 1984]  
 Northern Mariana Islands (Pagan, Saipan, Tinian) [Maciolek, 1984]  
 Federated States of Micronesia (Pohnpei, Pulusuk) [Maciolek, 1984; Nelson and Cushing, 1982]  
 American Samoa [Maciolek, 1984]  
 Cook Islands (Rarotonga, Mitiaro) [Maciolek, 1984]  
 French Polynesia (Tahiti) [Rougier, 1926; Maciolek, 1984]  
 Western Samoa (Savaii) [Maciolek, 1984]  
 Solomon Islands [Krumholz, 1948]  
 Vanuatu [Hass and Pal, 1984]

- Guppy [*Poecilia reticulata* Peters]  
 PNG [West, 1973; Glucksman et al., 1976; Allen, 1991]  
 Fiji [Ryan, 1980; Andrews, 1985]  
 Guam [Maciolek, 1984]  
 Palau (Balethuap) [Bright and June, 1981]  
 Cook Islands (Rarotonga, Mitiaro) [Maciolek, 1984]  
 French Polynesia (Tahiti) [Maciolek, 1984]  
 Western Samoa (Savaii) [Maciolek, 1984]  
 New Caledonia [Maciolek, 1984]  
 Vanuatu [Maciolek, 1984]
- Mexican molly [*Poecilia mexicana* Heckel]  
 Fiji [Ryan, 1980; Andrews, 1985]  
 American Samoa [Maciolek, 1984]  
 French Polynesia (Tahiti) [Maciolek, 1984]  
 Western Samoa (Savaii) [Maciolek, 1984]
- Sailfin molly [*Poecilia latipinna* (LaSeuer)]  
 Guam [Maciolek, 1984]
- Cuban limia [*Poecilia vittata* Guichenot]  
 \*American Samoa [Maciolek, 1984]
- Swordtail [*Xiphophorus helleri* Heckel] (Fig. 7)  
 PNG [Allen, 1991]  
 Fiji [Ryan, 1980; Andrews, 1985]  
 Guam [Maciolek, 1984]
- Southern platyfish [*Xiphophorus maculatus* (Gunther)]  
 Palau (Balethuap) [Bright and June, 1981]
- Channidae [Snakeheads]  
 Striped snakehead [*Channa striata* (Bloch)] [= *Ophiocephalus striatus*] (Fig. 8)  
 Streams near Bintuni, Vogelkop Peninsula, Irian Jaya; presumably introduced by Indonesian immigrants [Allen, 1991]  
 \*Fiji (Viti Levu) [Devambez, 1964; Andrews, 1985]  
 \*Guam [Maciolek, 1984]  
 New Caledonia [Devambez, 1964; Maciolek, 1984]
- Centropomidae  
 Barramundi [*Lates calcarifer* (Bloch)]  
 French Polynesia (Tahiti) [Fuchs, 1987; Preston, 1990]  
 \*Guam [Crisostomo, pers. comm.]
- Percichthyidae [Australian bass]  
 Australian bass [*Macquaria novemaculeata* (Steindachner)]  
 \*Fiji [Andrews, 1985]
- Estuary perch [*Macquaria colonorum?* (Gunther)]  
 \*Fiji [Ryan, 1980]  
 \*PNG [Glucksman et al., 1976, as *Percalates colonorum*]
- Golden perch [*Plectroplites ambiguus* Richardson]  
 PNG [Glucksman et al., 1976]
- Teraponidae [Terapon Perches]  
 Silver perch [*Bidyanus bidyanus* (Mitchell)]  
 \*PNG [Glucksman et al., 1976]

- Spangled perch [*Leiopotherapon unicolor* (Gunther)] [= *Madigania unicolor?* (Gunther)]  
 Fiji [Ryan, 1980]  
 \*Fiji [Andrews, 1985]
- Silver Grunter [*Mesopristes argenteus* (Cuvier)]  
 \*Fiji [Ryan, 1980; Andrews, 1985]
- Centrarchidae [Sunfishes]
- Bass [*Micropterus dolomieu* Lacepède]  
 \*Guam [Devambez, 1964; Maciolek, 1984]  
 \*Fiji (Viti Levu) [Devambez, 1964; Maciolek, 1984]
- Bass [*Micropterus salmoides* (Lacepède)]  
 Guam [Devambez, 1964; Maciolek, 1984]  
 New Caledonia [Devambez, 1964; Maciolek, 1984]  
 \*French Polynesia (Tahiti) [Maciolek, 1984]  
 Fiji [Farman, 1984]
- Cichlidae [Cichlids]
- Peacock cichlid [*Cichla ocellaris* Bloch and Schneider]  
 Guam [Maciolek, 1984]
- Oscar [*Astronotus ocellatus* (Cuvier)]  
 Guam [Maciolek, 1984]
- Tilapia [*Oreochromis mossambicus* (Peters, 1852)] (Fig. 9)  
 PNG [Glucksman et al., 1976; Allen, 1991]  
 Fiji [Andrews, 1985; Maciolek, 1984]  
 Guam [DeLeon and Liming, 1956; Maciolek, 1984]  
 Line Islands (Fanning, Washington) [Lobel, 1980; Maciolek, 1984]  
 Gilbert Islands [Maciolek, 1984]  
 Northern Mariana Islands (Pagan, Saipan, Tinian) [Maciolek, 1984]  
 Nauru [Maciolek, 1984]  
 New Caledonia [Maciolek, 1984]  
 Solomon Islands [Maciolek, 1984]  
 Vanuatu [Maciolek, 1984]  
 American Samoa [Maciolek, 1984]  
 Cook Islands (Rarotonga, Mitiaro) [Maciolek, 1984]  
 French Polynesia (Tahiti) [Maciolek, 1984]  
 Niue [Maciolek, 1984]  
 Tonga (Tongatapu, Vavau) [Maciolek, 1984], (Niufofo'ou) [Scott, 1993]  
 Wallis and Futuna (Wallis) [Maciolek, 1984]  
 Western Samoa (Savaii) [Maciolek, 1984]  
 Tuvalu (Funafuti, Namumanga, Niutao) [Uwate et al., 1984]
- Nile tilapia [*Oreochromis niloticus* (Linnaeus)]  
 Fiji [Andrews, 1985; Maciolek, 1984]
- Blue tilapia [*Oreochromis aureus* (Steindachner)]  
 \*Fiji [Andrews, 1985]
- Wami tilapia [*Oreochromis urolepis* Norman]  
 \*Fiji [Nelson and Eldredge, 1991, as *O. hornorum*]
- Redbelly tilapia [*Tilapia zilli* Gervais)]  
 \*Fiji [Andrews, 1985]  
 Guam [Maciolek, 1984]  
 New Caledonia [Devambez, 1964; Maciolek, 1984]

- Longfin tilapia [*Tilapia macrochir* Boulenger]  
Wallis (Lake Kikila) [Tahimili, pers. comm.]
- Redbreast tilapia [*Tilapia rendalli* (Boulenger)]  
Wallis (Lake Kikila) [Tahimili, pers. comm. as *T. melanopleura*]  
PNG, Sepik and Ramu Rivers, recent introduction [Osborne, 1993a; Coates, pers. comm.]
- Mugilidae  
Freshwater mullet [*Trachystoma petardi* (Castelnau)]  
PNG [Glucksman et al., 1976]
- Eleotrididae [Gudgeons]  
Western carp Gudgeon [*Hypseleotris klunzingeri* (Ogilby)]  
\*PNG [Glucksman et al., 1976; West and Glucksman, 1976 as *Crassiops klunzingeri*]
- Anabantidae [Climbing perches]  
Climbing perch [*Anabas testudineus* (Bloch)]  
PNG [Allen, 1991]
- Belontiidae [Gouramies]  
Snakeskin gourami [*Trichogaster pectoralis* (Regan)]  
PNG [Devambe, 1964; Glucksman et al., 1976; Allen, 1991]  
New Caledonia [Devambe, 1964; Maciolek, 1984]
- Threespot gourami [*Trichogaster trichopterus* (Pallas)]  
PNG [West, 1973; Glucksman et al., 1976; Allen, 1991]
- Fighting fish [*Betta brederi* Myers]  
Guam [Maciolek, 1984]
- Osphronemidae [Giant gouramies]  
Giant gourami [*Osphronemus goramy* Lacepède]  
PNG [Devambe, 1964; Glucksman et al., 1976; Allen, 1991]  
New Caledonia [Devambe, 1964; Maciolek, 1984]

### Tilapia Introductions to Pacific Islands [based on Nelson and Eldredge (1991) with additions]

#### *Oreochromis mossambicus*

##### Micronesia

Yap – from unknown source, 1970s; for culture, impact unknown (Nelson, 1987; Nelson and Hopper, 1989)

Tarawa – probably from Fiji, 1963; to establish subsistence aquaculture, impact unknown (Villaluz, 1972)

Fanning Atoll – from Hawaii, 1958; accidental introduction to lagoon, suspected negative impact on local fish (Lobel, 1980)

Washington Island – from Hawaii, 1958; no apparent purpose, impact unknown (Lobel, 1980)

Guam – from the Philippines, 1954; for culture in fresh and brackish water and for aquatic weed control (DeLeon and Liming, 1956; Brock and Takata, 1956)

Pagan – from Saipan, 1955; to enhance freshwater lakes; island no longer inhabited (Brown, 1955)

Saipan – from the Philippines, 1955; to enhance stocks, impact unknown (Anon., 1955)

Nauru – unknown source, 1960s; for mosquito control, impedes traditional aquaculture (Ranoemihardjo, 1981)

#### Polynesia

Cook Islands – from Fiji, 1955; for culture, impact unknown (Chimits, 1957; Devambez, 1964)

American Samoa – from Western Samoa, 1950s; to enhance stocks, fished at Aunu'u (van Pel, 1959)

Niue – unknown source, date and reason; impact unknown (Uwate et al., 1984)

Tahiti – unknown source, 1950s; impact unknown (Uwate et al., 1984)

Tongatapu – from Fiji, 1955; for mosquito control, impedes aquaculture development (Chimits, 1957; Devambez, 1964; Fa'anunu, pers. comm.)

Nomuka Island (Tonga) – from Tongatapu, 1970s; for mosquito control, fished, reduced milkfish population (Fa'anunu, pers. comm.)

Niufo'ou Island – probably from Tongatapu, 1982; to enhance subsistence fishery (Fa'anunu, pers. comm.); duck population decreased (Scott, 1993)

Vava'u Island – probably from Tongatapu, unknown date; subsistence fishery (Fa'anunu, pers. comm.)

Funafuti Atoll – unknown source, date, reason; impedes aquaculture development (Uwate et al., 1984)

Nanumanga Island (Tuvalu) – unknown source, date, reason; impact unknown (Uwate et al., 1984)

Niutao Atoll (Tuvalu) – unknown source, date, reason; used as pig feed (Uwate et al., 1984)

Wallis (Wallis & Futuna) – unknown source, 1966; impact unknown (Hinds, 1969)

Western Samoa – from Fiji, 1955; for small-scale culture (van Pel, 1961)

#### Melanesia

Viti Levu (Fiji) – from Malaysia, 1954; for culture, subsistence culture (Holmes, 1954; Andrews, 1985); well established (Adams, pers. comm.)

Vanua Levu (Fiji) – from Viti Levu, unknown date; for culture; well established (Adams, pers. comm.)

New Caledonia – from Philippines, 1955; for culture, (van Pel, 1956); well established (Adams, pers. comm.)

Papua New Guinea – from Malaysia, 1954; for culture, fishery established (Devambez, 1964; Glucksman et al., 1976; Allen, 1991)

Guadalcanal – unknown source, 1957; for culture, impact unknown (Nichols, pers. comm.)

Malaita (Solomon Islands) – probably from Guadalcanal, after 1957; impact unknown (Nichols, pers. comm.)

Santa Anna (Solomon Islands) – probably from Guadalcanal, after 1957; impact unknown (Nichols, pers. comm.)

Rennell (Solomon Islands) – from Guadalcanal, after 1957; to enhance stocks, subsistence fishery (Wolff, 1969)

Efate Island (Vanuatu) – from New Caledonia, 1950s; to enhance stocks, impact unknown (Uwate et al., 1984)

Tanna Island (Vanuatu) – from New Caledonia, 1950s; to enhance stocks, impact unknown (Uwate et al., 1984)

### *Oreochromis niloticus*

Viti Levu – from Israel, 1968; for culture, subsistence fishery (Adams, pers. comm.)

Vanua Levu – from Viti Levu, 1988–1990; for culture, subsistence fishery

Rarotonga, Cook Islands – from Fiji, 1993; 2 shipments, no survival during first shipment (Adams, pers. comm.)

### *Oreochromis aureus*

Viti Levu – unknown source, 1974; for research, not established (Andrews, 1985)

### *Oreochromis urolepis*

Viti Levu – from Taiwan, 1985; for research, not established (Nelson and Eldredge, 1991)

### *Tilapia macrochir*

Wallis (Lake Kikila) – unknown source, 1967–1970, spread to other freshwater areas (Tahimili, pers. comm.)

### *Tilapia rendalli*

Wallis (Lake Kikila) – unknown source, 1967–1970, as *T. melanopleura*, spread to other freshwater areas (Tahimili, pers. comm.)

\*Papua New Guinea – from U.K., 1991; to enhance stock, rapidly spreading (Coates, pers. comm.)

### *Tilapia zilli*

Guam – probably from Hawaii, 1956; for aquatic weed control, small recreational fishery (Brock and Yamaguchi, 1955; Brock and Takata, 1956)

Fiji – from Hawaii, 1957; for culture, distribution and impact unknown (van Pel, 1959; Adams, pers. comm.)

\*150,000 fingerlings stocked; *T. rendalli* is the first introduction undertaken using the EIFAC/ICES code of practice whereby pre-introduction evaluations were reviewed by an independent panel (Coates, pers. comm.).

Hybrid Tilapia (*O. mossambicus* and *O. niloticus*)

Guam – from Taiwan, 1973; for culture, commercial production (FitzGerald and Nelson, 1979)

## Freshwater aquarium fishes observed or established in Hawaii (1982–1992).

All species have been reported only from Oahu; date with each record is the first time the species was reported; area of origin is noted (modified from Devick, 1991) [?=current status unknown, \*=reported but not collected records].

*Ancistrus* spp.

[Bristle-nosed catfish] (1985, South America)

*Cichlasoma nigrofasciatum*

[Convict cichlid] (1983, Central America)

*Cichlasoma spilurum*

[Cutter's cichlid] (1984, Guatemala)

*Cichlasoma* sp.

[Cichlid] (1988, unknown)

? *Colossoma macropomum*

[Pacu] (1987, South America)

*Corydoras aeneus*

[Bronze corydoras] (1984, South America)

*Hemichromis elongatus*

[Jewel cichlid] (Africa) reported from Lake Wilson, 1991 (Miyada, 1991)

*Hypostomus* spp.

[Suckermouth catfish, Armored catfish] (1984, South America)

? *Leporinus fasciatus*

[Black-banded leporinus] (1984, South America)

\* *Osteoglossum* sp.

[Arowana]

\* *Peckoltia* sp.

[Armored catfish]

*Pelvicachromis pulcher*

[Rainbow krib] (1984, Nigeria)

*Poecilia* sp.

[Topminnow] (1986, unknown)

*Pterophyllum* sp.

[Angelfish] (1982, South America)

*Pterygoplichthys multiradiatus*

[Radiated ptero, Armored catfish] (1986, South America)

*Puntius filamentosus*

[Black-spot barb] (1984, India)

? *Serrasalmus* sp.

[Piranha] (1992, South America) (Sakuda, 1993)

\* *Synodontis* sp.

[African catfish]

*Tilapia* spp.

[Tilapia] (1983, Africa)

*Xenentodon cancila*

[Asian needlefish, Stickfish] (1988, Southeast Asia)

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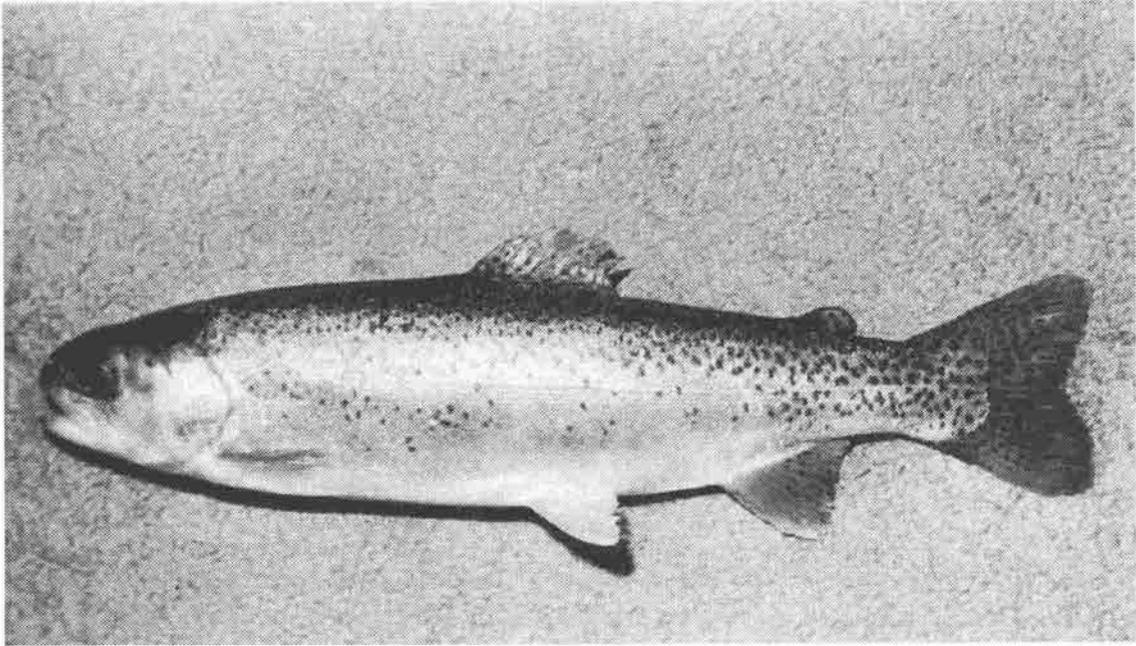


Figure 3. *Oncorhynchus mykiss*, Pemberton, Western Australia (22 cm SL) [Photo: G. R. Allen]

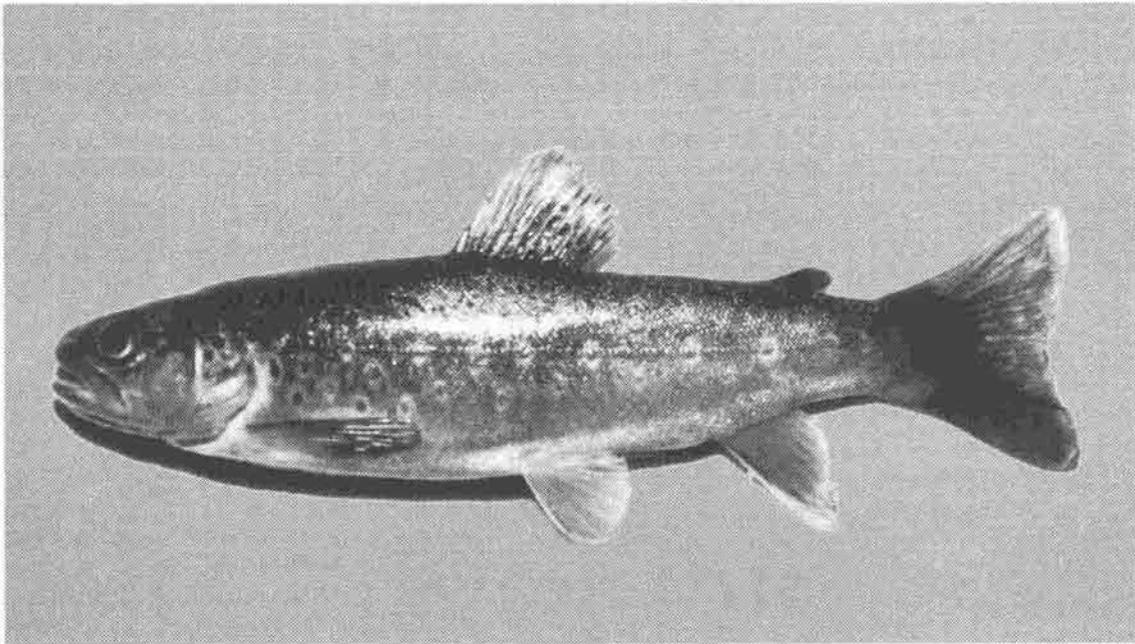


Figure 4. *Salmo trutta*, Western Australia (165 mm SL) [Photo: G. R. Allen]

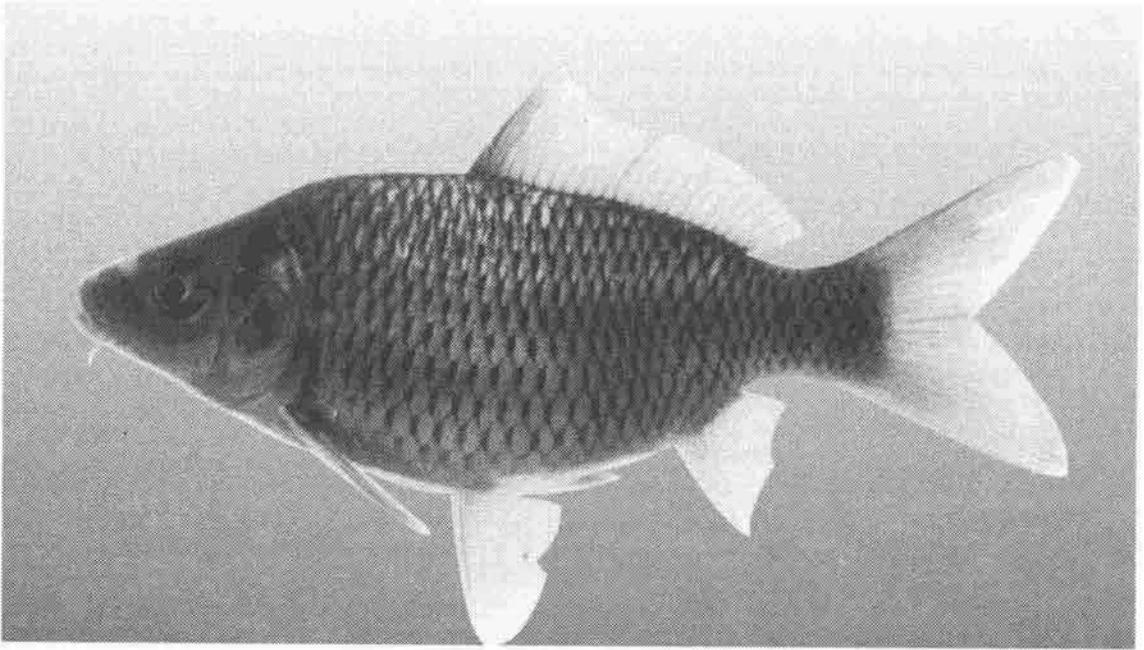


Figure 5. *Cyprinus carpio*, Ramu River, Papua New Guinea (141 mm SL) [Photo: G. R. Allen]

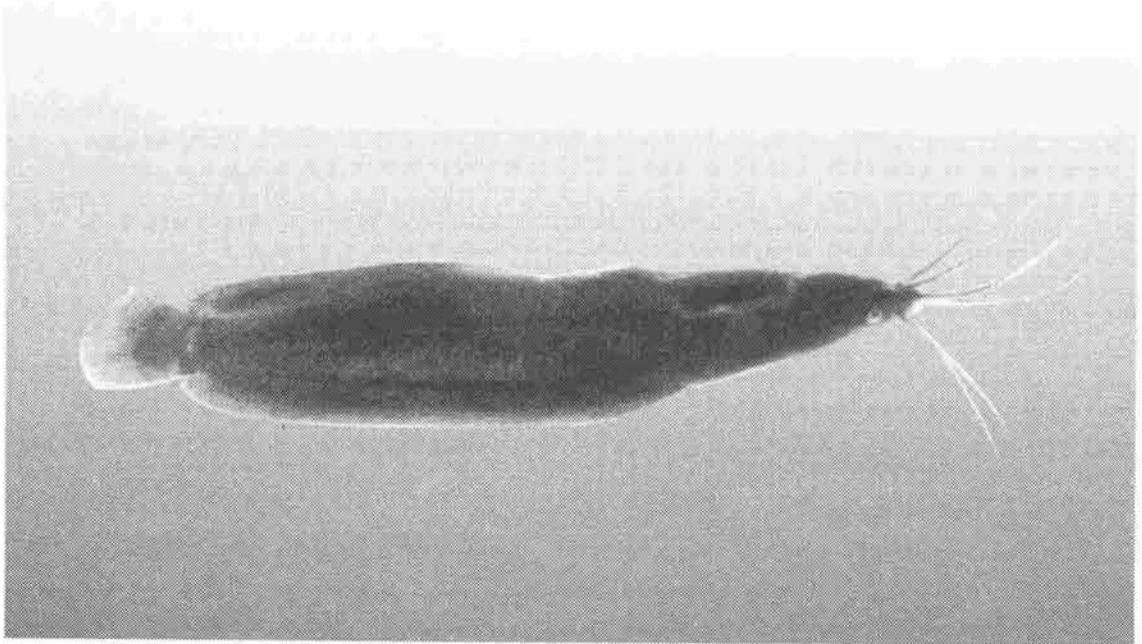


Figure 6. *Clarias batrachus*, near Manakwari, Irian Jaya (94 mm SL) [Photo: G. R. Allen]

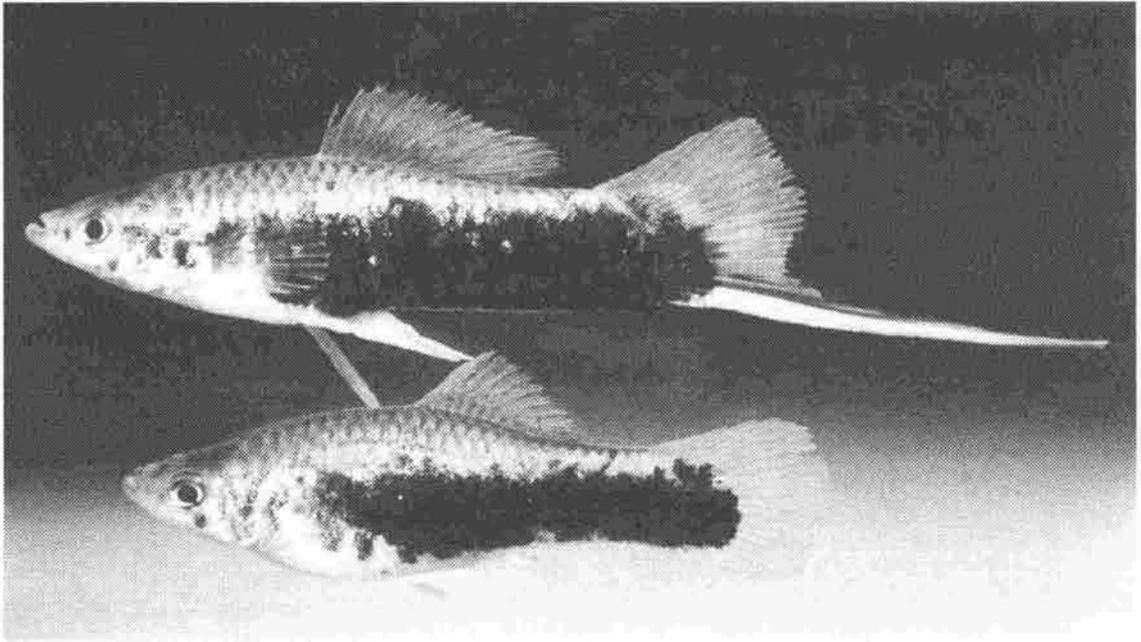


Figure 7. *Xiphophorus helleri*, Tributary of Bulolo River, Papua New Guinea (male 35 mm SL; female 40 mm SL) [Photo: G. R. Allen]

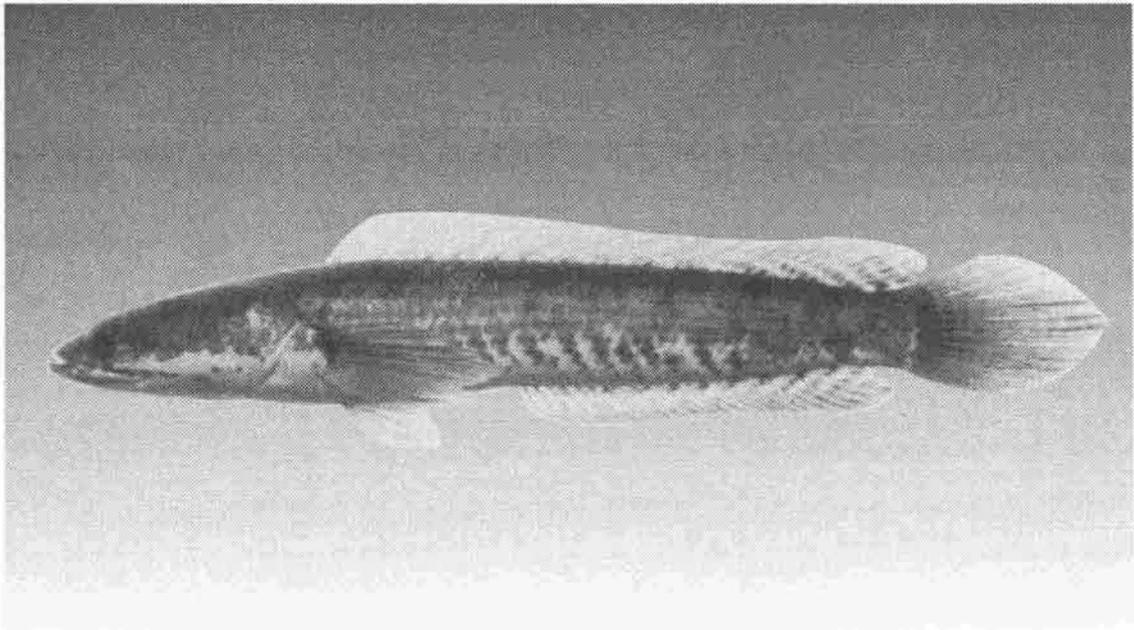


Figure 8. *Channa striata*, Biruni, Vogelkop Peninsula, Irian Jaya (126 mm SL) [Photo: G. R. Allen]

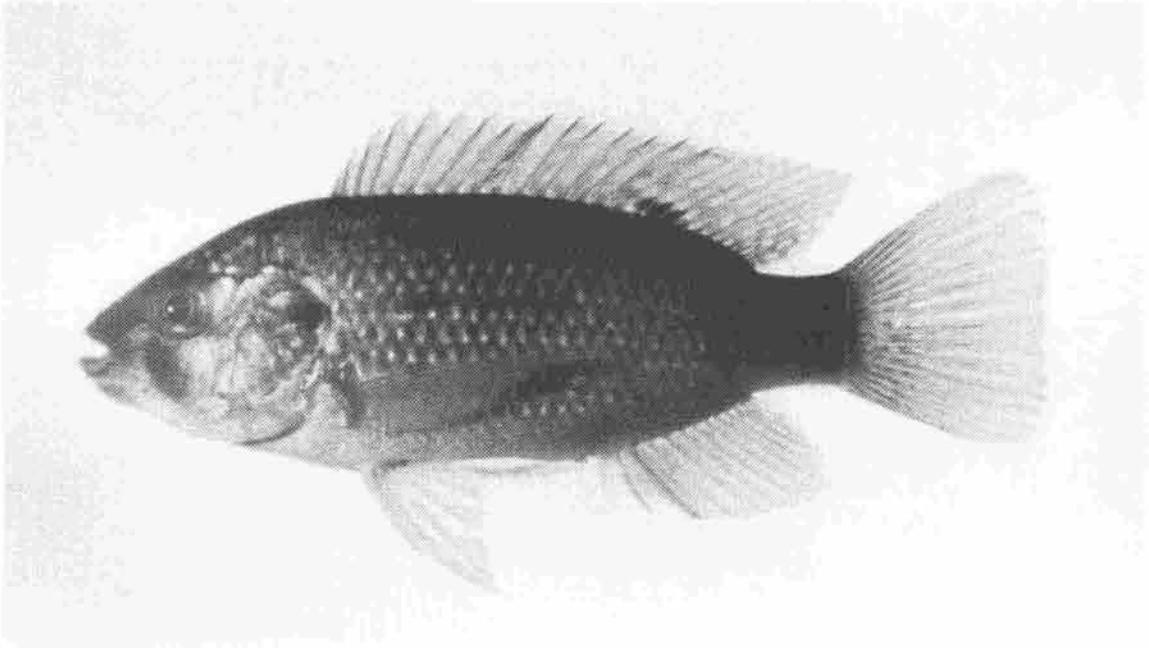


Figure 9. *Oreochromis mossambicus*, near Maprik, Sepik River System, Papua New Guinea (94 mm SL, female) [Photo: G. R. Allen]

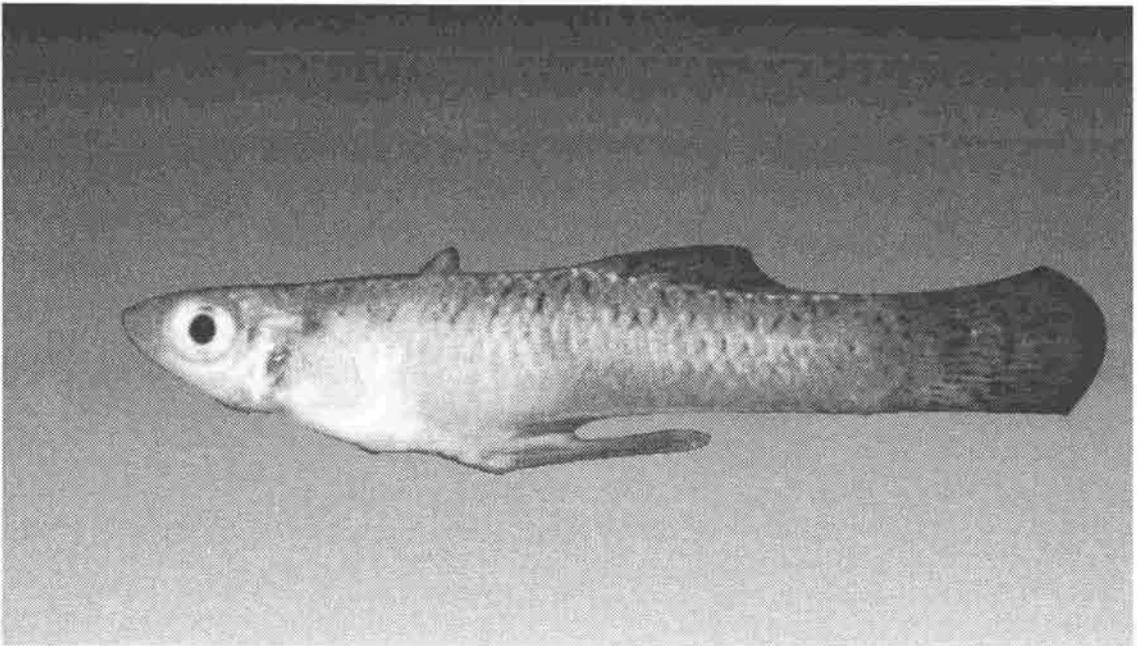


Figure 10. *Gambusia affinis*, Canning River, Western Australia (28 mm SL) [Photo: G. R. Allen]

# CRUSTACEANS

# PENAEID SHRIMPS

Penaeid shrimps have for many centuries been considered a good source of food. Most species are found naturally in shallow, inshore tropical and subtropical waters and many have been artificially cultured in ponds. The entire family has been reviewed taxonomically (Holthuis, 1980), and approximately 125 species are known from the broad Indo-west Pacific region (Dall et al., 1990). Reviews of the taxonomy and biogeography of most of the commercially valuable species have recently appeared (Dore and Frimodt, 1987; Dall, 1991; Bailey-Brock and Moss, 1992). Approximately 20 species are found naturally among the islands of the south Pacific and Hawaii. Nine have been cultured under varying conditions on the islands. Below is a summary of the historical information on the transfer and introduction of penaeid shrimps.

Of all the transfers and introductions, apparently only one species – *Penaeus merguensis* – has become established in an estuarine area of Fiji after having been introduced to ponds from Tahiti during 1974–1975. At the conclusion of the culture experiments, all individuals were released from Raviravi into the wild and now naturally occur in the Ba area (Choy, 1983; Andrews, 1985). *Penaeus japonicus* was also cultured at Raviravi and even after its release (Gundermann and Popper, 1977) failed to become established in the wild, since it was not found during the 1979 survey (Choy, 1983).

## Historical notes on penaeid species:

(modified from Uwate et al., 1984 with additions) [English common name (Holthuis, 1980)]

### *Metapenaeus ensis* (De Haan) [Greasyback shrimp]

- 1973: 40 wild-caught juveniles to Vairao, Tahiti, from New Caledonia (AQUACOP, 1975)
- 1975: spawned in New Caledonia (tanks)
- 1977: pilot-scale hatchery in French Polynesia
- 1983: stock imported from New Caledonia, spawning studies at French Polynesia

### *Penaeus aztecus* Ives [Northern brown shrimp]

- 1973: postlarvae imported to Vairao, Tahiti, from Galveston, Texas, first spawning 1974 (AQUACOP, 1975); satisfactory success (Anon., 1975)
- 1977: pilot-scale hatchery in French Polynesia
- 1979: species tested in New Caledonia

### *Penaeus indicus* Milne Edwards [Indian white prawn]

- 1981: cultured at Raviravi, Fiji, from stock from Tahiti

### *Penaeus japonicus* Bate [Kuruma prawn]

- 1973: postlarvae to Vairao, Tahiti, from Fujinaga Institute (AQUACOP, 1975)
- 1974: fry to Fiji from Japan, no maturation in fertilized females (Anon., 1975)
- 1979: species tested in New Caledonia
- 1983: stock brought from Japan, spawning studied in French Polynesia, satisfactory success

### *Penaeus merguensis* DeMan [Banana prawn]

- 1972: New Caledonia ponds stocked with 500 juveniles; tested by 1979
- 1972: brood stock transferred to French Polynesia from New Caledonia; satisfactory success; by 1977, pilot-scale hatchery in French Polynesia
- 1973: 500 wild-caught juveniles to Vairao, Tahiti, from New Caledonia (AQUACOP, 1975)
- 1974: larvae to Fiji from CNEXO, Tahiti (1000 individuals)

1978: natural reproduction at Fiji (Raviravi) ponds from locally collected stock; established in Ba estuarine system (Lichatowich et al., 1978)

1979: grow-out in Tatutu Lagoon, French Polynesia; poor growth

*Penaeus monodon* Fabricius [Giant tiger prawn]

1972: pond trials initiated in New Caledonia; results positive; species selected for further study

1975: stock imported to Fiji

1976–1981: post-larvae to Fiji from Tahiti

1977: pilot-scale hatchery at French Polynesia

1978: juveniles (160,000) imported to Guam from Taiwan, used as brood stock

1980: imported to Western Samoa ponds from Tahiti (1000 individuals) (Popper, 1982)

1983: selected for culture by CNEXO, experimental results good

1987: imported to Solomon Islands from Australia, successful (Munro, 1993)

1990–1991: postlarvae to ponds at Navua (Viti Levu, Fiji) from Australia (Adams, pers. comm.)

?: postlarvae to American Samoa (Crossland, 1978)

*Penaeus semisulcatus* De Haan [Green tiger prawn]

1973: wild-caught juveniles to Vairao, Tahiti, from New Caledonia, maturation but no spawning (AQUACOP, 1975)

1979: species tested in New Caledonia

1983: stock imported from New Caledonia, spawning in French Polynesia less successful

*Penaeus stylirostris* Stimpson [Blue shrimp]

1972: pond trials initiated in New Caledonia; results positive, species selected for further study by 1979

1980: Mexican strain imported to New Caledonia; by 1989 at commercial cultivation (Galinié, 1990)

1983: selected for culture by CNEXO, experimental results good

1990: 10 adults from Hawaii as broodstock to be held at Guam Aquaculture Development and Training Center; subsequent shipments to replace mortalities and increase broodstock; first post-larvae in June

1990: (FitzGerald, pers. comm.)

*Penaeus vannamei* Boone [Whiteleg shrimp]

1972: pond trials initiated in New Caledonia; results positive with 12th generation locally produced

1978–1979: experimental rearing continued

Six species of penaeids – *P. vannamei*, *P. monodon*, *P. stylirostris*, *P. japonicus*, *P. chinensis*, *P. indicus* – have been transported to Hawaii for aquaculture and research purposes; only *P. vannamei* is currently under extensive culture. Between 1978 and 1991, 89 shipments had been received, 90% of them between 1978 and 1985. Since this time there has been a sharp decline in importation, to only seven, because of the economic losses brought about by 'exotic' viruses in importation (Brock, 1992a). Of these seven, only three cleared pathogen screening; the remainder were destroyed in quarantine. Several pathogens, as well as some parasites, have been identified with penaeids imported into Hawaii; Brock (1992a) provides a list of known penaeid viruses.

Dall et al. (1990) noted in a recent review that information on Indo-west Pacific penaeid parasites was not well known. The review outlined that information which has been published, covering viruses, bacteria, fungi, protozoans, flatworms, nematodes, and crustaceans; however, little is reported from the region.

Individuals of four species – *P. vannamei*, *P. stylirostris*, *P. monodon*, *P. japonicus* – have escaped culture, primarily during flooding of ponds, but none is known to be locally established (Brock, 1992a, 1992b; Davidson et al., 1992).

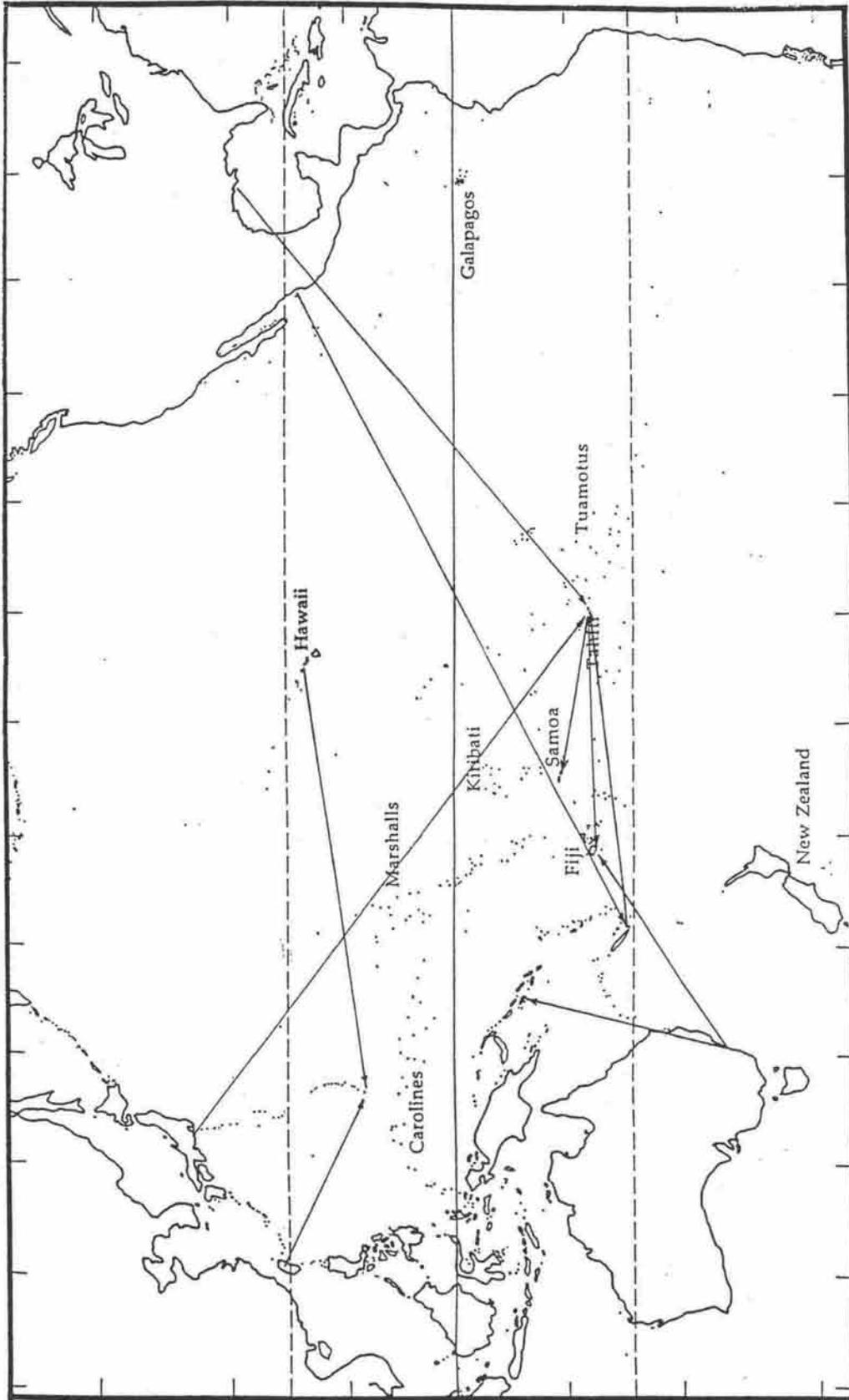
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*Penaeus stylirostris*, normal form, Hawaii [Photo: J. E. Brock]



**Penaeid shrimps – generalized map of Penaeid shrimps transfers among the Pacific Islands, all species included; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.**

## OTHER MARINE CRUSTACEANS

*Scylla serrata*, the mangrove or red crab, was intentionally introduced into Hawaiian waters. A total of 98 crabs had been released by 1935. A few crabs were brought annually from Samoa, beginning in 1926, hence the local Hawaiian name of 'Samoan crab' (Brock, 1960). In 1960, they were described as relatively common and brought a good price at the markets, and in 1992 they are among the major species collected in certain areas of the island of Hawaii.

Although mangrove crabs are native to Guam, individuals have also been intentionally imported. In 1975 the Government of Guam brought 270 specimens from Taiwan (FitzGerald, 1982). Some were experimentally cultured at the University of Guam Marine Laboratory until Typhoon Pamela destroyed the flowing seawater system on May 26, 1976. Additionally, at least three fish farmers, who occasionally found native crabs in their ponds, have imported juveniles from the Philippines (Anon., 1984). [The taxonomy of mangrove crabs is in an unsettled state. Originally described as one species, at least four names are currently in use (Preston and Tanaka, 1990; Kathirvel and Srinivasagam, 1992). Since a definitive review has not been undertaken, the continued use of the name *S. serrata* will cause less confusion.]

Several specimens, all females, of the blue crab *Callinectes sapidus* from the east coast of America have been trapped in Kaneohe Bay since around 1985 (Eldredge, MS). This crab has been transported to Hawaii since 1967 for human consumption; the majority of shipments originate from Louisiana. Special permits are required to bring live food into Hawaii; there are no sex restrictions; however, females are preferred. Speculatively, the crabs in Kaneohe Bay were purchased by an individual who released them in a personal attempt to have them available.

In Hawaii, individuals of five additional crab species have been reported from Pearl Harbor: from the hull of a barge arriving from Guam and ports to the west, four species of xanthid crab: *Atergatopsis* (= *Neoliomera*) *immigrans*, *Glabropilumnus seminudus*, *Panopeus herbsti* and *P. pacificus* (Edmondson, 1962), and *Schizophrys aspera* from an undesignated location (Edmondson, 1951).

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## FRESHWATER CRUSTACEANS

*Macrobrachium lar* and *M. rosenbergii* are two large freshwater prawns belonging to the crustacean family Palaemonidae. Their distribution is restricted, *M. lar* being found in the Indo-Pacific from East Africa to the Ryukyu Islands and the Marquesas (introduced to Hawaii); *M. rosenbergii* (known as the giant freshwater prawn) is more restricted in the Indo-Pacific, occurring from north-west India and Vietnam to the Philippines, New Guinea, northern Australia, and Palau (Holthuis, 1980). Aspects of the biology of *M. rosenbergii* have been outlined by New and Singholka (1985).

Specimens of *M. rosenbergii* were imported to Hawaii to develop mass rearing techniques, beginning with 36 individuals from Malaysia in 1965 (Fujimura and Okamoto, 1972). Successful hybridization experiments were conducted with three of the four morphs in Hawaii (Malecha, 1980). Some individuals were distributed in streams on all the major Hawaiian islands (Maciolek, 1972); however, Davidson et al. (1992) indicated that the species had not become established. This species (34,000 individuals) was taken to Guam from Hawaii in 1974 (FitzGerald, 1982) and import continued; 634,000 post-larvae or fry being reported under cultivation in 1983 (Anon., 1983). At Guam, after several known escapes and intentional releases, the only anticipated survival occurred following Typhoon Omar (August 1992) when a man-made reservoir dam burst, releasing all its contents into the watershed (Crisosotomo, pers. comm.).

Six hundred juvenile *M. rosenbergii* from Hawaii were shipped to Palau in 1974. This stock, which originated from Malaysia, was introduced to be raised with the local Palau stock. Approximately 300 remained after 12 month growth trials (Wong and Deese, 1975). Fifty adult specimens were transported in 1973 to Tahiti from Hawaii for aquaculture trials (AQUACOP, 1977). In a pilot project, post-larvae were airfreighted to the Solomon Islands from Tahiti in 1983 where they were released into earthen ponds and, after grow out, were harvested (Nichols, 1985). Specimens were sent to Fiji from Hawaii in 1975 to be stocked in several ponds; there is no evidence that they were established in the wild (Andrews, 1985). In 1979, 1000 *M. rosenbergii* were stocked in brackish water ponds at Vai'toia, Western Samoa (Popper, 1982). Since there were initially good results, Popper recommended that the pond facilities at Solaua be expanded. *Macrobrachium rosenbergii* were transported to Rarotonga from Tahiti in 1992 for commercial fishing trials; this project has since been abandoned (Adams, pers. comm.). New and Singholka (1985) noted that *M. rosenbergii* has been taken to many areas for aquaculture, but they do not mention specific islands other than the Hawaiian Islands.

Some 340 individuals of *M. lar* were brought to Honolulu, Hawaii, from Guam in 1956. Ninety-four were released on Molokai and a year later 27 on Oahu (Brock, 1960). Additional specimens were brought from Tahiti in 1961 (Maciolek, 1972). After just nine years, a large specimen was collected on the island of Hawaii (Kanayama, 1967). At present *M. lar* is established in streams on all the main Hawaiian Islands (Devick, 1991a).

Maciolek (1972) pointed out problems of introducing new species into insular freshwater ecosystems. He added that serious consideration should be given to the ecological consequences of such introductions. *Macrobrachium lar* should be cultured where it naturally occurs—on most of the islands other than Hawaii. In Hawaii, *M. lar* is in direct competition with the only native prawn, *M. grandimanus*. *Macrobrachium lar* is a vector for *Angiostrongylus cantonensis*, the cause of eosinophilic meningoencephalitis. A disease causing exoskeletal lesions called 'black spot' had not been seen on Oahu until after the introduction of *M. lar*.

The freshwater crayfish *Procambarus clarkii* was first introduced into Hawaii in 1934, when some of the 400 brought to Oahu as bullfrog food escaped (Penn, 1954). Penn further noted that individuals became established in taro patches where they burrowed into pond banks and fed to some extent on taro roots and corms. Brock (1960) reported that between 1937 and 1939 approximately 3,225 crayfish collected at Ahumanu, Oahu, were distributed on Hawaii and Kauai. Again, Brock remarked that this crayfish was a pest, burrowing through dirt dikes.

Apparently this crayfish has not been transported into the Pacific islands, since only Hawaii reports have been noted in a global review of introductions (Hobbs et al., 1989).

During 1990, a dense population of the freshwater atyid shrimp *Caridina weberi*, a species widely distributed throughout the Pacific islands, was first reported in Hawaii from Nuuanu Stream on Oahu (Devick, 1991b). Suggestions have been put forth that this shrimp may have arrived through the aquarium fish trade, since 'similar looking shrimp are sold as fish food.' This introduction could compete with the native atyid, *Atyoida bisulcata*, also a widely spread species.

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*Macrobrachium rosenbergii*, Hawaii [Photo: J. E. Brock]

# SEaweEDS

## SEAWEEEDS [*Eucheuma* and other species]

Some 150 species of marine algae (seaweeds), including species found in ballast water, have been introduced throughout the world (Russell, pers. comm.). About half of these have been transported by ships, nearly half have been transplanted with aquaculture experiments, some have been carried along with introduced oysters and clams, and the remainder transferred through canals or by unknown mechanisms (Russell, 1987).

Seaweed culture with *Eucheuma* was begun in the Philippines in the 1960s because some of these species produced carrageenans (some exclusively kappa-carrageenan and others, iota-carrageenan) (Doty, 1977). With the success in the Philippines, other countries attempted to experiment with algal culture. Many introductions were accomplished in Hawaii, beginning in the early 1970s [see **The Hawaiian Example II** (below) for details on the introductions and impacts in Hawaii].

Because of the growing interest in seaweed culture, a workshop organized by the South Pacific Aquaculture Development Project was held in December 1989 to encourage seaweed culture by describing and demonstrating culture techniques, by demonstrating seaweed handling techniques, and by providing opportunities for information exchange (Adams and Foscarini, 1990). Species of the red alga *Eucheuma* have been transported to several island countries. Material is being consistently produced at Fiji (Munro, 1993). Kiribati has developed a thriving village industry and is currently exporting more than 200 tons annually to Europe (Adams, pers. comm.).

The taxonomy for *Eucheuma* is confusing. The name *cottonii* is a general word used to describe a number of *Eucheuma* species (Doty, 1988). Recent taxonomic revisions have added to the confusion. *Eucheuma striatum* var. *tambalang* and *E. alvarezii* var. *tambalang* are now *Kappaphycus alvarezii* [common name 'tambalang'], *Eucheuma striatum* var. *elkhorn* is *Kappaphycus striatum* [common name 'elkhorn'], *Eucheuma cottonii* is *Kappaphycus cottonii*, and *Eucheuma spinosum* is now *Eucheuma denticulatum* [common name 'spinosum'] (Doty, 1988; Glenn and Doty, 1990).

All the *K. alvarezii* farmed in the Pacific Islands is part of a monoclonal, vegetatively propagated stock derived from the Philippines. Adams (pers. comm.) reported that he had never observed material attached to anything in the wild (the species lacks holdfasts) and that he had never seen any sexual stages; he added that it is very unlikely the material would survive in the wild and would have been noted, if it had, at least in Fiji.

Seaweeds have been transplanted to the Pacific Islands since the 1970s. Below is a review of transplantations, arranged by country:

### Cook Islands

In the late 1980s, *K. alvarezii* was introduced to Aitutaki from Fiji but was unsuccessful (Sims, pers. comm.).

### Federated States of Micronesia

Seed material of *E. denticulatum* and *K. alvarezii* was taken to Pohnpei for experimental culture; subsequently, material was transported to Kosrae (Doty, pers. comm.).

### Fiji

In 1976, two trials were initiated with *K. striatum*; the first from Cebu, Philippines, being planted near Suva and at Mana Island, and the second (2 kg) from Hawaii, planted near Telau Island, Bau, east of Suva. These trials were monitored and propagated for two years (Booth et al., 1983; Prakash, 1990) but were all destroyed during a cyclone (Luxton et al., 1987). In 1984, *K. alvarezii* was transported from Tonga and was planted at four sites north of Rakiraki (Luxton et al., 1987).

## French Polynesia

Introductions into French Polynesia apparently were unsuccessful (Uwate et al., 1984); however, there was a small farm at Bora Bora and subsequent development at Raiatea (Doty, pers. comm.)

## Kiribati

In October 1977, material of *K. alvarezii* and *E. denticulatum* were transported from Hawaii to Fanning Island (Russell, 1982) and to Kiritimati (Christmas Island). Even though great care was taken to clean the material, four additional algal species appeared at Metaua Point, Fanning Island, during the first month. These were *Acanthophora spicifera*, *Dictyota acutiloba*, *Hypnea musciformis* and *Ulva reticulata* which are all commonly found in Kaneohe Bay, Oahu, but had not previously been reported from Fanning (Russell, 1982). *Acanthophora spicifera* was also reported from Christmas Island. In 1977, *K. cottonii* and *E. denticulatum* from the Philippines were introduced (Uwate et al., 1984). Seed material from the original Kiritimati project was transplanted to Tarawa in 1981 where it has become an adequate subsistence venture (Uan, 1990). In 1982, trials were carried out at Marakei Island which proved to be unsuccessful, and in 1983, the Government instituted a research program to investigate the development of a seaweed cash crop. Mature plants were collected and transplanted to six outer islands—Butaritari, Abaiang, Maiana, Abemana, Beru, and Onotoa (Why, 1985).

## Marshall Islands

Material from Pohnpei was transported to Majuro lagoon in 1990 [although there was none by June 1992 (A. Smith, pers. comm.)]; from Majuro material was taken to Mili and Likiep (Zingmark, 1990); and specimens have been observed growing on floating giant clam trays at the Likiep Mariculture facility (Clarke, pers. comm.).

## Solomon Islands

Material from *K. alvarezii* was transported in three lots to the Solomon Islands from Fiji in 1987 and held in quarantine in ICLARM raceways (Smith, 1990). Further transplants were made to Vonavona, Munda, Gizo, and Ontong Java; apparently not successful (Adams, pers. comm.).

## Tonga

In 1982, material transplanted (*K. alvarezii*) from Tarawa to Vava'u showed growth rates equal to or greater than that in well-established commercial farms (Fa'anunu, 1990); all stock was lost through neglect by heavy siganid grazing, original strain re-introduced from Fiji around 1989 (Adams, pers. comm.).

## Tuvalu

In 1977, seed material was introduced to Tuvalu from Kiribati (Gentle, 1990) reported as *K. cottonii* but was probably *K. alvarezii*.

## Western Samoa

In July and December 1975, 420 lb of *K. alvarezii*, along with 80 lb of *E. denticulatum*, were sent to Upolo, Western Samoa (Russell, pers. comm.).

**The Hawaiian Example II:**

Since 1950, 17 species of marine macroalgae have been introduced to Oahu, Hawaii (Russell, 1992). Two—*Acanthophora spicifera* and *Hypnea musciformis*—have displaced native species. The latter species forms long and tangled one-foot-high rope-like windrows along the beaches of north and south Maui and represents the most disruptive introduced species (Abbott, 1987, pers. comm.). The former species was first seen in the early 1950s and is the most widespread and successfully introduced algae in Hawaii; the remaining species all arrived during the 1970s.

Below is a chronological listing of marine algae introduced to Oahu, Hawaii (modified from Russell, 1992):

1950: *Acanthophora spicifera* from Guam [possibly arriving on the hull of a barge (Doty, 1961) or with algal-covered substrate with fish to the Waikiki Aquarium (Russell, pers. comm.)] to Pearl Harbor/Waikiki, after 1950 or 26 April 1952; highly successful

1950(?): *Nemacystus decipiens* from unknown source to Waikiki; successful

October 1970 to late 1976: *Eucheuma denticulatum* [= *E. spinosum*] from Philippines to Honolulu Harbor, Kaneohe Bay, etc.; successful

mid-1970s: *Gracilaria eucheumoides* from Philippines to Kaneohe Bay; unknown success

mid-1970s: *Gracilaria tikvahiae* from Florida to Kaneohe Bay and Kahuku; successful

August 1970 to late 1976: *Kappaphycus striatum* [= *Eucheuma striatum* var. *elkhorn*] from Pohnpei and Philippines to Honolulu Harbor, Kaneohe Bay, etc.; successful

1971 and 1978: *Gracilaria epihippisor*a from Hilo, Hawaii to Waikiki and Kaneohe Bay; marginally successful

1971 and 1978: *Gracilaria salicornia* from Hilo, Hawaii to Waikiki and Kaneohe Bay; highly successful

1971: *Gracilaria* sp. from Philippines to Honolulu Harbor; unknown success

1972 and 1980s: *Macrocystis pyrifera* from California to Makapuu and Keahole Point; not successful

January 1974: *Hypnea musciformis* from Florida to Kaneohe Bay; highly successful [deliberate introduction or accidental epiphyte on another algae from Florida or California (Abbott, 1987)] [January 1976 is also given for this introduction (Russell, pers. comm.)]

January 1974: *Eucheuma isiforme* from Florida to Kaneohe Bay; not successful [January 1976 is also given for this introduction (Russell, pers. comm.)]

September 1974 to late 1976: *Kappaphycus alvarezii* [= *Eucheuma striatum* var. *tambalang*] from Philippines to Honolulu Harbor, Kaneohe Bay, etc; successful

1974(?): *Wrangelia bicuspidata* from unknown source to Kaneohe Bay; successful

1976: *Lola lubrica* from California to Makapuu and Kahuku; not successful (transported with oysters)

1976: *Pilinella californica* from California to Makapuu and Kahuku; not successful (transported with oysters)

?: *Porphyra* sp. from Japan to Oahu; unknown success

The majority were deliberately transplanted for commercial interests for chemical or agar production; two were accidentally carried in oyster shipments.

The introduction of *K. striatum* to Kaneohe Bay, Oahu, became very controversial. Dr. A. H. Banner (in litt.) wrote that '...this gross plant spread especially westward towards the reef edge. Suddenly people here at the lab [HIMB] got all excited about it for it was growing so fast in the polluted waters and lodging in the corals at the edge and apparently overgrowing and killing them....'. Russell (1983) stated that this alga did not produce spores and that reproduction was by fragmentation. Small fragments spread over short distances and grew to full size. The alga was thought not to tolerate waters as deep as 5 m. Some time later Banner (in litt.) indicated that he observed only a few specimens of this alga.

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# MISCELLANEOUS

# CROCODILES

The Indo-Pacific crocodile *Crocodylus porosus* is native to Papua New Guinea, Solomon Islands, northern Vanuatu and Palau. Numerous individuals have been transported to Palau from the Philippines (Kimura, 1968). In 1938, a Mr. Saeki imported 1000 crocodiles from Davao. They 'seemed to be Philippine crocodiles and saltwater crocodiles' (p. 40). A second 1000 were imported at an unspecified later date. Kimura did not provide scientific names; however, Messel and King (1991) interpreted the common names to scientific names. Kimura (1968) also reported that 10 American alligators were imported. At the beginning of World War II, only 200 individuals were left. By the end of the war, there were fewer; some had escaped from the rearing pens.

In the extensive survey of Messel and King (1991), they concluded that only the Indo-Pacific crocodile, *C. porosus*, was found at Palau. [Ross (1989) has chosen to use Indo-Pacific crocodile in preference to this species' other common names – estuarine or saltwater crocodile – because it is the only one with a habitat-associated name rather than one based on anatomical or geographic features.]

*Crocodylus porosus* has also been reported once from Pohnpei, Caroline Islands (Anon., 1971; Allen, 1974). A male 380 cm in length was caught in a trap March 1971. Previously to this crocodiles were unknown at Pohnpei. In late March/early April 1986, tracks of a crocodile were found at Paliyaw Island, Woleai Atoll. The tracks, 2 to 3 feet wide with a slide mark in the middle, went from the lagoon to a brackish swamp.

At the same time a large log (4-foot diameter, 30-40 feet long) was seen floating in the lagoon. The islanders theorized that the crocodile had ridden on the drifting log from Palau (A. Smith, pers. comm.). Crocodiles have also been reported from Fiji and New Caledonia. In 1993, a specimen was caught in the Loyalty Islands, New Caledonia, and taken to the Noumea Aquarium (Adams, pers. comm.).

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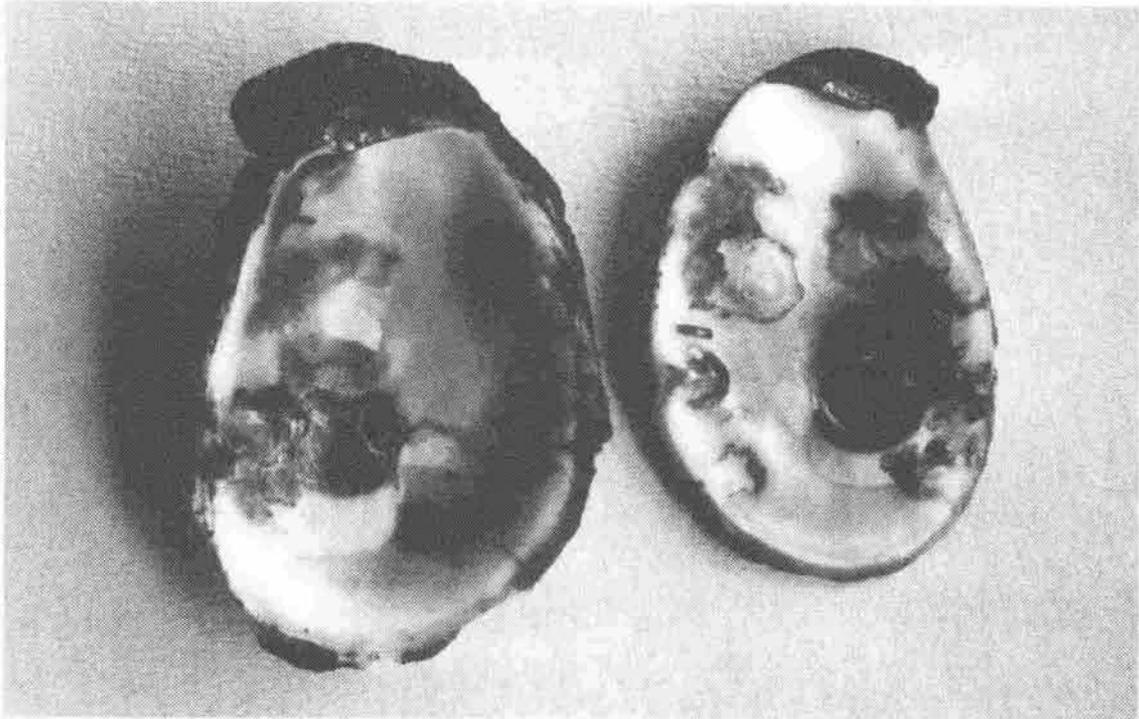
## POLYCHAETE ANNELIDS

In oyster aquaculture, infection by the mud blister worm, *Polydora websteri*, may effect the health of the oyster and its marketability (Bailey-Brock and Ringwood, 1982). The mud blister worm is a tubicolous polychaete which bores into the shells of oysters and other mollusks and forms a small mud-filled pocket. These are the mud blisters seen on the inner surface of the shell (Bailey-Brock and Ringwood, 1982). They lower the marketability of the oyster and can cause health problems. Mud blister worms were found in a land-locked intensive oyster (*Crassostrea gigas*) farm at Kahuku, Oahu. The oyster raceway was located some distance from the shore and flushed with brackish well water. The worms were introduced either with oysters transported from Kaneohe Bay or from oyster spat imported from U.S. west coast hatcheries. Control experiments were conducted, and it was found that worm larvae formed burrows in the oyster raceways. The oyster farm eventually ceased operation.

Another spionid polychaete, *Polydora nuchalis*, is a commercially undesirable species and an accidental introduction into Oahu, Hawaii, where specimens were collected at two aquaculture farms (Bailey-Brock, 1990). These worms form masses of mud tubes which accumulate large amounts of sediment in the bottoms of culture ponds and may completely block drains and pipes. In self-contained systems these worms may compete for planktonic food introduced for filter-feeding animals, such as oysters, or may occupy space intended for microbial or algal growth. These worms are considered a pest, since no real detrimental effects are known to be caused by them. It is thought that the worms may have been transported with penaeid shrimps from western Mexico to stock ponds on Oahu and from there to other ponds with purchased individuals (Bailey-Brock, 1990).

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Two oyster valves with *Polydora websteri* blisters on inside of shell [Photo: R. Brock]

# MARINE SPONGES

During the 1946 fisheries survey of Micronesia, sponges which were being cultured between 1940 and 1943 at Ailinglaplap, Marshall Islands, by the Japanese were collected and initially identified as *Spongia officinalis mollissima* (Smith 1947a, 1947b). This form, known exclusively from the eastern Mediterranean Sea, was thought to have been introduced. However, upon further investigation, interview with the manager of the sponge operations, and taxonomic study, it was decided that these sponges were not the Mediterranean form but perhaps a new subspecies. It was later substantiated that the sponges were not introduced but were of local origin (Cahn, 1948). These forms were later described as *Spongia officinalis matamata* by deLaubenfels (1954).

Current feasibility studies for sponge culture at Yap (Bridgeland, 1992) and Pohnpei (Stevely, 1989; Croft, 1990) plan to use locally collected material.

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# FRESHWATER JELLYFISH

The small freshwater medusa or jellyfish, *Craspedacusta sowerbyi*, has been transported to most freshwater areas of the world, probably with ornamental aquatic plants or with water hyacinths (Slobodkin and Bossert, 1991). Little is known about the biology of the freshwater medusa. Its larval stage is a minute colony of polyps without tentacles. These animals were first reported in Hawaii from Maui in 1938 (Edmondson, 1940). Specimens were collected at Fena Lake, Guam, in May 1970 (Belk and Hotaling, 1971). Since the dam at Fena Lake was completed in 1952, it must be assumed that introduction occurred some time after that, perhaps at the time when tilapia were released.

Introduction of this medusa can occur wherever aquatic plants or their transport water are released into the environment.

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## AMPHIBIANS [*Bufo marinus* and other species]

The marine toad *Bufo marinus* occurs naturally from southern Texas and western Mexico to central Brazil (Zug and Zug, 1979). Because of their large size and their wide adaptability, toads were thought to be good biological control agents. They have been introduced throughout much of the Pacific area during the past 50 years. Transplantation of *B. marinus* has been reviewed by Honegger (1970), Tyler (1975), and Easteal (1981).

In the Pacific, the first toads were brought to Oahu (Hawaiian Islands) in 1932 from Puerto Rico (Pemberton, 1934). Toads were later introduced to Guam, originally for insect and garden slug (*Veronicella leydigii*) control. Some nineteen individuals from Hawaii were released at Agana Springs, Guam, in July 1937 (Anon., 1937a). By September of that year, toads were found as far as Piti, several miles to the south (Anon., 1937b). [Easteal (1981) reported from unpublished Hawaii Sugar Planter's Association material that 'fewer than 39 individuals' were released in 1937.] In January 1938, more than 5000 young toads were collected near Piti and were transplanted in lots of 500 each to Umatac, Merizo, Inarajan, Yona, Dededo, Talofoto, and Sumay (Anon., 1938). On Guam the toad has spread sufficiently to be considered a nuisance (McCoid, 1993).

The first record for Micronesia outside Guam was that from Tinian in 1944 (Stohler and Cooling, 1945) where approximately 4000 individuals were found in cisterns and lily ponds. Original stock arrived from Guam (Townes, 1946) during the Japanese occupation, although Downs (1946) stated that he did not know their source. Townes (1946) further added that toads were found at Saipan and at Rota, having been introduced to Rota as recently as 1944. A single toad was taken to Pagan in the mid-1960s (Aldan, pers. comm.). Toads continue to be common on Tinian (Wiles et al., 1989) and may spread to other islands in the Marianas (Rodda et al., 1991).

Fisher (1948) noted that toads were abundant on Pohnpei and Yap. Toads were taken to Ulithi in October 1948 but were all destroyed upon arrival (Langford, 1948). [They were later introduced in 1973 (McCoy, pers. comm.).] Savage (1960) reported toads from Palau and studied larvae collected at Koror. Because of the many similarities between Palauan and Mexican specimens, Savage suggested that the Palau forms may have originated directly from the west coast of Mexico.

In early 1936, 67 half-grown adult toads were imported to Fiji from Hawaii (Jack, 1936). Shortly afterwards individuals were released in several locations on Viti Levu. By 1938, *B. marinus* had spread throughout Viti Levu and onto Vanua Levu, Taveuni, Rabi, and Kadavu (Lever, 1938); Easteal (1981) also reported them on Ovalau.

Because of supposed success as biological control animals, individuals from Hawaii were imported in February 1937 to Papua New Guinea directly to a governmental experiment station on New Britain (Zug et al., 1975; Pippet, 1975). From here they were distributed throughout the 'Territory of New Guinea'. Unsubstantiated evidence indicates that toads were either released or escaped in Port Moresby in 1938. Individuals were also imported from Australia in 1937 (Lever, 1942). Zug et al. (1975) provided a lengthy list of site-specific introductions within most of the Papua New Guinea provinces.

In November 1939, 150 adult toads were imported to Funafuti, Tuvalu, from Suva, Fiji (Lever, 1942). Individuals were taken to Vaitupu. In February 1940, toads were taken to Guadalcanal, Solomon Islands (Lever, 1942). Several other islands of the Solomon Islands are reported to have *B. marinus* (Easteal, 1981).

Toads were introduced to Tutuila, American Samoa, from Hawaii in 1953 (Anon., 1953) although Simmonds (1957) had strongly advised against such action. Several pairs were imported and bred in artificial ponds; tadpoles were distributed on Tutuila (Amerson et al., 1982). These authors provided details of the status of the species, indicating that they have done more harm than good. Their introduction to Aunu'u is not documented (Amerson et al., 1982; Lauofa, pers. comm.).

Studies are available on the status of *B. marinus* for Papua New Guinea (Zug et al., 1975), Guam (Chernin, 1979), and American Samoa (Amerson et al., 1982). In Papua New Guinea, toads were found to be ten times more dense on the savanna than in the rain forest, but rain forest toads were longer and heavier (Zug et al., 1975). At Guam, five sites—a spring with standing water, a swamp with fluctuating water, a limestone forest, a savanna, and an area of human habitation—were studied. Populations were greatest in areas of standing water and human habitation. Toads were excluded from the savanna and were found in low numbers in the limestone forest. Densities varied seasonally. During late 1978 and early 1979, the population density was 185 per hectare in areas of human habitation and 225 per hectare for standing water at Agana Springs (Chernin, 1979). For areas of human habitation this density is similar to that (184 per hectare for 1975 and 138 per hectare for 1976) found by Zug and Zug (1979) at Panama. On Tutuila, toad population densities were estimated at 121 per hectare (extrapolated from 'per 100 m<sup>2</sup>' data) for areas near human habitation and 110 per hectare along the coastal rock strand (Amerson et al., 1982). These authors added that toads were active only at night; hiding during daylight. Adults and tadpoles were observed during each month of the study.

The consensus indicates that toad introductions have been more disastrous than beneficial. Toads are a nuisance and have poisonous parotid glands behind the head which secrete toxins that can be 'squirted in jets of a distance of at least one meter' (Tyler, 1975, p. 3). Numerous cat and dog deaths are reported; human deaths have also been recorded (Tyler, 1975); an estimated 50 dogs are killed each year in Hawaii (Otani et al., 1969). In American Samoa there is no direct evidence, but the high incidence of polluted drinking water and dysentery may be correlated with high densities of toads in areas of human habitation (Amerson et al., 1982). Kourany et al. (1970) and Speare (1990) reported high incidence of *Salmonella* associated with amphibians. The toad can also act as a vector for human helminth parasites (Speare, 1990).

In a general assessment of the impact of toad introductions, Tyler (1975) noted that 'in the long term the toad failed to live up to expectations'. Beneficial insects were also eaten by toads; the impact on native vertebrates is not known. Anecdotal evidence has indicated that toads have had a major impact on Australian snakes; Shine (1991) provided a photograph of a dead snake with a dead toad in its mouth. In addition to contaminating drinking water, toads are known to have killed freshwater exotic fishes. The problem remains. *TIME* magazine (July 29, 1985, p. 49) highlighted their introduction to Australia, detailing the effects of this 'cold-blooded killer'.

More than 30 years ago, Mead (1961, p. 105) wrote: 'Who could have guessed that introducing *B. marinus* would, in addition to reducing the black slugs, aggravate the rat problem, kill the monitor lizard, reduce natural control of coconut pests and the giant snail, bring some relief to the poultry industry, kill pigs and house pets, and ameliorate a public health problem of cockroaches and flies brought on by the introduction of the giant African snails? As a final ironic twist, the native peoples are convinced that their dogs and cats have died from eating the 'poisonous' giant African snail!'

Several other amphibians have been introduced to Pacific Islands. Bullfrogs (*Rana catesbiana*) were brought to Hawaii in 1867 and 1879 as a source of food (Oliver and Shaw, 1953; McKeown, 1978). In 1977, the Mariana Food Corporation proposed the establishment of a frog-leg farming project at Lake Susupe, Saipan (Mariana Food Corporation, 1977). Several other amphibians have been introduced to Oahu, Hawaii, including *Dendrobates auratus*, the gold-and-black (or green-and-black) poison frog, which was imported in 1932, originating from islands in the Gulf of Panama (Oliver and Shaw, 1953; McKeown, 1978).

A small tree frog, *Litoria fallax*, was first found in the central courtyard of the then Guam International Airport in 1968 (Falanruw, 1976; Eldredge, 1988). The species, native to southern Queensland, has now spread throughout Guam and is associated with wetlands (McCoid, 1993). Speculation might lead one to wonder whether the frog's arrival might not have resulted from the escape or release of a child's pet during an airline layover.

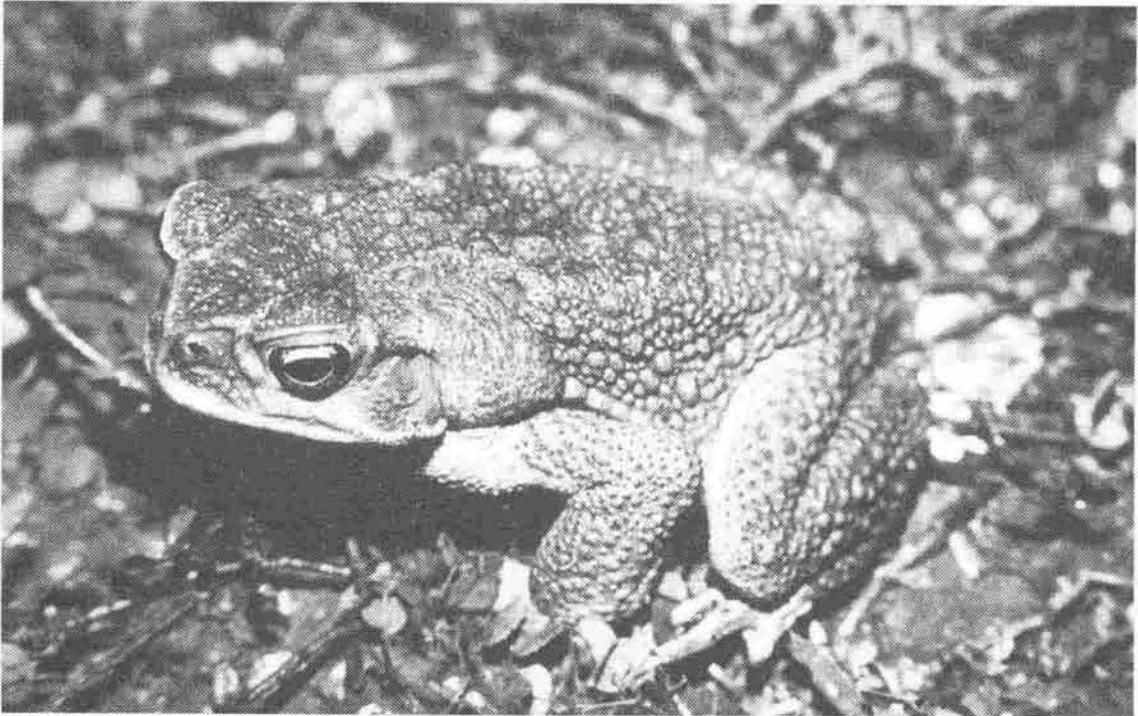
Another hybrid frog has been introduced to New Caledonia. *Litoria aurea*, the green and golden bellfrog, is thought to have been in New Caledonia for more than a century, since it was widely distributed by 1912 (Bauer and Vindum, 1990). Specimens were reported from Efate, Malekula and

Espiritu Santo in Vanuatu by 1971 (Tyler, 1979). These were presumably transported intentionally by plantation people. Individuals have also been reported from Wallis Island (Goldman, pers. comm.).

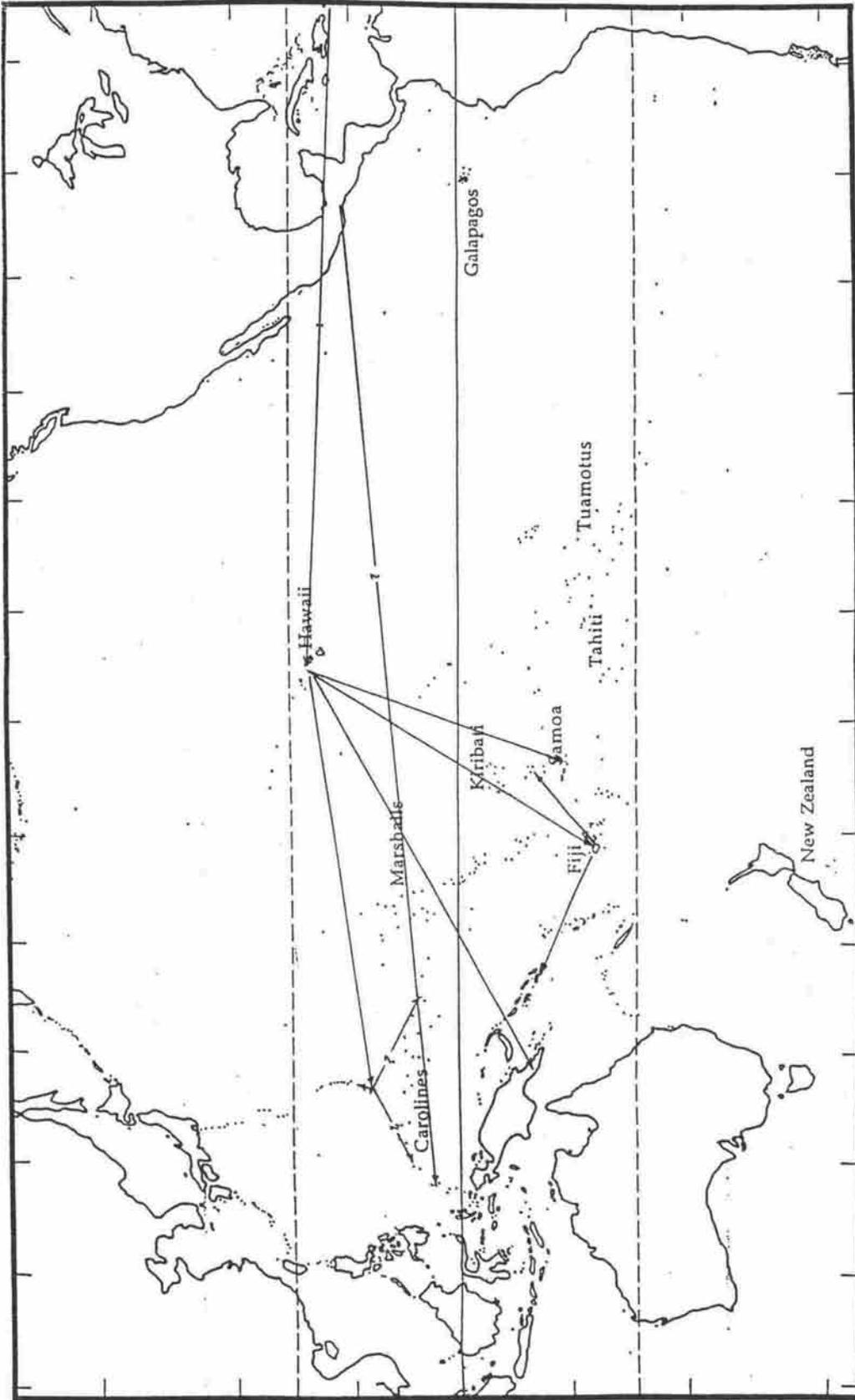
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The marine toad *Bufo marinus*, Yigo, Guam [Photo: R. Krizman]



*Bufo marinus* – generalized map of marine toads transfers among the Pacific islands; each direction of transfer is indicated only once, although numerous transfers may have occurred in that direction.

## FRESHWATER TURTLES

The aquarium/pet-trade turtle, *Trachemys scripta*, commonly called red-eared slider or slider, is apparently established at Guam and probably at Lake Susupe on Saipan (Rodda et al., 1991). Individuals have been seen in the rivers of southern Guam, and in Fena Valley Reservoir and Agana Swamp. Nesting has been observed along the Ugum River (McCoid, 1992). With further human assistance this turtle could become established on other islands with sufficient streams or ponds. This species has been established in many ponds and streams of Oahu since about 1980 (Devick, 1991). It is probably innocuous but does show rapid human-related spread. [This species has also been referred to as *Chrysemys scripta*.]

The softshell turtle *Pelodiscus sinensis* was imported to Guam from Taiwan for aquaculture purposes in 1977 and held in earthen ponds (FitzGerald, 1982). Established populations are known from southern and central Guam, and hatchlings were seen among the southern population in November 1990 (McCoid, 1993).

Two species of softshell turtles are established in Hawaii at Oahu and Kauai. Specimens of *Pelodiscus sinensis* (reported as *Trionyx sinensis*) were first collected in 1945 (Brock, 1947) at Kauai. *Palea steindachneri* (reported as *Trionyx steindachneri*) was first found at the Honolulu Zoo in November 1980 following the draining of an outdoor moat (McKeown and Webb, 1982). Additional support for this is found in newspaper articles in September 1969 and August 1974. Both species are well established in Hawaii. Softshell turtles are highly prized as food, especially by Chinese. These two turtle species naturally live together and were probably introduced together.

[The generic name changes used here are based on those of Ernst and Barbour (1989).]

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