Invasion by the Mozambique Tilapia (*Sarotherodon mossambicus*; Pisces; Cichlidae) of a Pacific Atoll Marine Ecosystem

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Abstract—The cichlid fish, *Sarotherodon mossambicus*, native to southern Africa and introduced into many other areas of the world, was released by personnel of the U.S. Bureau of Commercial Fisheries in a saltwater pond on Fanning Atoll and in a freshwater lake on nearby Washington Island, Line Islands, in 1958 from stocks obtained in Hawaii. Since then, this exotic fish has become established and has dispersed into several estuaries and the lagoon of this atoll. The range of this fish, two decades after its introduction, encompassed approximately 16 km of lagoon coastline at Fanning Atoll. Resident islanders have not utilized this tilapia except to kill them when the fish becomes too abundant; they are not used as baitfish or as food. *S. mossambicus* is preyed upon by predatory fishes and piscivorous birds, but such predation has failed to stem the range expansion of this exotic fish.

Introduction

In 1951, the Hawaii Division of Fish and Game imported a stock of the Mozambique tilapia, *Sarotherodon mossambicus* (Peters), from Singapore and successfully introduced this exotic fish to all major islands of Hawaii (Hida et al. 1962). Although the rationale for this introduction is unclear, this species was subsequently used as skipjack bait (Brock and Takata 1955; King and Wilson 1957). In the interim, the U.S. Bureau of Commercial Fisheries, at the request of the Hawaii Division of Fish and Game, made what Murphy (1960) considers to be the first successful introduction of an exotic marine fish, the Marquesan sardine, *Harengula vittatus* (Cuvier and Valenciennes), to Hawaii. The rationale for this introduction was stated as "suitable for tuna fishing. . . to supplement the somewhat tenuous supply of the nehu, *Stolephorus purpureus* Fowler", a native bait-fish used for tuna, . . . and the "attendant vacant niches" (Murphy 1960), an often-used rationalization for introductions of exotic species to which Murphy attributed successful establishment there and of other fishes elsewhere.

The U.S. Bureau of Commerical Fisheries began experiments in the late 1950s on the potential of the Mozambique tilapia as tuna bait. Two research vessels, the HUGH M. SMITH and CHARLES H. GILBERT, were supplied with this tilapia from Hawaiian stocks as late as the end of 1959 (Hida et al. 1962). Although there is no official mention of introducing tilapia at Fanning Atoll and neighboring

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Washington Island in either the ship's scientist or deck logs during cruise 42 of the CHARLES H. GILBERT (8 October to 17 November 1958), Paul Strusaker (pers. comm.) located a crew member on that cruise who remembered the releasing of this tilapia at both locations.

The purpose of this report is to document the status (as of 1978) of the Mozambique tilapia at Fanning Atoll, two decades following its release. Preserved specimens of *S. mossambicus* collected at Fanning Atoll are deposited at the Museum of Comparative Zoology, Harvard University.

Distribution at Fanning Atoll

Fanning Atoll is one of the Line Islands, Central Pacific Ocean (3°55′N; 159°23′W). Chave (1970), Chave and Kay (1973), and Chave and Eckert (1974) provide comprehensive survey data on the fauna, flora and geology of this atoll. The saltwater estuarine environment, including both biotic and physical parameters, were described by Guinther (1971). The estuaries typically are equal in salinity with the lagoon except during periods of heavy rainfall. The salinity, however, never drops below a level usually tolerated by native estuarine fishes.

During the summer of 1978, every major estuary on Fanning Atoll, with one exception, was surveyed for the presence of Mozambique tilapia. We found extensive dispersal from the original site of introduction (Fig. 1) but this exotic fish had not yet succeeded in spreading throughout the atoll. *S. mossambicus* was absent in the estuaries in the northeast sector possibly due to water barriers at North Pass and Teharoa Iti. The dispersal of this species is a natural phenomenon as resident islanders do not collect the fish except to kill them when they become too abundant; they are not used as a baitfish or food fish.

We also surveyed the freshwater lake at nearby Washington Island. The Mozambique tilapia was abundant throughout the lake but, unfortunately, time was not available for a more thorough survey.

Predation on Tilapia

It is clear that the introduced *Sarotherodon mossambicus* has adapted to the marine environment of Fanning Atoll with respect to reproductive habits and to the extent that this species has been able to expand its range, despite the presence of several predators. The risk of predation by larger predators varied with the tidal cycle.

Water depth in the estuaries fluctuated tidally between 0.5 and 1 m. Consequently, different sections of the estuaries were either flooding or draining. Predaceous marine fishes entered the estuaries from the lagoon during rising tides. At high tide, tilapia were pursued by piscivorous fishes. During low tide, however, tilapia trapped in shallow pools or on nests (Fig. 2) were vulnerable to predaceous seabirds.

At low tide, the estuaries were too shallow for jacks (*Caranx* spp., mostly *C. ignobilis* [Forskål]) and juvenile blacktip sharks (*Carcharhinus melanopterus* [Quoy

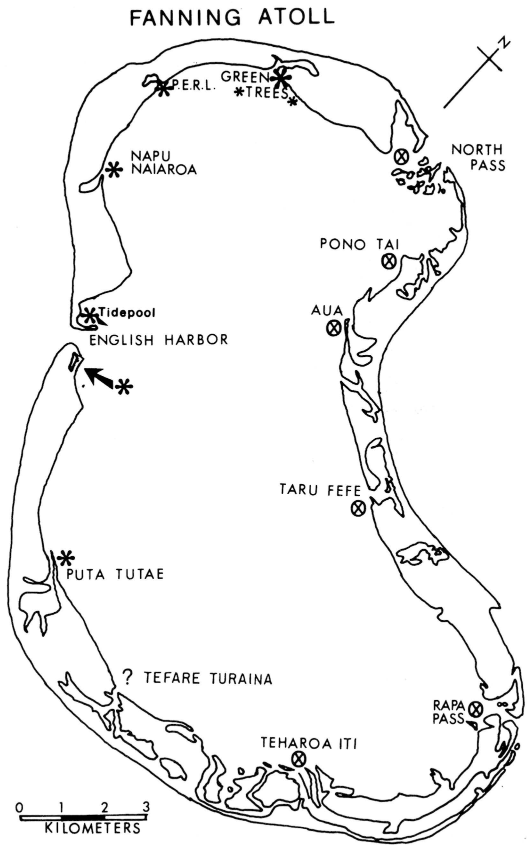

Fig. 1. Distribution of tilapia at Fanning Atoll June-September, 1978. The arrow with asterisk identifies the pond into which tilapia were released in 1955. A limited number of tilapia were also released in the tidepool on the other side of English harbor at the same time. Other locations marked with an asterisk identify estuaries where tilapia are present. The Green Trees estuary with smaller asterisks is the site where schools of juvenile tilapia were frequently observed migrating into the lagoon. Locations marked with a circled X are estuaries that did not contain tilapia. One estuary marked with a question-mark was not inspected. P.E.R.L. is the site of the Pacific Equatorial Research Laboratory.

and Gaimard]) to enter them or the surrounding reef area. Tilapia occupied nest-pits in the deeper sections at this time; nest-pits in the shallow sections were semiexposed and vacant. Juvenile tilapia moved in large schools into the lagoon but remained in shallow water.

On the incoming tide, juvenile tilapia moved back into the estuaries first, followed later by the adults as water depth increased. Once the water was sufficiently deep, numerous jacks and blacktip sharks entered the estuaries. At this time, tilapia

Fig. 2. Tilapia in nests at Napu Naiaroa estuary.

crowded into the shallow sections of the estuary, shaded by low, overhanging palm fronds and other vegetation. Tilapia stranded in shallow areas beyond this cover area were exposed to piscivorous birds that we observed frequently swooping to catch these fishes. Jacks and sharks were observed attacking tilapia aggregations, often splashing as they invaded the shallows.

The Mozambique tilapia was the predominant prey of predatory fishes collected at high tide in the estuaries between 0900 and 1500 hrs in August 1976 and July 1978 (Table 1). Other estuarine species present in abundance are listed in Table 2. The relative abundance of estuarine fishes was estimated by seining an area of approximately 3050 m^2 in the Green Trees estuary (Fig. 1). The collection yielded 447 fishes of which 7% were tilapia, 33% juvenile mullet and 60% juvenile bonefish. Thirteen *Caranx* spp. were also collected in the same site. Although the tilapia was the least numerous fish in this single seine sample, this fish was the most frequent prey of the piscivores (Table 1). One explanation for this is that the Mozambique tilapia is particularly vulnerable because of its habit of crowding along shallow shorelines. Bonefish and mullet, however, aggregated at the surface over the deepest sections in the estuaries or moved into the lagoon during high tide.

Table 1. Specimens of piscivorous fishes collected in estuaries of Fanning Atoll.

	Caranx spp.	*Carcharhinus melanopterus*
specimens collected (n)	41	5
standard length: $\bar{Y}$ (range) in cm.	19 (12–30)	49 (46–69)
specimens containing tilapia	14 (34%)	3 (60%)
stomach contents:		
Sarotherodon mossambicus	45	4
Oxyurichthys lonchotus (Jenkins)	4	0
small octopus	0	1
unidentifiable (including invertebrate parts)	7	0
stomachs empty	15	1

Table 2. Common native fishes occurring in estuaries at Fanning Atoll.

Family	Species	Notes
Albulidae	*Albula vulpes* (Linnaeus)	mostly juveniles
Chanidae	*Chanos chanos* (Forskål)	″
Gobiidae	*Oxyurichthys lonchotus* (Jenkins)	adults & juveniles
Lutjanidae	*Lutjanus vaigensis* (Quoy and Gaimard)	″
	L. monostigma (Cuvier)	″
Mugilidae	*Mugil cephalus* Linnaeus	mostly juveniles
	M. engeli Bleeker	″
Tetraodontidae	*Arothron hispidus* (Linnaeus)	adults & juveniles

Discussion

Sarotherodon mossambicus is tolerant of estuarine environments in its native southern Africa (Jubb 1967; Whitfield and Blaber 1978) and other locales where it has become established such as California (Knaggs 1977) and Florida (W. R. Courtenay, Jr., pers. comm.). Bond (1979) cited salinity tolerances to 69 ppt for this fish. Brock (1954) first noted that the Mozambique tilapia in Hawaii was capable of growing and reproducing equally well in freshwater and seawater (see also Neil, 1966). Knaggs (1977) reported a reproducing population in California's marine waters with salinities up to 34.5 ppt at Colorado Lagoon in Long Beach. Popper and Lichatowich (1975) stated that *S. mossambicus* reproduced prolifically in saltwater ponds in Fiji with salinities up to 49 ppt.

One might expect saltwater environments with a variety of predatory fishes to be inhospitable to invasion by the Mozambique tilapia. Popper and Lichatowich (1975) speculated that the spread of *S. mossambicus* in Fiji was curtailed mainly by the predator *Elops hawaiiensis* Regan. In South African estuaries where *S. mossambicus* is native, Whitfield and Blaber (1978) found mullet to be the major prey of predators, particularly *Caranx ignobilis* which ate only mullet. *S. mossambicus* there was eaten by *Argyrosomus hololepidotus* (Lacépède) and *Elops machnata* (Forskål), but mullet was the preferred food of these predators. *S. mossambius* was found in less than 10 percent of all predator stomachs examined. Whitfield and Blaber (1978) also noted that juvenile Mozambique tilapia and other estuarine fishes inhabited shallow marginal areas, perhaps in response to roving predators. Jubb (1967) suggested that invasions of *S. mossambicus* from one estuary to another along the east coast of South Africa was via marine waters.

At Fanning Atoll, the Mozambique tilapia occupied the estuaries at low tide and retreated to shallow, covered areas on the incombing tide. Tilapia trapped in exposed shallows during low or high tides were preyed upon by seabirds. *S. mossambicus* was the major prey species of piscivorous fishes collected at Green Trees estuary in August 1976 and July 1978 (Fig. 1; Table 1). Despite predation by seabirds and predatory fishes, the Mozambique tilapia has successfully occupied 16 km of coastline in 1978 from its original site of introduction in 1958.

Haphazard or otherwise thoroughly untested introductions of exotic species to new habitats can produce devastating consequences to native communities (Courtenay 1979; Laycock 1966). Despite the obvious dangers, tilapias and other cichlid fishes are being introduced throughout the tropical areas of the world. Careful assessments of the real and potential impacts of cichlids, particularly tilapias, on native fish communities should be required prerequisites for any consideration toward introduction. The demise of much of a freshwater fish community in Gatun Lake, Panama, resulted from the introduction of the peacock cichlid, *Cichla ocellaris* Schneider (Zaret and Paine 1973). Knaggs (1977) has indicated a decline in native fishes in the San Gabriel River, California, and attributes this decline to increases in the population of *S. mossambicus*; he also suggests similar future effects on coastal marine fishes.

Although no quantitative data are available, Fanning Atoll fishermen claimed that the introduction and subsequent spread of the Mozambique tilapia has resulted in a decrease of mullet, bonefish and milkfish. These fishes utilize the estuaries as nursery grounds and Fanning islanders are dependent on these species for food and bait. Therefore, any decrease in supply can have serious consequences for Fanning islanders. Furthermore, these fishes represent a viable but, as yet, an unexploited fishery that could provide a profitable industry, particularly as the present copra industry declines.

Clearly, the careless and needless introduction of the Mozambique tilapia at Fanning Atoll has had no beneficial effects. It is vital that tilapias, other euryhaline exotic fishes or nonindigenous marine fishes not be released to other Pacific island ecosystems unless the benefits of such releases can be shown through careful and thorough research to outweigh any negative impacts. Nevertheless, as the result of a release in 1958 with subsequent establishment and range expansion by an exotic fish in marine waters, Fanning Atoll provides an ideal site for future studies on impacts of *S. mossambicus* in central Pacific marine ecosystems.

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