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EXPLOSIVE SPREAD OF THE ORIENTAL
GOBY *ACANTHOGOBIUS FLAVIMANUS*
IN THE SAN FRANCISCO BAY-DELTA
REGION OF CALIFORNIA

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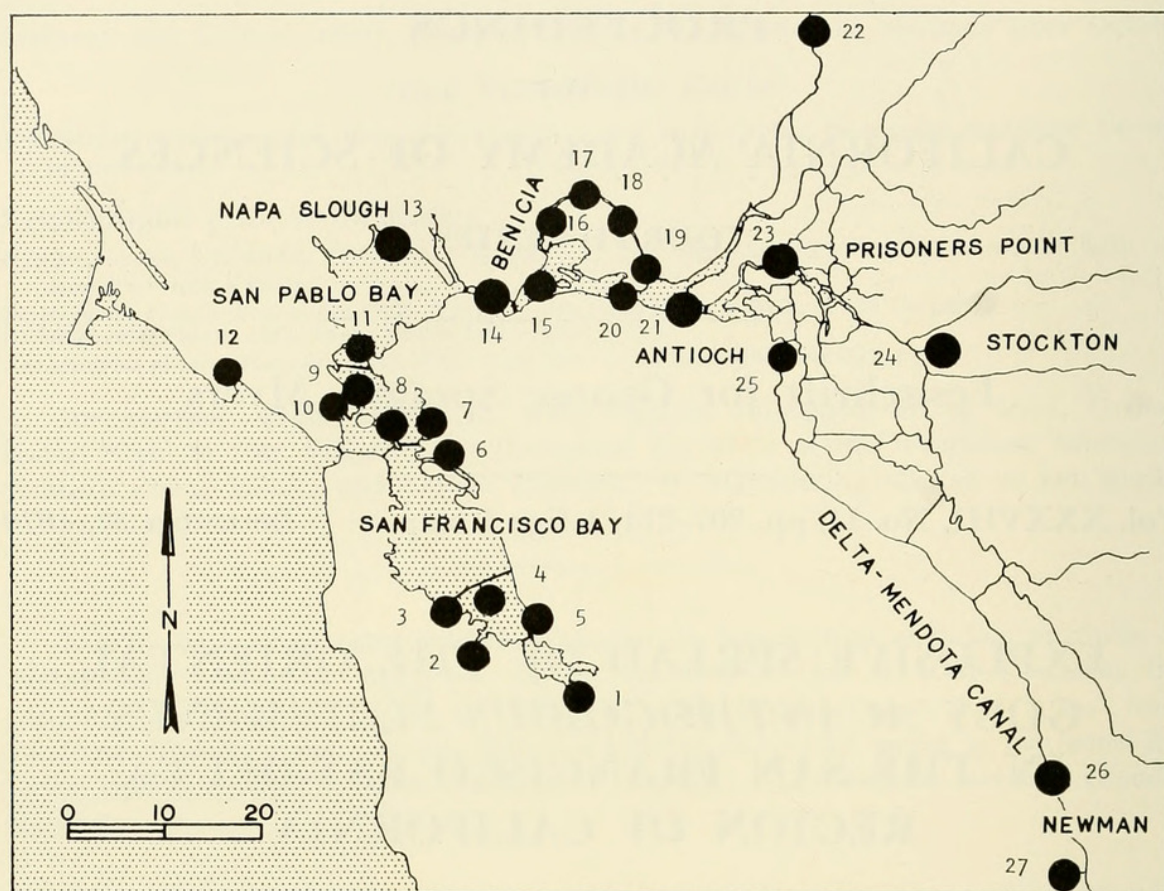
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One of the features of animal distribution in recent years is the unexpected appearance of a species from far-off lands which rapidly, sometimes explosively, expands its range in its new homeland, often in direct competition with established elements of the native fauna.



MAP 1. Collection localities for *Acanthogobius flavimanus* in the San Francisco Bay and Sacramento-San Joaquin Delta regions, 1963-1968 (the many verbal reports by fishermen in 1968 and later are not recorded). 1. Alviso, Santa Clara County. 2. Palo Alto Yacht Harbor, Santa Clara County. 3. Foster City Lagoon, San Mateo County. 4. San Mateo Bridge, San Mateo-Alameda counties. 5. Plummer Creek, near Newark, Alameda County. 6. Lake Merritt, Oakland, Alameda County. 7. Aquatic Park, Berkeley, Alameda County. 8. Treasure Island, San Francisco-Alameda counties; Angel Island, Marin County. 9. Tiburon, Paradise Cay, Belvedere, Marin County. 10. Richardson Bay, Belvedere, Marin County. 11. Marin Islands, San Rafael, Lower San Pablo Bay, Marin County. 12. Bolinas Lagoon, Solano County. 13. Napa Slough, Solano County. 14. Benicia, Carquinez Strait, Solano County. 15. Suisun Bay, Solano County. 16-19. Montezuma Slough, Solano County. 20. Suisun Bay, Solano County. 21. Antioch, San Joaquin River, Contra Costa County. 22. Snodgrass Slough off Sacramento River, opposite Walnut Grove, Sacramento County. 23. Prisoners Point, San Joaquin County. 24. Stockton (Deep Water Channel), San Joaquin County. 25. Tracy Pumping Plant, Alameda County. 26. Delta-Mendota Canal at Newman Wasteway, Stanislaus County. 27. San Luis Reservoir, Merced County.

In 1963 two specimens of *Acanthogobius flavimanus* Temminck and Schlegel, a euryhaline goby of Japan and adjacent mainland waters, were taken in the Sacramento-San Joaquin River Delta of California. The first specimen of the "mahaze" (its Japanese name; Okada, 1960) was taken on January 18 at Prisoners Point on Venice Island, and the second was taken on March 29 in the Stockton Deepwater Channel at the entrance of the Calaveras River, just below

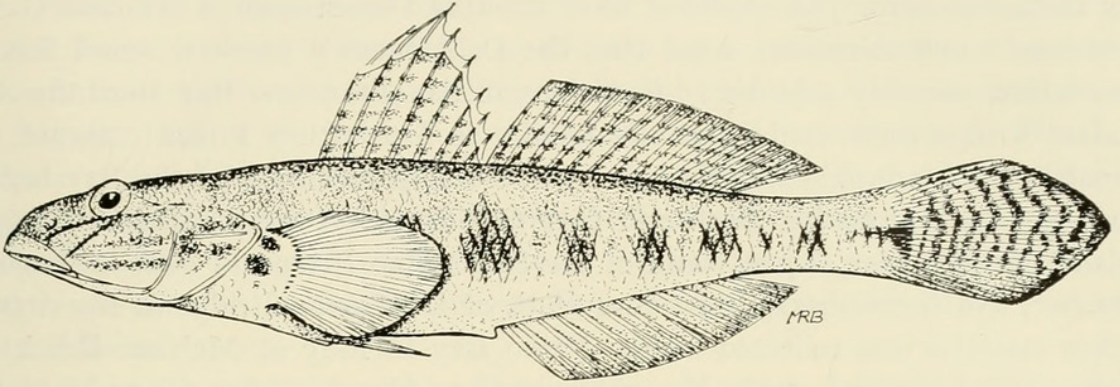


FIGURE 1. *Acanthogobius flavimanus* (Temminck and Schlegel). 123 mm. standard length, from the San Joaquin River at Prisoners Point, Venice Island, San Joaquin County (from Brittan, Albrecht, and Hopkirk, 1963). The higher outline of the dorsal fin added to the drawing is from a specimen of 176 mm. standard length from the Delta-Mendota Canal at Newman Wasteway, Stanislaus County, and illustrates the condition typical in larger individuals.

the Port (and city) of Stockton. The first 2 specimens were 123 and 69 mm. standard length, respectively.

No further examples were collected until late 1964 when several were taken from Palo Alto Yacht Harbor (Robert Hassur, verbal communication) and from a trap in Leslie Salt Company evaporation ponds at Alviso (4; 141–153 mm.). These localities are roughly 80–90 water miles from the initial collection points.

No further specimens were taken until August, 1965, when one was obtained off Marin Island near San Rafael, Marin County (male, 161 mm.) and, surprisingly enough at the time, an additional one at Newman wasteway on the Delta-Mendota Canal, which carries fresh water for irrigation from the Delta to the central San Joaquin Valley. The latter locality is approximately 80 water miles from the other farthest point from which the mahaze had been collected: Alviso, Santa Clara County.

In 1966, specimens of *A. flavimanus* were taken from widely spread localities and in increasing numbers, a trend which persisted during 1967. Starting in May, 1966, Jerrold Conners, using a small trawl mainly around Treasure Island, which lies adjacent to Yerba Buena Island between San Francisco and Oakland, took a total of 65 gobies on 12 different collecting trips; the largest number taken at any one time was 27. Specimens were also taken in San Francisco Bay in 1966 in the San Rafael Channel in May (1 male; 149 mm.), in the lower tidal reaches of Plummer Creek near Newark in May (3; 24–31 mm.), July (2; 44–64 mm.), and August (9; 80–108 mm.), and off Treasure Island in September (4 males and 2 females; 102–125 mm.), October (7 males and 1 female; 132–176 mm.), and November (1 male and 2 females; 124–129 mm., and 1 unsexed specimen of 115 mm.). A specimen was also taken in Richardson Bay in October (119 mm.). The small size of the first Plummer Creek specimens indicates breed-

ing at that locality. J. A. Aplin of the California Department of Fish and Game (personal communication) notes that the Department's research vessel *Nautilus*, taking monthly samples at 6 stations in San Francisco Bay from the San Rafael Bridge southward 20 nautical miles to Dunbarton Bridge collected no Japanese gobies during the first 3 years of a biological survey of the Bay beginning in 1963, but during the fourth year (1966) took 10 specimens near Angel Island in September, 3 just south of the San Mateo Bridge (1 each in August, October, and November), and 1 just south of Dunbarton Bridge in November. Other material was collected in San Pablo Bay in May at McNear Beach (3 males; 139–168 mm.) and in November at Napa Slough (2 females and 1 male; 92–123 mm.), in Carquinez Strait between San Pablo and Suisun Bay at Benicia (4 males and 1 female; 107–177 mm.), and in the Delta at Antioch (1 male; 114 mm.). In March, a single adult was taken from the screen of the Tracy Pumping Plant; young fish would easily pass through the screen as water is pumped into the Delta-Mendota Canal.

During 1967 more records poured in. Fifty-five fish were taken in January between Angel Island and Treasure Island, and exhibited alive for several months in pure seawater at 50°F. at Steinhart Aquarium in San Francisco; these specimens were fully adult. In February, 7 females (117–155 mm.) were taken off Treasure Island and 20 females and 1 male (113–157 mm.) were collected east of San Rafael. In September, 5 were taken at Foster City Lagoon near the west end of San Mateo Bridge, and in December, 14 were taken at several locations in Suisun Bay and adjacent Montezuma Slough by the California Department of Fish and Game. During 1967, specimens also were taken in Lake Merritt, a tidal lake in Oakland, in Belvedere Lagoon near Belvedere-Tiburon, at Aquatic Park in Berkeley, at Paradise Cay on the Tiburon Peninsula, and at other localities on San Francisco Bay.

Two surprises came to light in 1967. In July, checking operations by the California Department of Fish and Game noted approximately 10,000 dead "trash" fishes in the San Luis Reservoir in Merced County, as a result of total depletion of oxygen because of an algal bloom and following die-off. This is a large, recently filled, man-made reservoir behind a gigantic earth-fill dam, and is located in the arid foothills of the inner Coast Range about 100 air miles southeast of San Francisco. It receives fresh water from the Delta (and eventually from the Feather River, a tributary of the Sacramento) via the California Aqueduct of the California Water Project and the Delta-Mendota Canal of the Central Valley Project. About half of the kill consisted of *A. flavimanus*! The balance were bluegills (*Lepomis macrochirus*), crappie (*Pomoxis*), and sticklebacks (*Gasterosteus aculeatus*). In December, a single goby (215 mm. total length) was taken from lower (tidal) Pine Gulch Creek in Bolinas Lagoon. This lagoon has no connection with San Francisco Bay except by approximately 15 miles of open rocky seacoast.

During 1968 the mahaze continued to be taken by biologists and fishermen in San Francisco Bay, in San Pablo and Suisun bays, and the Delta. Two collections indicate the species is spreading northward from the Delta in fresh water. In August, 1968, a specimen 95 mm. long was taken from Snodgrass Slough, a tributary of the Sacramento River near Walnut Grove (the mahaze is said by fishermen to be "common" here; Robert McKechnie, California Department of Fish and Game, personal communication). In October, an example 100 mm. in length was collected in the Sacramento Ship Channel just south of the Port and City of Sacramento.

Most of the collections made during 1963-67, which delineated the buildup of *Acanthogobius flavimanus* from 1 specimen or a few specimens taken at widely scattered localities to specimens taken nearly everywhere in the bays and the Delta, frequently in considerable numbers, were made by Connors while trolling for English sole in San Francisco Bay, by Al Aplin during the California Department of Fish and Game's biological survey of San Francisco Bay, and by the Department's Delta Study team. These collections and others, between 1963 and 1967, indicate a slow buildup period in which the goby was steadily increasing its numbers while wandering greatly (specimens taken from widely separated areas with many young of the year and of the previous year caught), followed by a great increase after widespread establishment. During 1966 the species apparently reached nearly the full extent of its distribution in San Francisco Bay and the Delta. When the species first gained access to the area it is impossible to say, but the first specimen collected in January 1963, was, from its size, probably entering its second year of life; the second specimen was a large subadult. It is probable they were spawned in the Delta. However, the fact that the species was not previously collected in spite of the considerable sport fishery in the region (as well as scientific collecting) indicates that the date of introduction was probably not more than 3 or 4 years previous to 1963.

In the central portion of San Francisco Bay the principal goby species taken with the mahaze is the bay goby, *Lepidogobius lepidus* (Girard), while in the collections made in the tidal portion of Plummer Creek, near its exit into south San Francisco Bay, it occurred with the mudsucker goby, *Gillichthys mirabilis* Cooper; the arrow goby, *Clevelandia ios* (Jordan and Gilbert); and the cheek-spot goby, *Ilypnus gilberti* (Eigenmann and Eigenmann), the last being the most common. Salinities in Plummer Creek ranged from 16.9 percent on May 26 to 30.8 percent on August 17. At Palo Alto Yacht Harbor specimens belonging to *Acanthogobius flavimanus* have been taken since 1964; this species now heavily outnumbers the staghorn sculpin, *Leptocottus armatus*, formerly the commonest bottom fish (Robert Hassur, verbal communication).

The specimen taken one mile west of Antioch Bridge in the San Joaquin River was found with the cyprinids *Lavinia exilicauda* (Baird and Girard), *Orthodon microlepidotus* (Ayres), and *Pogonichthys macrolepidotus* (Ayres), the

catostomid *Catostomus occidentalis* Ayres, the embiotocid *Hysterocarpus traski* Gibbons, and small striped bass, *Roccus saxatilis* (Walbaum) (Serranidae); all except the last are California lowland freshwater endemics. They were collected over a fine sand bottom; the water was fresh, but muddy, with an incoming tide. The 16 specimens taken from the Newman wasteway of the Delta-Mendota Canal were associated with white catfish, *Ictalurus catus* (Linnaeus) (1309 specimens), and with American and threadfin shad, *Alosa sapidissima* (Wilson) and *Dorosoma petenensis* (Günther) (1317 specimens, about 4:1 in favor of former); striped bass, *Roccus* (350); channel catfish, *Ictalurus punctatus* (Rafinesque) (7); splittail, *Pogonichthys* (2); and tule perch, *Hysterocarpus* (1). The specimens from the Delta-Mendota Canal were taken in freshwater in November, 1966, and December, 1965, and were examined by Michael Martin. On the basis of scale annulae and standard lengths, they were assigned to age classes: class 0 ranged up to 132 mm. for males and 130 mm. for females, class I from 107–171 mm. for males and 121–162 mm. for females, while 1 male of 177 mm. was assigned to class II. The ovaries of 7 class I females were measured by water displacement, the ovarian volume increasing from an average of 0.0061 cc. per millimeter (of the standard length) in early November (Napa Slough) to 0.015 cc./mm. in December (Delta-Mendota Canal), though average water temperature decreased 5 degrees F. in the interim. This rapid gonadal development indicates a spawning season from January to March, similar to that reported for Japan (Dotu and Mito, 1955). Sexual maturity in the California population may not arrive until the end of the second or third year of life. Ripe adults were generally scarce in the San Francisco Bay areas sampled by Connors from spring 1966 to winter of 1966–67. In addition, females predominate in the mahaze catch in February, 1967, the males apparently being in shallow water involved in the construction of territories and breeding burrows (Dotu and Mito, 1955). Males have darker and longer median fins, but do not differ noticeably in size from females. The largest specimen taken so far outside the Orient was taken in Aquatic Park, Berkeley, in March, 1970, measuring 185 mm. standard length and 234 mm. total length.

The species is unusually tough and resilient. Five adult specimens were taken from brackish water (sodium chloride concentration unknown) off Napa Slough in San Pablo Bay in September, 1968, and unceremoniously dumped into fresh water. They survived, and 10 days later were transferred to pure sea water at 24 hour intervals and in 20 percent increments. After 48 hours in salt water, they were transferred back to pure fresh water in the same manner. While not subject to any systematic temperature manipulation, the specimens were kept in water of various salinities that ranged between 52° and 83° F.

The dispersal of the mahaze up various freshwater river and canal systems appears less startling in view of the above facts. The goby obviously possesses the ability to penetrate up mud-bottomed lowland rivers; it commonly does this

in the Orient and is doing it here. *Acanthogobius flavimanus* has apparently been carried out of the Delta in the strong southward flowing current of the Delta-Mendota Canal, which has a distinct problem with silting and with the establishment of a Japanese freshwater mussel, which will favor the establishment of such mud-associated bottom fish; its phenomenal increase in the San Luis Reservoir may be explained in terms of a habitat unoccupied by other bottom fishes (no catfishes were observed among the fish killed by the algal bloom and following die-off). The spreading of the species from San Francisco Bay to Bolinas Lagoon would be more difficult. While the mahaze can tolerate pure salt water, the shore between San Francisco Bay and Bolinas Lagoon is open rocky coast with a large assemblage of predaceous fishes. Either a migration occurred in the face of severe ecological opposition, or transfer through human agency took place. Ocean-going ships do not enter Bolinas Lagoon, so direct transfer from the Orient is contra-indicated, though fishing boats and pleasure craft sometimes make the trip from San Francisco Bay. Further, *A. flavimanus* is being used as a bait fish to some extent in the Bay and Delta regions. Consequently, it is likely introduction into Bolinas Lagoon came about through discarding of bait fish or by tiny young fish carried out in discharged coolant water. It is not known whether the species is firmly established in Bolinas Lagoon, as only 1 specimen (an adult) has been taken to date.

Aquarium specimens remain on the bottom, burrowing in mud or sand but not in gravel. Swimming is accomplished by short jerks. Buccal respiration, or air gulping, was observed on 1 occasion, apparently initiated by an oxygen deficiency in the water.

Virtually nothing is known of the ecology of the mahaze in California, although Okada (1960) gives some data for Japan. J. A. Aplin (personal communication) observed that regurgitant intended to be fed by 3 great blue herons to their young in a rookery on Bair Island, one mile north of the port of Redwood City, in early August, 1969, consisted totally of several mahaze, the larger ones being about 8 inches total length.

Besides *Acanthogobius flavimanus*, 2 other exotic fish species have appeared in San Francisco Bay in the last 10 years or so through unknown means of introduction (Ruth, 1964, on information supplied by W. I. Follett). The rainwater fish, *Lucania parva* (Baird), a cyprinodont from brackish waters along the U.S. Atlantic Coast, appeared first (Hubbs and Miller, 1965). Within a few years *A. flavimanus* and another Oriental goby, *Tridentiger trigonocephalus* (Gill), made their appearance. The latter, called "shimahaze" in Japan, is known from only 2 localities around the Bay (1966), but is assumed to be firmly established; it is also recorded from Los Angeles Harbor (Hubbs and Miller, 1965). Brittan, Albrecht, and Hopkirk (1963) give distinguishing characters for *A. flavimanus*.

In addition to the paper by Newman (1963) on the introduction into San Francisco Bay of an oriental commercial shrimp, *Palaemon macrodactylus*

(Rathbun), discussed by Brittan *et al.*, (1963), a recent paper by Nijssen and Stock (1966) concerning the explosive spread of an eastern North American euryhaline amphipod, *Gammarus tigrinus* Sexton, in the Ysselake (or IJsselmeer, the present name for the old, now smaller, Zuydersee), Netherlands should be of considerable value to those interested in such phenomena. Certainly more foreign euryhaline fishes and invertebrates will show such sudden appearances, followed by rapid expansion of ranges, in estuarine systems the world over.

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