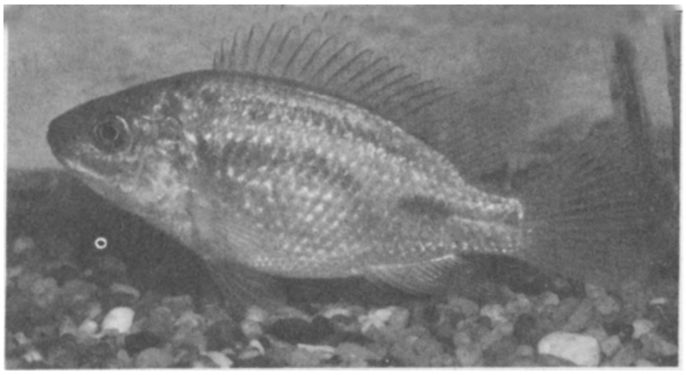

Fig. 1. Female mouthbreeder *Tilapia mossambica* in typical pose with young fry protected in her mouth.

Fig. 2. Male *Tilapia zillii*, showing heavy bone structure of the head, enabling effective grazing of aquatic vegetation, including *Typha* species.

Biological Aquatic Weed Control by Fish in the

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Use of fish for biological aquatic weed control is becoming widespread in the irrigation system and recreational lakes of the lower Sonoran Desert of California. Two African species, *Tilapia zillii* and *T. mossambica* are currently employed. The expansion of this program with development of better mass production techniques and the addition of one or two other fish species, is expected to significantly reduce environmental pollution through reduction in use of herbicides and mechanical disruptions, and to favor development of game-fish such as large-mouth bass.

Soaring costs of labor and herbicides plus increasing awareness of the threat of pollution from herbicides, pesticides, and nutrients from agricultural runoff are complicating aquatic weed control programs in irrigation systems of the low desert areas of southern California. Canals, drains and tiles become choked or clogged with aquatic vegetation, requiring continued maintenance for successful operation of the extensive irrigation and drainage system (over 6,000 miles of waterways!). Higher aquatic weeds and algae in stable habitats characteristically reduce and limit their population density after a period of time through antimetabolite pollution and nutrient exhaustion, but those in the low desert drainages inhabit water that is constantly cleansed and resupplied with a stream of new nutrients. The inevitable consequence is a potential for prolonged nuisance of aquatic vegetation.

Control methods vary somewhat within different areas of the desert but in general all have been experiencing an unacceptable increase in control/cost ratio. Chemical control with known materials and formulations is difficult and increasingly expensive because of the dilution factor and the neutralizing effect that waters of high organic content have upon many compounds, and the wide dispersal of weeds through the irrigation system. Also, there is the potential danger to aquatic-dependent fauna in the Salton Sea deltas and Colorado River and drinking-water supplies that is posed by runoff of herbicides and other pollutants.

The best known natural enemies of submerged aquatic weeds are herbivorus fish, which are presently being used over an increasingly greater portion of the Imperial, Coachella, and Palo Verde valleys. Other natural enemies that are being considered for wider use are aquatic snails. One species, *Marisa convarietis* (L.) has been demonstrated to practically reduce aquatic plant growth in recent tests at Riverside. At least two other species of snails have been accidentally introduced into the area around the Salton Sea, but their role in aquatic weed control is yet to be determined.

Weed species and natural enemies

A survey of aquatic weed species begun in 1970 identified those weed species that are actually creating problems and those that can be at least temporarily disregarded. The principal weed species as assessed from completed surveys include in order of their abundance, sago pondweed *(Potamogeton pectinatus* L.), Eurasian watermilfoil *(Myriophyllum spicatum)*, and southern naiad *(Najas guadalupensis* Morong). The algae *Chard* sp. is abundant in several locations and hollyleaf naiad *(Najas marina* L.) and *Chara* sp. are typically abundant in only a few localities of the low desert.

Candidate weed-feeding fish studied include three African species of *Tilapia (T. hornorum* Trewazas, T. *mossambica* Peters (Fig. 1) and T. *zillii* (Gervais) (Fig. 2), the South American *Mollienesia latipinna* LeSueur, and the native desert pupfish, *Cyprinodon macularius* (Baird & Girard). Of these, *Tilapia mossambica* and *T. zillii* have been most valuable in weed control. Another fish which is currently under study but which has not yet been released into the irrigation system is the white amur, *Ctenopharyngodon idellus*. Studies have shown it to be useful for consuming enormous amounts of diverse kinds of aquatic vegetation without any harmful effects on crop plants such as rice. These observations, plus the knowledge that the white amur will not reproduce naturally in America, enables us to consider its importation on a quarantined basis into portions of the low desert.

Fish behavior and management

Our data show a high degree of

Fig. 3. Effects caused by two male and three female 1 month-old *Tilapia mossambica* feeding for 1 week on aquatic vegetation in 2 sections of a divided shallow pond (foreground) during the summer of 1972. The center section of this replicate is the control (no fish). Floating filamentous algae and submerged aquatic plants were significantly reduced in three replicated ponds.

Fig. 4. Effects caused by two male and three female 6 weeks-old *Tilapia zillii* feeding for 3 weeks on the roots of cattails (*Typha* sp.) and other aquatic vegetation in one section of a divided shallow pond (foreground) during the summer of 1972. Only the center section contains fish. Floating filamentous algae and submerged aquatic plants were also significantly reduced in three replicated ponds.

Lower Sonoran Desert of California

inter-compatibility among all species of fish studied thus far including *Gambusia*, the mosquitofish, so that the establishment of a complex of desirable species throughout the low desert is practical.

Territorial behavior of *Tilapia* especially poses a recognized problem to practical biological control. For these fish to be effective in reducing aquatic plant growth, a minimum density per unit of area must be maintained. In controlled habitats, adequate densities are generally attained during the first year of establishment where water temperatures exceed 70°F during which time the aquatic environment consistently becomes remarkably cleansed of noxious plant growth. Ways to interrupt or alter this territorial behavior are being investigated in areas where fish populations persist over winter. In most areas, however, low winter temperatures thin out the *Tilapia* so that territoriality does not seem to play a major role in restricting biological weed control.

Dispersal poses another problem to the effective use of *Tilapia zillii*. Studies show that these fish tend to remain near the stocking area, so that manual dispersal must be implemented for maximum effectiveness.

Weed control in irrigation canals

In June, 1974, we introduced *Tilapia zillii* at the rate of 1,920 fish/surface-acre into one lateral canal in the Imperial Valley. Four months later only one small, poor stand of Eurasian watermilfoil persisted in the treated section of the canal, while extensive stands of this weed and sago pondweed, southern naiad and *Chara* sp. were found in control sections. A conservative estimate of the *T. zillii* density after this time was 4,776 fish/acre. Similar spectacular results have been repeated again and again with this species in drains, portions of canals, and recreational lakes throughout the low desert.

Impact on other fish populations

The high density of *T. zillii* and *T. mossambica* often attained in connection with control studies have had no adverse effect on associated game species. In fact, the game-fish population is often observed to increase markedly in the presence of these fish. Largemouth bass from test areas contained *Tilapia* in their stomachs, indicating that they play an important role in the game-fish food chain.

Temperature requirements

Overwintering survival of *Tilapia mossambica* and *T. zillii* is poor so that continuous annual stocking is essential for maximum biological control. The most important factor in survival is temperature, with about 60°F and 50°F being critical lower limits for *T. mossambica* and *T. zillii*, respectively. The upper limit of temperature tolerance is around 100°F, with death ensuing at about 104°F. Predatory fish such as large-mouth bass are apparently able to kill *Tilapia* in large numbers over the winter period when they become lethargic in the colder water.

Reproduction and growth of Tilapia

These fish spawn almost continuously when the average water temperature is around 70°F, with most natural spawning for *T. zillii* observed during May and June in the Imperial Valley.

Studies in Riverside of fish population growth during a 170-day period from March 9 to August 25, 1972, showed that *T. zillii* biomass increased 1,060-fold (to 534 fish), while *T. mossambica* increased 519-fold (to 418 fish) from an initial stocking of two males and three females each in 18- x 30-foot shallow ponds. Similar results have been produced from rearing ponds in the Imperial, Coachella and Palo Verde Valleys.

Under ideal conditions, *T. zillii* in the Imperial Valley can grow as fast as 6.5 inches in the first year and about 3.4 inches in the second year. This rate is greater than in their native African home.

Environmental considerations

Environmental impact of the *Tilapia* is the man-made and sustained irrigation system and recreational lakes of the lower Sonoran Desert is being carefully considered and studied both as intensely as our support funds permit, and in close cooperation with biologists of the California Department of Fish and Game. Any adverse effects are already expected to be minimal compared to the over-all benefits derived from the reduction of herbicide usage and labor costs. Therefore, it is certain that through the use of inexpensive non-polluting biological control organisms the water quality can be expected to improve. As a result, this country's commitment to the Mexican government to supply better-quality water from the Colorado River drainage system can be more readily realized. Also, the widespread distribution of fish such as the *Tilapia* that are capable of reducing mosquito-breeding habitats undoubtedly will reduce significantly the threat of invading mosquito-carried viruses such as Venezuelan equine encephalitis, and the need to control such mosquitoes with insecticides.

We anticipate that within a year most waters in the Southern California desert will be treated at savings of one-half to one-third over current techniques . . . a savings over $500,000 in direct costs alone. In addition, water will be delivered to users more efficiently, and indirect savings to users will be realized in the form of more efficient irrigation and greater crop returns.

Conclusions

The biological control of aquatic weeds by imported African *Tilapia* fish in the lower Sonoran Desert of California is possible in practical levels in irrigation canals and drains, and in recreational lakes. In order to extend this control to all portions of the irrigation system, a concentrated effort to increase fish production and efficiency of dissemination are being emphasized to make available large numbers of fish early in the season for annual stocking in problem areas. Severe winter water temperatures reduces the numbers of these tropical species to levels below those necessary for practical control.

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Restricted feeding of

A number of variables govern the amount of feed consumed daily by full-fed laying hens. Most important are body weight, ambient temperature, energy level of the feed, and egg production rate. A change in any one of these variables causes a compensatory change in feed intake as the birds attempt to adjust energy consumption to energy needs. But chickens are not all equally proficient in making that adjustment.

For a number of years, broiler breeder stock has routinely been maintained on limited feeding programs, because these heavy strains tend to overconsume energy when given continuous access to feed. Overconsumption results in a buildup of excessive body fat and less efficient conversion of feed to hatching eggs.

White Leghorn strains, which produce most of California's market eggs, are considerably more efficient than the broiler breeds in regulating energy intake to meet energy requirements. Therefore, it is common commercial practice to full-feed Leghorn layers, giving them access to feed 24 hours a day.

In the past, few questions have been raised concerning the validity of this practice, but more recently, researchers have been reexamining the possibility that Leghorns, too, tend to overeat and that some feed restriction might result in more efficient egg production. The dramatic rise in feed prices has prompted an increase interest in the subject.

The University of California Cooperative Extension has been conducting field trials over the past several years to test the practicality of restricted feeding of Leghorn layers in cages under commercial conditions. The trial to be reported here was carried out in open-type housing at the Orange County Industrial Farm. Access to feed was controlled by hinged covers on the feed troughs (see diagram). From a central cable running the length of the house, a nylon cord was attached through a set of pulleys to each trough cover. A hydraulic ram, when activated by an automatic time clock, pulled the central cable and raised the hinged covers, giving the birds access to the feed. At the end of each feeding period, the ram action reversed and the covers returned to a closed position.

Experimental design

This trial was designed to test three different treatment effects:

1) Effect on performance of full feeding (free access 24 hours per day) vs. restricted feeding (three 1-hour feeding periods per day).

2) Bird density effect on feed intake under full- and restricted-feeding regimes (3 vs. 4 birds per 12-inch by 18-inch cage).

3) Effect of age of bird at initiation of feed restriction (24 vs. 32 vs. 40 weeks) on performance.

The eight treatments were replicated four times, with each rep consisting of 24 layers (eight 3-bird cages or six 4-bird cages). The 768 birds in the test were all of the Shaver strain. Egg production, egg size, feed consumption, and body weight records were kept, starting at 24 weeks of age and continuing through 64 weeks of age.

All treatments received the same ration. During the warm months of the year it was formulated to contain 17 percent protein and 1,225 kilo-calories of metabolizable energy per pound; for the colder winter period the protein level was dropped to 16 percent and the energy raised to 1,250 kcal per pound.

Results

Bird density effect. A comparison of the data in tables 1 and 2 quickly confirms what we have learned in other trials: that crowding layers in cages adversely affects egg production and feed conversion. The higher density treatment was included in this test to determine if crowding further reduced feed intake when feeding time was limited. Percentage-wise, there was a greater restriction in the 4-bird than in the 3-bird cages. However, average daily intake in pounds was