FEEDING RATES AND GROWTH OF THE FISH *TILAPIA ZILLII* [CICHLIDAE] ON *HYDRILLA VERTICILLATA*, *POTAMOGETON PECTINATUS* AND *MYRIOPHYLLUM SPICATUM* VAR. *EXALBESCENS* AND INTERACTIONS IN IRRIGATION CANALS OF SOUTHEASTERN CALIFORNIA

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ABSTRACT. Studies in 40 liter aquaria indicated a preference by *Tilapia zillii* (Gervais) for the aquatic weeds *Hydrilla verticillata* Royle and *Potamogeton pectinatus* L., especially when fed in combination. *Myriophyllum spicatum* var. *exalbescens* Jepson was generally avoided and nutritionally inferior. However, in irrigation canals of southeastern California, the growth of *M. spicatum* was effectively reduced when *T. zillii* were present. Alternate nutritionally suitable food sources such as aquatic snails, crustaceans, and insects inhabiting the *M. spicatum* weed mass in canals could account for the effective feeding and significant reduction of this weed. Extensive reduction of *H. verticillata* in the All-American Canal by *T. zillii* feeding was also apparent.

Three aquatic weed species, sago pondweed (*Potamogeton pectinatus* L.), Eurasian watermilfoil (*Myriophyllum spicatum* var. *exalbescens* Jepson), and the recent invader *Hydrilla verticillata* Royle, assume annual importance in the irrigation system of the Lower Colorado Desert of southeastern California by restricting water flow in delivery canals and by providing breeding habitats for *Culex tarsalis* Coquillett (Legner 1978a, Legner and Pelsue 1977, Legner and Fisher 1980). Herbivorous fish of the genus *Tilapia* have been investigated as biological aquatic weed controls in the land-locked, subtropical deserts of the Coachella and Imperial Valleys, with considerable reduction of the principal weed, *P. pectinatus* (Hauser et al. 1977, Legner and Fisher 1980). However, preliminary laboratory studies on fish indicated that *T. zillii* (Gervais) may selectively exclude *M. spicatum*, leaving it as a persistent monoculture (Hauser et al. 1977). The present study was conducted to explore feeding rates and growth of *T. zillii* on the 3 principal aquatic weeds, to correlate this with actual weed densities in irrigation canals where fish were introduced for weed control, and to expand a previous report on the biological control of aquatic weeds (Legner and Fisher 1980).

METHODS AND MATERIALS

AQUARIA FEEDING STUDIES. Three series of experiments were conducted in aquaria to determine *T. zillii* feeding preferences as follows: In Experiment 1, fish of 2 size classes, secured in natural breeding areas of the Imperial Valley, were compared. Small fish averaged 92 mm and large ones 156 mm in length. Fish were introduced separately into 40 liter plexiglass aquaria containing aerated tap water, and maintained at a temperature of 27.5 ± 2°C with 75 watt, Jewell-combination heater thermostats. Four replicated aquaria each for 2 sizes of fish and 3 feeding regimes (total of 24 aquaria) were used, arranged in a completely random design in a greenhouse at 13-hr daylight. In the 1st regime, *H. verticillata* was fed to the fish; in the 2nd, *P. pectinatus*, and in the 3rd, an equal mixture by weight of both weed species was provided.

Weeds were secured directly from canals in the Imperial Valley at each feeding interval. The weeds were flushed with water to remove adhering organisms, silt and sand, then spin-dried in a dip net and further dried between two cloth towels. The weeds were weighed on a single pan, top-loading Mettler® balance, and introduced into each aquarium. Weeds were handled in a similar fashion when removed from the aquaria to determine amount eaten.

Sufficient weed biomass was supplied to produce ca. 30% surplus for each of 21 feeding intervals, spaced ca. 46-hr apart (total 37 days experimental time).

At 2-week intervals, fish were removed from the aquaria, measured and weighed on the same Mettler balance used for the weeds.

In Experiment 2, small (93 mm) and large (166 mm) *T. zillii* were separately introduced into aquaria under 3 feeding regimes, (1) *H. verticillata* only, (2) commercial trout pellets[1], and (3) comparable weights of *H. verticillata* and trout pellets. There were 4 replicates, and conditions were identical to the 1st experiment.

In Experiment 3, under identical conditions, fish of intermediate size (118 mm) were compared, using an equal biomass of each weed species in 7 feeding regimes as follows: (1) *H. verticillata* only, (2) *P. pectinatus* only, (3) *M. spicatum* only, (4) *H. verticillata* + *P. pectinatus*, (5) *P. pectinatus* + *M. spicatum*, (6) *H. verticillata* + *M. spicatum*, and (7) *P. pectinatus* + *M. spicatum* + *H. verticillata*, four replicates of each.

CANAL STUDIES. The effects of *T. zillii* introductions specifically on *M. spicatum* were examined in the All-American, Central Main, East Highline, and Rositas Canals of the Imperial Valley and the Coachella Main Canal of the Coachella Valley, by expanded computer analyses of data previously stressing *P. pectinatus* (Legner and Fisher 1980). Fish impact on *H. verticillata* also was studied in the All-American Canal.

Tilapia zillii that were originally obtained from the Arizona Cooperative Fisheries Unit, University of Arizona, Tucson in 1970 (Legner and Pelsue 1977, Legner and Fisher 1980), were released in 1977 at 4 sites along 39.4 km. of the All-American Canal east of Calexico, 4 sites along 14 km. of the Central Main Canal, 3 sites along 49.9 km. of the East Highline Canal, 6 sites along 15.5 km. of the Rositas Canal, and 7 sites along 59.6 km. of the Coachella Main Canal. In 1978 fish were stocked only in the Coachella Main Canal at 18 sites. The dates and numbers of fish released per surface ha. are shown for entire canals in Figs. 1–5. Average water velocities ranged from 0.9–1.5 m/sec in the canals.

The density of principal weeds, *M. spicatum*, *P. pectinatus* and *H. verticillata*, was periodically surveyed by measuring the width of the weed mass at each study site. In the Rositas Canal, the entire weed mass across the canal could be measured when water levels were dropped periodically. However, in the other 4 canals, measurements were confined to 1 side of the canal. At any given site, 17 measurements were made, spaced every 15 m for 244 m of canal length (Legner and Fisher 1980). Data were plotted to show comparisons between months and the 2 years. Correlation coefficients were derived for the density of *M. spicatum* with *P. pectinatus* to test interrelationships between these species.

RESULTS AND DISCUSSION

AQUARIA FEEDING STUDIES. The smaller fish in aquaria consumed only the lateral leaves of aquatic weeds, leaving their stems largely untouched. Although the larger fish sometimes consumed the entire *H. verticillata* plant, they also left the thickest stems of the other 2 weed species. This amounts to substantial biomass in *M. spicatum* but is nearly insignificant in the *P. pectinatus*. This behavior demonstrates a preference for the more tender plant parts when food was in excess. In irrigation canals, *T. zillii* may consume the entire plant of all 3 weed species, especially where fish density is high, or the fish may pull large parts of the plant loose as they tug at the leaves. Feeding scars on *H. verticillata* remaining attached were often in evidence in the

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[1] Crude protein 35%, fat 4%, fiber 4%, ash 14%, minerals 1.1%, manufactured by Star Milling Co., Perris, CA.

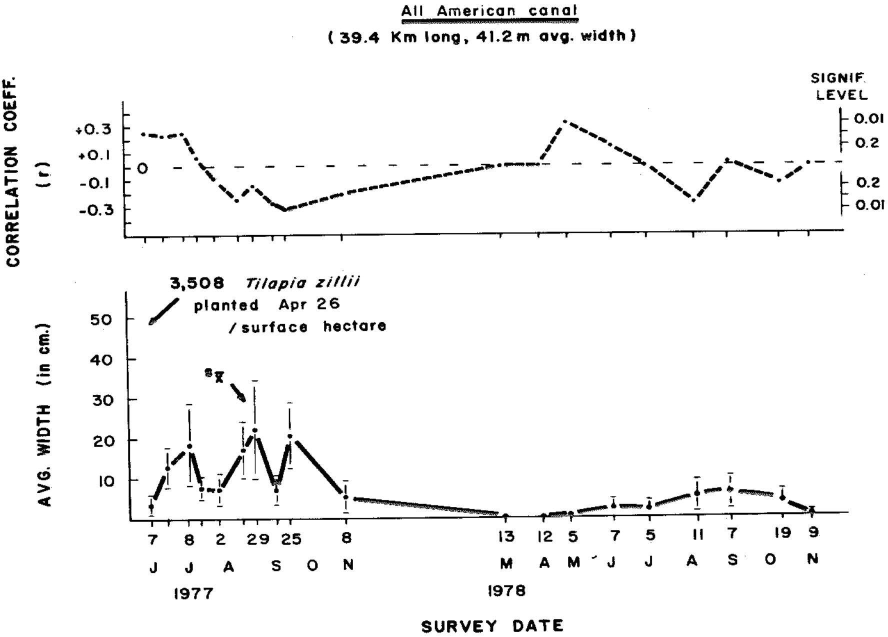

Fig. 1. Density of *Myriophyllum spicatum* along the north side of the All-American Canal during 1977–1978 (bottom) and correlation coefficients with *Potamogeton pectinatus* density (top).

presence of fish; no feeding scars were noted on *M. spicatum*, in canals.

The large fish lost weight at all 3 feeding regimes in the 1st experiment (Table 1), but this loss was significantly less (5% level) when a mixture of both weeds, *H. verticillata* and *P. pectinatus*, was provided. All fish gained in length with no significant differences recorded for any feeding regime.

Weed consumption was expectedly greater by the larger fish, and neither size category reduced the biomass of 1 weed species significantly more than the other when fed singly. However, the combination of both weeds seemed to stimulate feeding by the large fish, and consumption of total biomass was ca. ⅓rd higher than when either weed was fed alone (1% Signif.) (Table 1). A similar trend was not observed with the smaller fish. There was a tendency for fish to consume more *P. pectinatus* than *H. verticillata*, this preference being significant (5% level) in the small fish (Table 1).

The addition of trout pellets to fish diet in the 2nd experiment significantly increased gains in fish weight and length (5% level) (Table 1). Large fish apparently preferred trout pellets to *H. verticillata* when given a choice as a considerably lower weed biomass was consumed with the combination of the weed and pellets (Table 1).

In the third experiment, significantly less *M. spicatum* was consumed (5% level) than *H. verticillata* or *P. pectinatus* in both single and combined feedings (Table 1). There also was a significant weight loss in fish fed only *M. spicatum*. Contrary to results in the 1st experiment, *H. verticillata* was preferred to *P. pectinatus* when both

Table 1. Comparison of the nutritional quality of *Hydrilla verticillata*, *Potamogeton pectinatus*, trout pellets and *Myriophyllum spicatum* for small and large sized *Tilapia zillii* in 40 liter aquaria at 27.5 ± 2° C.[1]

	Avg.						
Feeding regime[2]	Initial weight (g)	Fish size (mm)	Fish weight gain or loss (g)	Fish length gain or loss (mm)	No. hrs in feeding interval		Average weed biomass consumed per feeding interval in grams
Experiment I (37 days)							
Hydrilla only	12.7	92.3	+1.1^a	+4.8	46	7.7^a	
	81.8	154.2	−9.2^b	+5.0	″	21.7^b	
Potamogeton only	12.7	92.3	−0.2^a	+3.8	″	9.1^a	
	81.8	154.2	−8.1^b	+5.3	″	22.2^b	
Hydrilla + *Potamogeton*	12.7	92.3	+0.4^a	+4.3	″	9.4^a	*Hydrilla* = 3.4^a *Potamogeton* = 6.0^b
	81.8	154.2	−4.0^c	+3.0	″	31.3^c	*Hydrilla* = 14.8 *Potamogeton* = 16.5
Experiment II (37 days)							
Hydrilla only	13.5	93.5	−2.8^a	−3.0^a	60	3.3^a	
	89.0	166.2	−6.9^b	+0.3^a	″	26.7^b	
Trout pellets only	13.5	93.5	+4.6^c	+8.3^b	″	—	
	89.0	166.2	+4.9^c	+4.0^c	″	—	
Hydrilla +	13.5	93.5	+5.0^c	+10.8^b	″	3.5^a	
Trout pellets	89.0	166.2	+7.5^d	+4.5^c	″	7.3^a	
Experiment III (18 days)							
Hydrilla only	32.2	118.4	+0.1^a	+1.7	58	10.5^a	
Potamogeton only	32.2	118.4	−1.2^a	−1.7	″	15.5^a	
Myriophyllum only	32.2	118.4	−2.6^b	+0.7	″	3.1^b	
Hydrilla + *Potamogeton*	32.2	118.4	+0.1^a	+2.3	″	16.1^a	*Hydrilla* = 9.5^a *Potamogeton* = 6.6^b
Potamogeton + *Myriophyllum*	32.2	118.4	−0.7^a	+0.8	″	14.3^a	*Potamogeton* = 12.2^a *Myriophyllum* = 2.1^b
Hydrilla + *Myriophyllum*	32.2	118.4	−1.1^a	+1.0	″	13.7^a	*Hydrilla* = 12.4^a *Myriophyllum* = 1.4^b
Hydrilla + *Potamogeton* + *Myriophyllum*	32.2	118.4	−0.5^a	+2.3	″	14.1^a	*Hydrilla* = 9.6^a *Potamogeton* = 3.8^b *Myriophyllum* = 0.7^c

[1] Numbers in any experimental set followed by different letters are significantly different at Duncan's 0.05 level.

[2] *Hydrilla* = *H. verticillata* Royle; *Potamogeton* = *P. pectinatus* L.; *Myriophyllum* = *M. spicatum* var. *exalbescens* Jepson.

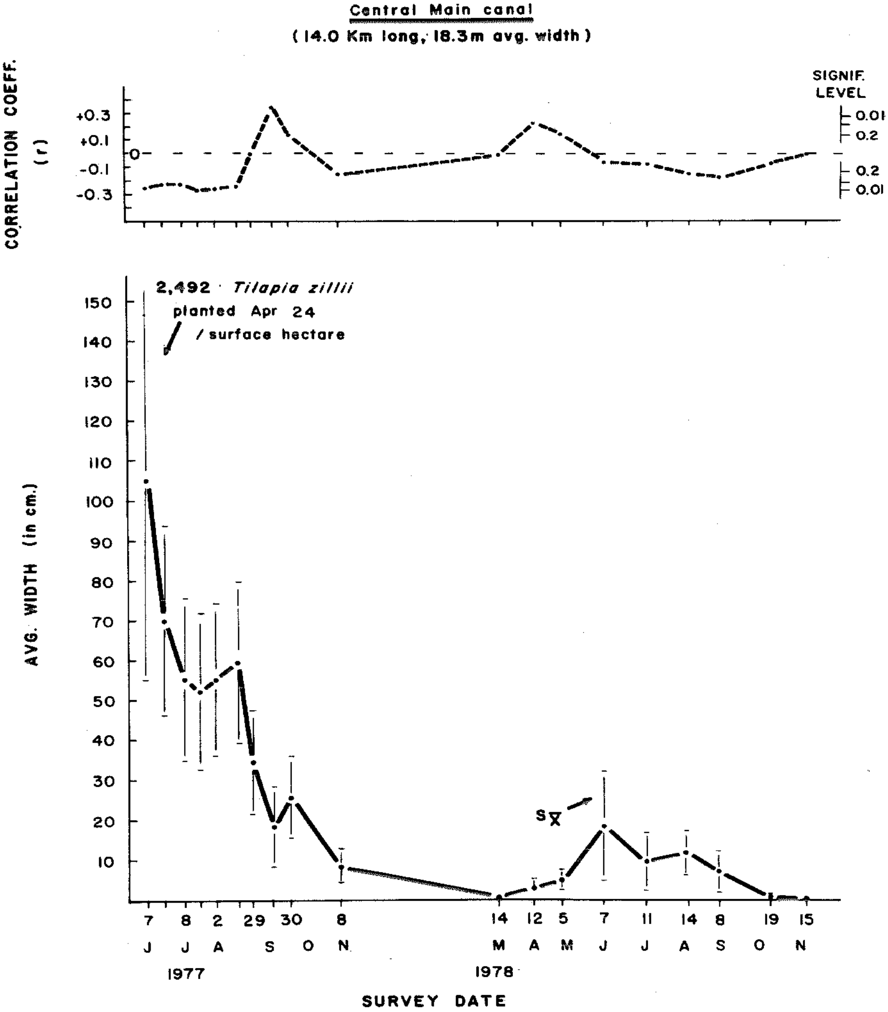

Fig. 2. Density of *Myriophyllum spicatum* along the south side of the Central Main Canal during 1977–1978 (bottom) and correlation coefficients with *Potamogeton pectinatus* density (top).

weeds were fed in combination (Table 1). This possibly reflects seasonal differences in one or both of the respective weeds secured in irrigation canals.

CANAL STUDIES. The 1977 spring introductions of *T. zillii* were followed by widespread natural reproduction in all canals. The warm winter of 1977–78, when canal water temperatures were never below 14°C, allowed for substantial survival of the fish population in all canals. Mortality is believed to have been greater in the Rositas Canal because of low water levels and consequent greater exposure to lower temperatures. However, the widespread occurrence of mature fish in late spring and summer of 1978 may have lowered reproduction through territorial aggressiveness resulting in a shortage of spawning sites, as judged by visual observations. The importance of territoriality among year-old *T. zillii* in reducing population density in canals was emphasized relative to aquatic weed control (Legner 1979) and suggested in mass culture studies (Legner 1978b). Reduced fish population densities may be accompanied by renewed aquatic weed growth. Such a growth tendency was reported with *P. pectinatus* in some canals where *T. zillii* adults overwintered, although weed reductions remained significant (Legner and Fisher 1980). However, fish impact on *M. spicatum* appeared to compound in 1978 in all canals except the East Highline (Figs. 1–5). In the latter case, the fish population probably moved downstream beyond survey sites when the water level in the canal was dropped to an abnor-

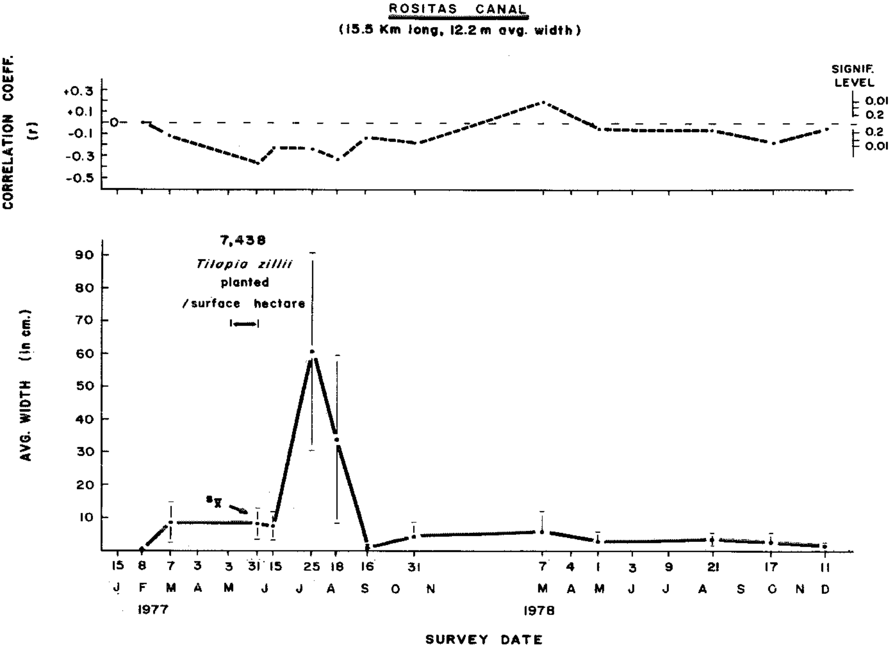

Fig. 3. Density of *Myriophyllum spicatum* along the entire width of the Rositas Canal during 1977–1978 (bottom) and correlation coefficients with *Potamogeton pectinatus* density (top).

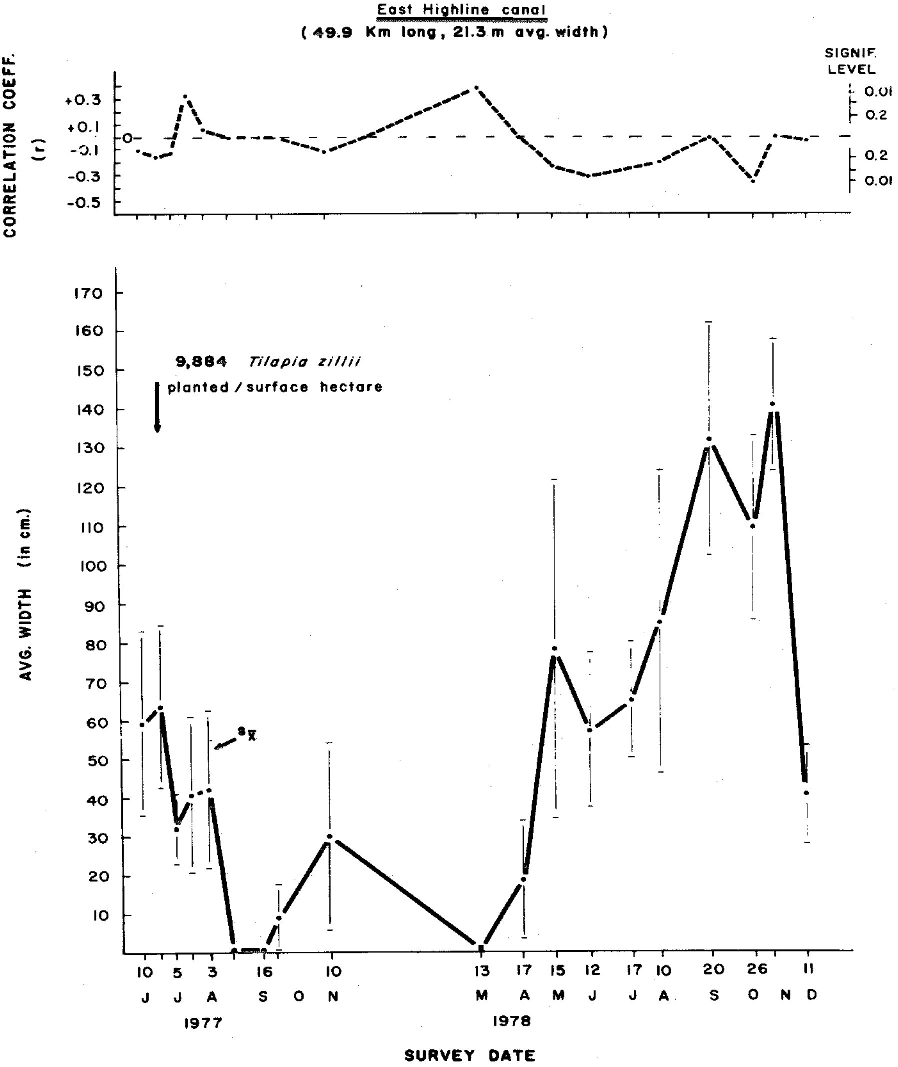

Fig. 4. Density of *Myriophyllum spicatum* along the west side of the East Highline Canal during 1977–1978 (bottom) and correlation coefficients with *Potamogeton pectinatus* density (top).

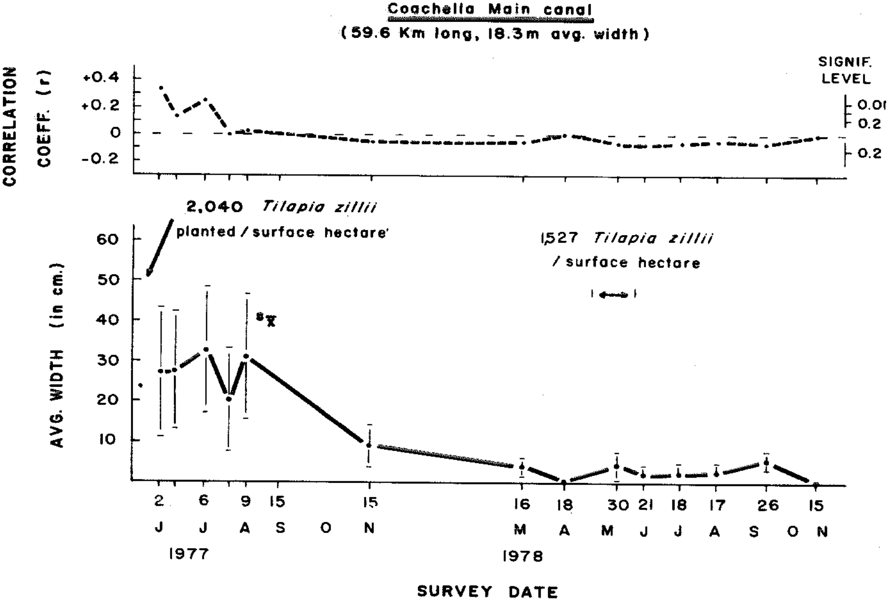

Fig. 5. Density of *Myriophyllum spicatum* along the southwest side of the Coachella Main Canal during 1977–1978 (bottom) and correlation coefficients with *Potamogeton pectinatus* density (top).

mally low level in April, 1978. This movement is believed to have occurred as few fish were observed in survey sites after the drop. Any upstream migration was precluded by structural drops in the canal system. In the Rositas Canal, the few overwintering fish reproduced a large enough population to maintain significant weed suppression in 1978 (Fig. 3).

An examination of the correlation coefficients of *M. spicatum* with *P. pectinatus* density showed significant negative correlations at relatively high *M. spicatum* densities (Figs. 1–4) or none at all (Fig. 5), suggesting that the latter might replace the niche vacated by *P. pectinatus*. But later, when *M. spicatum* density also declined due either to the feeding pressure of *T. zillii*, or changes in temperature and/or nutrient levels in the canal, there was little significance detected in the coefficient. This is especailly clear in the Coachella Main Canal (Fig. 5) which sustained the highest *T. zillii* density in 1978 because of releases made in the spring of that year and survival from the previous year's stocking. Therefore, *T. zillii* apparently maintained *M. spicatum* at a very low density in spite of the laboratory avoidance of this weed.

The reduction of *M. spicatum* may be explained by the fact that it occurred naturally in mixed stands with *P. pectinatus*, so that fish could not easily discriminate between the 2 species. Also, *M. spicatum* in the field provides a substrate and refuge for crustaceans, mosquito and chironomid midge larvae, and aquatic snails, all of which could serve as suitable nutrients for *T. zillii*.

The density of *H. verticillata* varied

from 2.6 m at the invasion site to less than 0.2 m at other sites by autumn 1978 in the All-American Canal (Fig. 6). *Tilapia zillii* were observed actively feeding at all 5 study sites, and their feeding scars occurred on most plants. The fish density at these sites was wholly dependent on downstream dispersal from upstream release sites, and was believed to be comparatively lower. In 1979 *T. zillii* failed to overwinter in the All-American Canal, so that the *H. verticillata* regenerated to almost complete coverage of the canal at the invasion site (37.2 m). Mechanical control could not prevent weed growth there and chemical treatment could not be applied because this site is a source of drinking water.

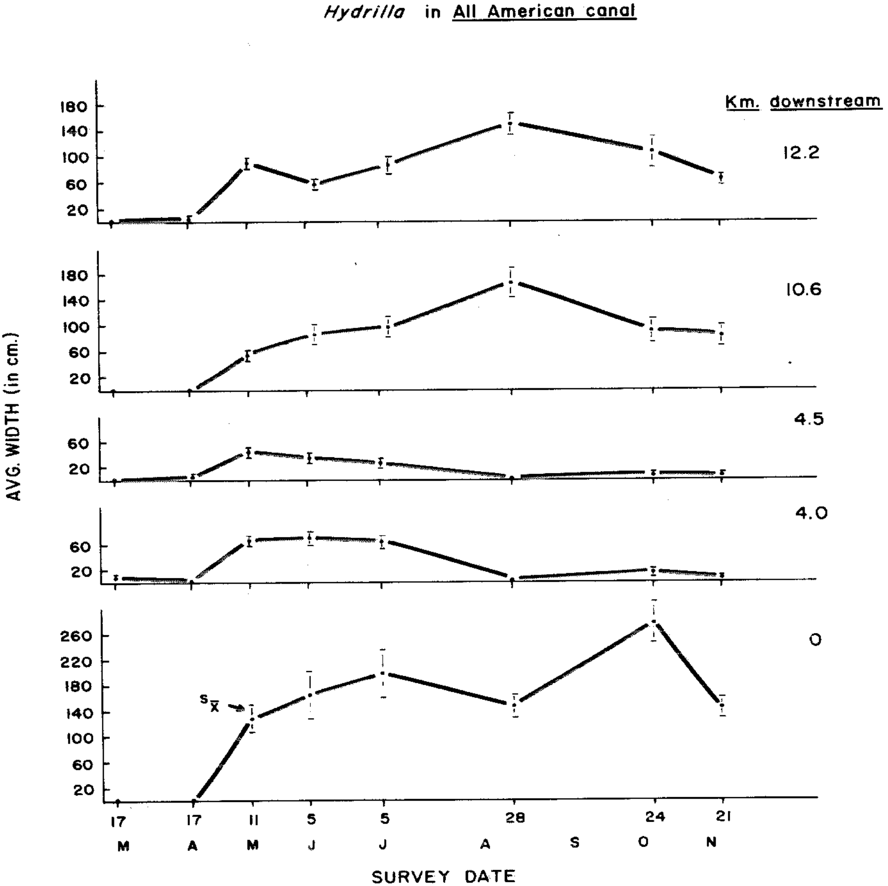
Hydrilla in All American canal

Fig. 6. Density of *Hydrilla verticillata* at 5 untreated sites along the north side of the All-American Canal beginning at the Meadows Road introduction site and extending 12.2 km. downstream in 1978.

In 1979 the Coachella Main Canal continued to show extremely low weed densities of all species, following spring *T. zillii* releases. However, full mechanical clean-out operations were required in all the Imperial Valley canals because no fish were released there in 1979, and overwintering was precluded by a cold winter during which canal water temperatures dropped to 8°C.

These results show advantages of incorporating effective herbivores into the irrigation system at subtropical latitudes, where prolonged periods of warm water favor aquatic weed growth. Other advantages to using biological, rather than mechanical or chemical, methods to control weeds in canal systems are, fish are stocked once a year in each canal, while mechanical cleanout can be required as often as once a month. For best results with mechanical control, water cannot remain in the canal during dredging. For this reason, canals are drained for a period of 3 to 5 days during which there are no water deliveries to agriculture. When water is brought back into the canal, silt, sand, debris and weeds broken loose are carried downstream. The weeds and debris become lodged in siphons and other canal structures where they have to be manually removed. With biological control these problems do not arise because the weeds are consumed. Furthermore, because canals are never drained, water delivery is constant allowing for better farming practices and more efficient use and conservation of water. Fuel is also conserved because there is less machinery needed less often, and there are no chemical related problems as herbicides are not used.

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