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BIOLOGICAL CONTROL OF AQUATIC WEEDS: THE EFFICACY OF HYBRID GRASS CARP IN TWO SOUTHERN CALIFORNIA IRRIGATION CANALS

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16. ABSTRACT

The use of hybrid grass carp (a result of crossbreeding female grass carp, *Ctenopharyngodon idella*, with male bighead carp, *Aristichthys nobilis*) for aquatic weed control in irrigation canals was evaluated in a 3-year cooperative study. Studies were conducted in both a small lateral and a large delivery canal in southern California. Data were collected on macrophyte distribution, biomass, stem length and density, tuber density, and soil composition. During the 1980 growing season, field techniques were developed and baseline measurements were made. Hybrids were stocked from June to September 1981, at rates from 56 to 296 kilograms per hectare. During the summer of 1982, all test sections showed trends of lower plant biomass in stocked areas than in corresponding control areas. An increase in aquatic weed biomass was observed in one test section in the fall of 1982. This indicated a suboptimal stocking rate. The principal aquatic weeds controlled were hydrilla (*Hydrilla verticillata*), sago pondweed (*Potamogeton pectinatus*), and curlyleaf pondweed (*Potamogeton crispus*). The control of Eurasian watermilfoil (*Myriophyllum spicatum*) by hybrids was inconclusive.

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INTRODUCTION

Aquatic vegetation displaces water from irrigation canals, lakes, ponds, and reservoirs and reduces their water-carrying capacities; as the vegetation increases, so does the water displacement. This is a major concern to all public and private water-supply companies throughout the Western States. Chemicals and mechanical harvesting control techniques are expensive and often only temporary solutions. These techniques can cause unacceptable environmental impacts on aquatic ecosystems. Interest in biological control techniques as a solution to these problems has increased in recent years. Biological control is becoming more practical as an alternative method of effectively controlling the growth of aquatic vegetation with minimal environmental impact. This report investigates the use of biological control in two irrigation systems in southern California.

In 1980, a cooperative research program was initiated to evaluate the use of hybrid grass carp (a sterile hybrid fish resulting from crossbreeding a female grass carp, *Ctenopharyngodon idella* Val., with a male bighead carp, *Aristichthys nobilis* Richardson) as a biological agent for controlling aquatic vegetation (macrophytes) in western irrigation canals. The sterility of this fish eliminated the possibility of overpopulation, thereby reducing the chance of adversely affecting the aquatic ecosystem. The objectives of the 3-year project were threefold: to assess the efficacy of hybrid grass carp for controlling aquatic vegetation, to determine the impact of the fish on faunal and phyicochemical components of the canal ecosystem, and to develop a weed-control technology using hybrid grass carp in a systems approach that could be incorporated into the operations of irrigation systems. The program was a joint undertaking with the combined resources of the following agencies: CVWD (Coachella Valley Water District), IID (Imperial Irrigation District), California Department of Fish and Game, California Department of Food and Agriculture, California Department of Water Resources, U.S. Fish and Wildlife Service, and USBR (Bureau of Reclamation).

Adequate understanding of aquatic weed growth and reproductive cycles is critical to successful control. An important indicator of hybrid grass carp efficacy is macrophyte biomass monitored through time. This is the feature of aquatic weed population that most directly affects irrigation system operations. Stem density and stem length measurements, components of biomass, were made to confirm biomass measurements, to monitor weed growth characteristics, and to identify possible physiological responses of plants to grazing. Two of the most common species in the study areas, hydrilla (*Hydrilla verticillata* Royle) and sago pondweed (*Potamogeton pectinatus* L.), produce tubers (specialized stolon buds functioning as hibernacula). Because these structures play important roles in aquatic weed repopulation after the removal of vegetation, their production and density in the hydrosoil was monitored. The effects of fish grazing on tuber production is critical to the use of fish for biological aquatic weed control. Individual plant species were measured in an attempt to observe any unique response by plants to fish grazing and to identify the dietary preferences of the fish.

The purpose of the 1980 study was to develop field techniques and to collect baseline information on the aquatic vegetation and on the general ecosystem of the two study canals, before hybrid grass carp were introduced. These investigations indicated considerable variability among test sections in both test canals. This prevented any section from being used as the control. Therefore, in 1981, internal controls in the form of exclosures, were built into each test section. The work of the second year of the 3-year program was to include evaluating hybrid grass carp as an effective aquatic weed control technique. Yet, the 1981 results did not demonstrate efficacy, possibly because the fish were stocked late in the growing season and there was poor replication of the aquatic weed habitat within canal exclosures. However, during the 1982 field season, several improvements were made on the exclosures, and a full year of data were collected to evaluate the effectiveness of the fish in controlling aquatic weeds. The test areas will be monitored through 1984, by cooperators. Parameters such as stocking rates, fish movement, and fish behavior will be studied.

The ability of hybrid grass carp to control aquatic vegetation in southern California irrigation canals has been assessed and is discussed in this report. The faunal and physicochemical components of this program are discussed in three annual reports by Beaty, et al. [1, 2, 3].[1]

CONCLUSIONS

Wormwood Lateral 3

1. Hybrid grass carp effectively controlled hydrilla and sago pondweed in Wormwood Lateral 3 during the summer of 1982. Control of Eurasian watermilfoil by the fish was not conclusive. Hybrid grass carp stocking densities were too low to adequately control macrophytes during the fall of 1982, in section 2.

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[1] Numbers in brackets refer to entries in the bibliography.

2. When hybrid grass carp stocking densities are being determined, consideration must be given to macrophyte growth when the water is cooler and normal fish feeding rates decline.

3. Hybrid grass carp should be stocked early in the growing season before heavy plant growth.

4. Preliminary data suggest that during suboptimal stocking rates, hybrid grass carp feeding on macrophyte apical buds may increase stem density. Removal of the apical buds, and thus the site of axillary bud inhibition, may stimulate formation of additional shoots and biomass.

5. Because of the considerable variability among test sections, especially in regard to predominant macrophyte species, the dietary preferences of the hybrid grass carp could not be reliably identified.

6. Preliminary tuber-density data on hydrilla and sago pondweed indicate that plant removal by fish may increase tuber production.

7. The hydrilla and sago pondweed seasonal tuber formation periods did not seem to change as a result of fish feeding.

Coachella Canal

Macrophyte biomass was too low in the test reaches of the Coachella Canal throughout the study period to demonstrate fish efficacy adequately. However, hybrid grass carp controlled limited stands of sago pondweed and curlyleaf pondweed in reach 27. Eurasian watermilfoil control was not conclusive.

MATERIALS AND METHODS

Study Locations and Site Preparations

Studies were conducted at two sites: the Coachella Canal in the CVWD and the Wormwood Lateral 3 in the IID (fig. 1). These sites were selected primarily because of their differences in canal size, their operational characteristics, and their dissimilar species of macrophytes. The Coachella Canal is a large delivery canal that provides the main water supply to the Coachella Valley. The Wormwood Lateral 3 is a substantially smaller lateral canal.

The Coachella Canal study area is an earth-lined portion east of the north shore of the Salton Sea, at 21 m above mean sea level (33°30'40" N., 115°49'45"W.). The Coachella Canal has a water design capacity of 34.0 m^3/s at an approximate velocity of 1.2 m/s. Waterflow rates through the study area ranged from 2.8 m^3/s to 25.5 m^3/s, depending upon irrigation demand and occasional drawdowns for routine canal maintenance. These changes in flow rates cause large fluctuations in the depth (1.5-3 m), width (20-22 m), and water velocity (0.2-2.2 m/s) of the canal. The canal bottom is lined with clay and silt of local origin.

The Coachella Canal study area was divided into four study reaches (reaches 25 through 28)[2] located between siphons No. 25 and 29. The lengths of study reaches 25, 26, 27, and 28 are 2.3, 1.3, 0.7, and 2.4 km, respectively. The upstream boundary of the study area at siphon No. 25 is equipped with a mechanical screen that prevents the passage of both fish and floating vegetative debris (fig. 2). During the 1980 study, the fish barriers at siphons No. 26, 27, and 28 consisted of panels of 51-mm square wire mesh. However, chemical deterioration and persistent fouling of the screen with debris necessitated a design change. In November 1980, the CVWD refit the siphon structures with horizontal bar screens with openings of 38 mm on center and equipped the screens with cathodic protection.

The principal macrophytes in the Coachella Canal are Eurasian watermilfoil (*Myriophyllum spicatum* L.), sago pondweed, and curlyleaf pondweed (*P. crispus* L.). The principal emergent and terrestrial vegetation along the banks of the Coachella Canal include cattail (*Typha spp.*), smartweed (*Polygonum spp.*), bermudagrass (*Cynodon dactylon* Pers.), and common reed (*Phragmites sp.*).

The Wormwood Lateral 3 is a branch of the Wormwood Canal, located near the terminus of the All-American Canal in the southwest corner of the IID (32°42'30"N., 115°41'40"W.). Wormwood Lateral 3 has a design capacity of 3.0 m^3/s. The average depth of the lateral in the study area is 1 m, and the average width is 3.2 m. The canal substrate is principally silt and clay.

The Wormwood Lateral 3 study area is divided into four study sections identified as test sections 1 through 4. The lengths of these study sections are 0.8, 1.1, 0.6, and 0.6 km, respectively. To prevent movement of the hybrid grass carp and other large fish between sections, vertical bar screens (30 mm on center) (fig. 3) were installed on drop structures. Additional bar screens were located over the openings of takeout points along the lateral.

Routine weed-control measures, such as drawdown and dredging, were discontinued during the study to

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[2] Reach numbers identify the section of the Coachella Canal between the siphon structure of corresponding number and the next siphon structure downstream. For example, reach 25 is a stretch of the canal between siphons No. 25 and 26.

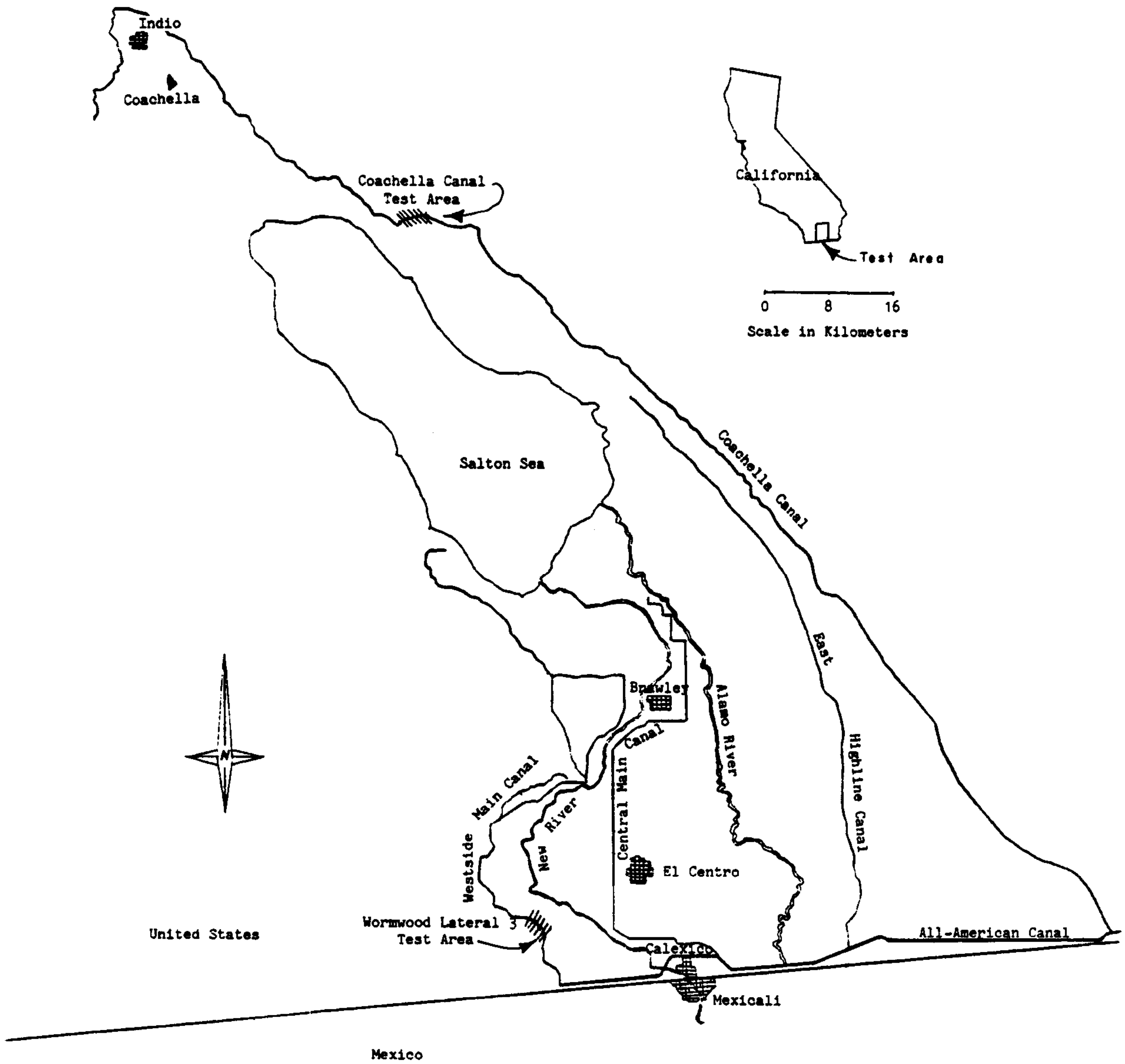

Figure 1. – Location of the hybrid carp study areas in the Imperial Irrigation District and the Coachella Valley Water District of Southern California.

allow stabilization of the aquatic vegetation. However, section 1 and parts of section 4 were dredged before the study. These cleaner canals lacked the stability or maturity of established macrophyte populations found elsewhere at the onset of the 1980 growing seasons. By July 1980, hydrilla had reduced the water-carrying capacity in one section by 50 percent. Since Wormwood Lateral 3 operates at or near design capacity for much of the growing season, certain accommodations were made to allow the IID to clear portions of the aquatic vegetation when it impeded water deliveries. The entire test area was widened approximately 1 m along the east bank. A 2-to 3-m swath along the east bank of the canal was then set aside, and the IID was permitted to remove weeds there, by disking and dredging. Daily removal of drifting vegetation from the fishscreens was necessary to permit adequate flow of water. These operations were continued throughout the entire study period.

As part of the hydrilla control program of the State of California and IID, Wormwood Lateral 3 canal was treated on June 17, August 4, and September 19, 1980, with the copper-complexed herbicide, Komeen (bis (ethylenediamine)-copper (II) sulfate, 95.9 g a.i. (active ingredient) metallic copper per liter, product of Sandoz, Inc.), combined with the viscosity index modifier, Nalquatic (30 percent polycarboxylate polymer by Nalco Chemical Co.). Because all

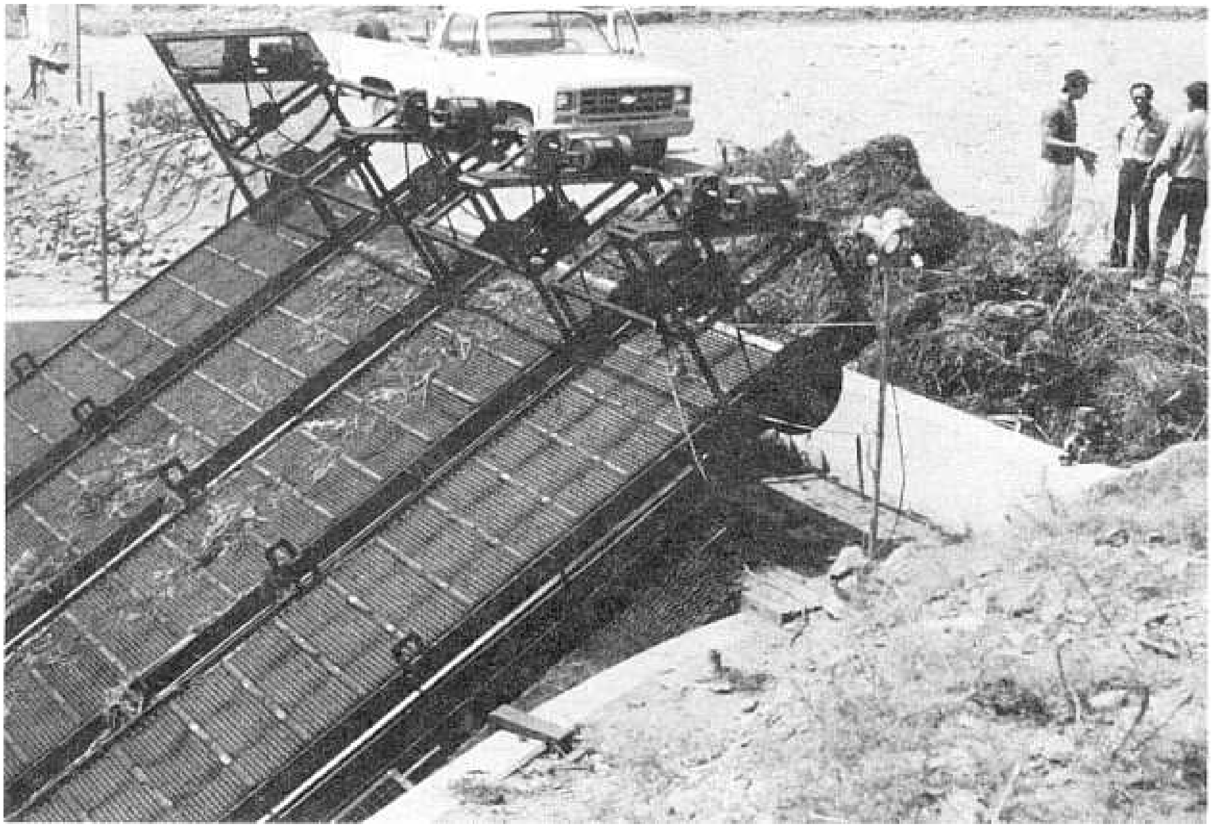

Figure 2. – Mechanical fishscreen barrier on the inlet structure of siphon 25 of the Coachella Canal.

areas within the confines of the study were treated, any assessments of the effect of these treatments must be made in the absence of controls.

The principal macrophytes occurring in the Wormwood Lateral 3 are hydrilla, Eurasian watermilfoil, sago pondweed, and southern naiad (*Najas guadalupensis* Magnus). Occasional curlyleaf pondweed and coontail (*Ceratophyllum demersum* L.) plants have been found. Riparian vegetation includes cattail, bulrush (*Scirpus sp.*), common reed, bermudagrass, and smartweed.

The original study was designed to evaluate the effectiveness of three densities of hybrid grass carp for aquatic weed control by comparing plant populations in stocked and unstocked sections. However, the 1980 baseline vegetation data revealed variations in plant species and in abundance among the test sections [4]. This prevented any single section from being used as the control. As an alternative, internal controls, in the form of exclosures, were built into each of the four study sections and two of the reaches, before fish stocking in 1981. Each of these exclosures were approximately 2-m wide, 65-m long (except for exclosures in sections 3 and 4, which were 30-m long), and extended 0.25 m above the high watermark on each canal. They were constructed of 25-mm nylon mesh and 25-mm "stucco wire" that prevented fish from entering. Horizontal bar screens were constructed at the upstream ends of the exclosures in Coachella Canal (fig. 4).

A change in the design of the study occurred when only a limited number of fish were available for stocking [2, 3]. Only reach 27 of the Coachella Canal and sections 1, 2, and 4 of Wormwood Lateral 3 were stocked for the entire study. Section 3 of Wormwood Lateral 3 was stocked from June 20, 1981, to May 5, 1982, when the fish were removed to augment the density of section 4. Section 3 and reach 26 of Coachella Canal became unstocked controls to evaluate the affects of the exclosures on macrophytes. These unstocked areas were also monitored to collect information on the resident fishes and the invertebrate populations [1, 2, 3]. The stocking densities of the hybrid grass carp at the beginning of the 1982 growing season are listed in table 1.

In 1981, section 4 was free of vegetation. In August, a planting experiment was conducted to determine whether an environmental factor was responsible. The lower two-thirds of each transect line including the exclosure in section 4 was planted with hydrilla.

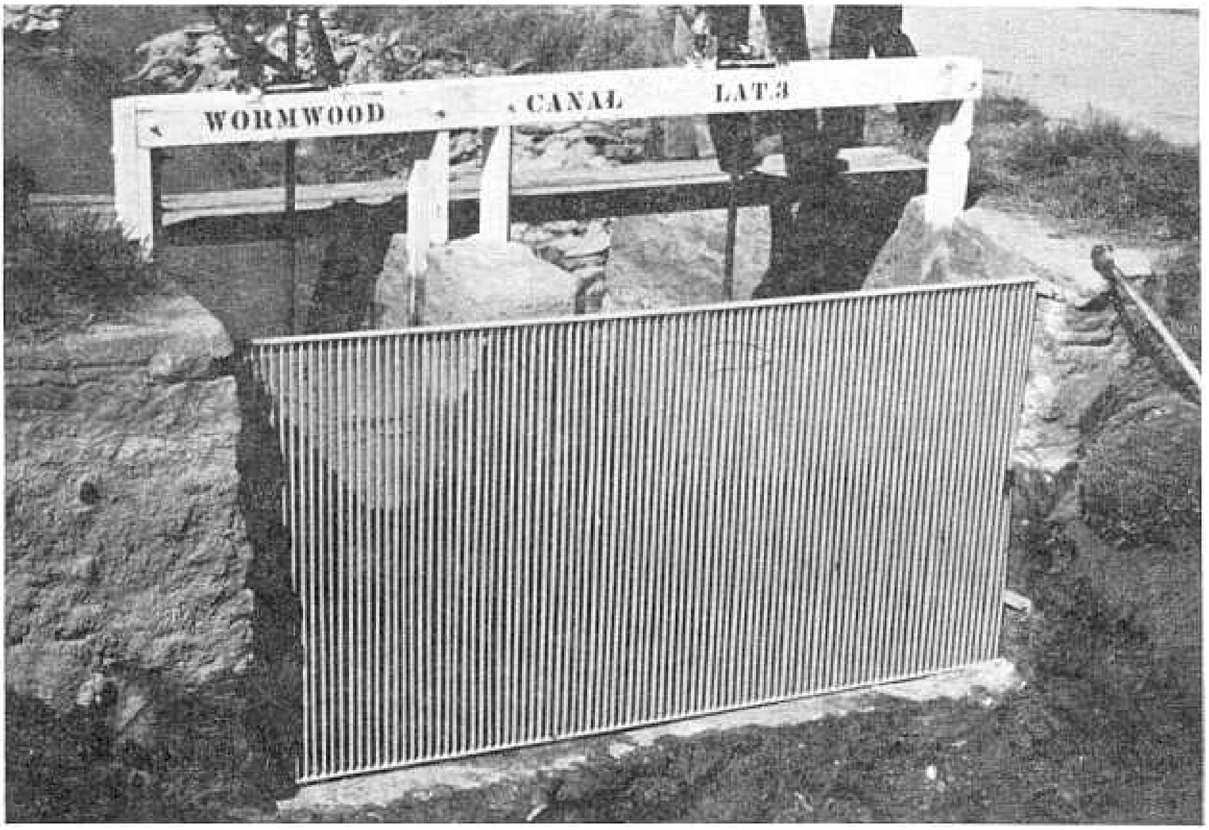

Figure 3. – Vertical bar fishscreen between test sections on Wormwood Lateral 3.

Sprigs 250 to 300 mm long were planted three to a cluster, with three replicates across the lateral at 3-m intervals along the 60-m lines coinciding with survey stations. The lower two-thirds of the exclosure and its adjacent line were similarly planted across the lateral but at 1-m intervals along the line. This section was sampled in the same manner as sections 1, 2, and 3.

Vegetation Distribution Surveys

Each test area on the Coachella Canal and on Wormwood Lateral 3 was mapped to determine the distribution and abundance of aquatic weed species. This mapping technique was adapted from a method developed by Braun-Blanquet [5] (table 2) and was conducted periodically to give a long-term record of plant distribution and abundance within each test area of the two study sites. In the Coachella Canal, the mapping observations were made by two scuba divers recording their observations on underwater slates. In the shallower Wormwood Lateral 3, these investigations were accomplished by skindiving or by wading.

In the Coachella Canal, belt transects [6] were marked with 60-m long polyethylene line, staked to the bottom of the canal with steel rods. These lines were divided into 20 segments at 3-m intervals with metal rings, and they were placed along the base of the slope parallel to the bank. At each ring marker along the line, a quadrat extended 1 m downstream and 3 m up the slope of the berm to the high watermark. After each belt transect was mapped, divers followed a transect perpendicular to the canal bank across the bottom to the base of the opposite side-slope to document the presence of vegetation. In 1980, five belt transect stations were evenly spaced along alternate sides in reaches 25, 26, and 28. Reach 27 was appreciably shorter than the other reaches and had three belt transect stations evenly spaced on alternate sides of the canal. Because of the changes to the study, reaches 25 and 28 were not evaluated after June 1981. Five new 60-m transects (two transects were enclosed by exclosures) were established in reach 27, and three new 60-m transects (one enclosed by an exclosure) were established in reach 26. These newer transects were mapped according to the procedures used for the original transects.

The Wormwood Lateral 3 sections contained four 57-m long belt-transect lines, equally spaced along the center of the test areas. The upstream and down-

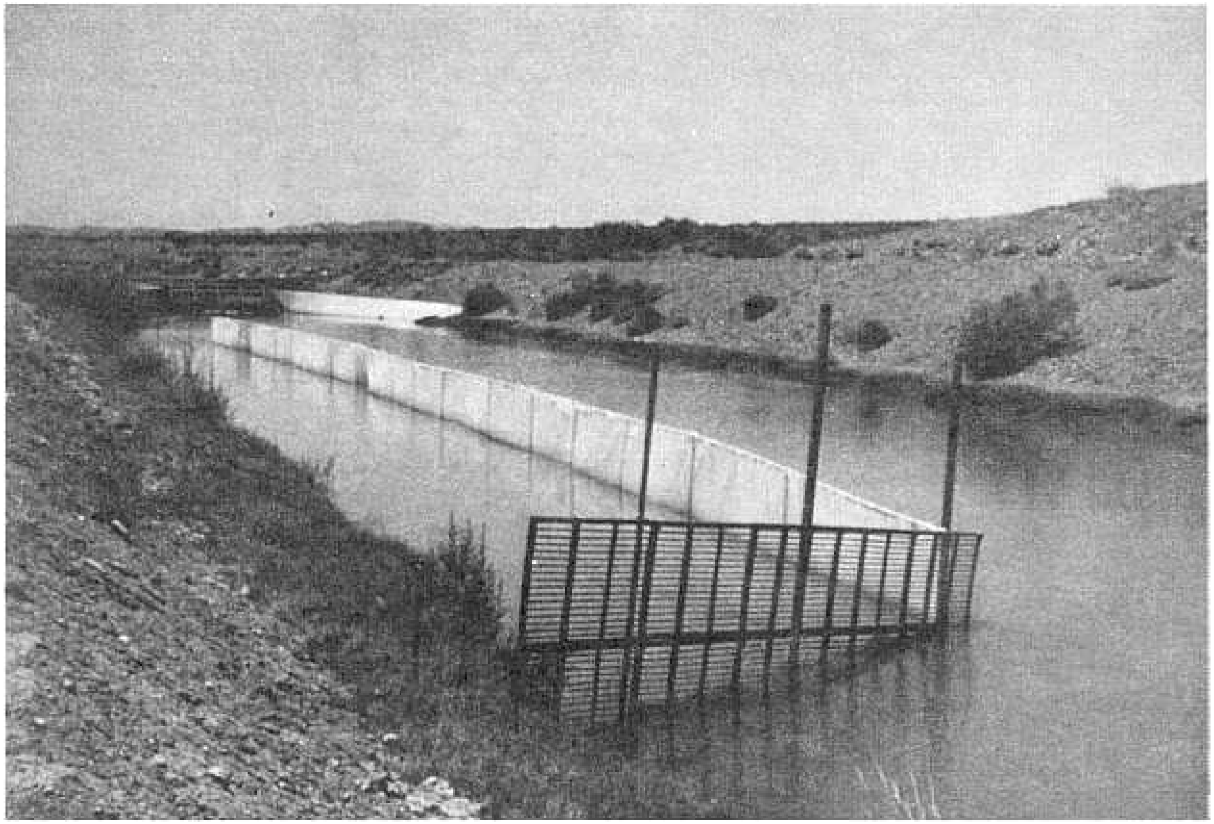

Figure 4. – Lower exclosure in reach 27 of the Coachella Canal.

Table 1. – Densities of hybrid grass carp in Wormwood Lateral 3 and in the Coachella Canal during May 1982 [3].

Location	Surface area ha	Number	Stocking density kg/ha	Stocking date	Year class -source
Wormwood 1	0.47	128	296	Sept. 1981	1979– Hogan
Wormwood 2	0.57	80	56	July 1981	1980–Malone
Wormwood 3	0.23	--	*		--
Wormwood 4	0.21	36	98	June 1981	1979–Malone
Coachella 27	1.49	302	134	May 1982 July and Sept. 1981	1979– Hogan 1980–Malone

* 1979–Malone fish were stocked at 76 kg/ha in June 1981, but were transferred to section 4 on May 5, 1982.

Table 2. – Total estimate scale combining abundance with coverage (adapted from Braun-Blanquet [5]).

+	Individuals of species very sparsely present in the stand (less than 10 individuals per quadrat); coverage very small
1	Individuals plentiful (greater than 10 individuals per quadrat), but coverage small
2	Individuals very numerous if small; if large, covering at least 5 percent of quadrat
3	Individuals few or many, collectively covering 25 to 50 percent of the quadrat
4	Plants cover 50 to 75 percent of the quadrat
5	Plant species cover 75 to 100 percent of the quadrat

stream limits of the Wormwood belt transects were marked along the bank with concrete markers. The transect lines were located midstream of the study area, with a metal stake directly opposite the concrete marker. Twenty quadrats were referenced along the transect line with metal rings at 3-m intervals. As mapping was completed, the metal stake and transect lines were removed to prevent any loss of the lines caused by the overgrowth of aquatic vegetation or by vandalism. Mapping quadrats in the Wormwood studies consisted of a 1-m band running across the canal perpendicular to the transect line. These quadrats were bounded on the east by the margin of the IID weed-control dredging (approximately 2 m from the eastern canal bank) and on the west bank by the high watermark. In 1981, when the exclosures were built in each section, enclosing one of the preestablished mapping lines, an additional 60-m line was installed immediately upstream. This new line was then mapped according to procedures used for the original lines.

Mapping data were used to determine: (1) percent occurrence by species, and (2) general trends in plant abundance or percent coverage by species, within the 60-m areas. Percent occurrence was determined by dividing the number of quadrats containing a particular plant species by the total number of quadrats per section [7]. Percent coverage was determined by estimating the area covered by the particular plant species in each quadrat. The mean percent coverage estimates were the average of the number of quadrats within a study area, i.e., in 1982, exclosures in Wormwood Lateral 3 contained 20 quadrats, while the treatment area contained a total of 80 quadrats. The rating values for percent coverage were tested for significance using the nonparametric Kolmogorov-Smirnov test [8], which compared exclosures with treatment areas.

Population Density and Biomass

Macrophyte population-density and biomass-sampling areas were located adjacent to vegetation mapping sites. In 1980, in the Coachella Canal, biomass samples were taken at five random points along the adjacent transect line. In these samples, scuba divers harvested plants from a 0.25-m^2 quadrat by clipping and bagging the plant material. In 1981, five 0.5-m by 3.0-m quadrats from each mapping transect were clipped and bagged, and in 1982, ten 0.5-m by 3.0-m quadrats from each transect were sampled. In the laboratory, harvested plant material was sorted according to species; stems were counted to determine plant density; and the lengths of 10 random stems from each species were measured. Various phenological observations (flowering, tuberization, etc.) were recorded. Both fresh-weight and dry-weight biomass measurements were taken. Fresh-weight determinations were made after excess adherent water was removed by spinning or blotting with a towel. Dry weights were taken after the plant material had been dried at 105 °C for 24 hours or until there was no further weight loss [9]. These data were collected to quantify the amount of plant material that grew in a particular area. All biomass and density values were calculated on the basis of grams per square meter and stems per square meter, respectively.

In 1980, six 0.25-m^2 samples were taken from each of the two biomass sampling areas in the Wormwood sites. These samples were taken by diagonally traversing the test area. In 1981, the pattern of sampling was changed to obtain more samples. Nine 0.25-m^2 samples were collected from each exclosure and from each adjacent line. These were collected by perpendicularly traversing the sample area. From each 0.25-m^2 quadrat, five 76-mm-diameter substrate core samples, approximately 200-mm deep, were collected using a substrate core sampling device. Samples were washed through a No. 6 mesh screen (W. S. Tyler Company) to separate tubers from the hydrosoil. Tuber counts were used to monitor tuber production during specific periods. All biomass and density values were obtained using the same procedures used on the Coachella Canal samples. Data were analyzed using the Student's t-test for comparing control and treatment values within each test area.

The qualitative method of rating plants using an abundance-plus-coverage scale (mapping) is imprecise for developing quantitative values for vegetation density. However, such methods are advantageous when large areas must be surveyed. Biomass sampling and stem counts, on the other hand, give quantitative values for population densities, but they are time consuming and subject to sampling errors when the collection of many replicates is impractical. By combining qualitative subjective scales with quantitative values, an entire plant community system can be better understood.

RESULTS AND DISCUSSION

Because each section or reach in this study was different from its adjacent section or reach, it is discussed separately, under each individual topic. However, similarities are noted in the discussion, and general conclusions are made concerning all study sections after the discussion of each study location. Topics begin with the qualitative method of rating plants (see the section, "Materials and Methods"), followed by the quantitative methods of sampling biomass, stem counts, stem lengths, and tuber counts.

WORMWOOD LATERAL 3

Qualitative Rating – Vegetation Distribution Surveys

Percent Occurrence of Macrophytes

Section 1. – Section 1 was essentially devoid of vegetation until late July 1980. By this time colonization began to occur, dominated by sago pondweed, but also with appreciable quantities of Eurasian watermilfoil (fig. 5) and southern naiad. Sago pondweed, which previously had not been detected in this section, increased from 16 percent of the mapping quadrats to 100 percent, in the interval between late July and November. Percent occurrence of Eurasian watermilfoil increased from 11 percent in late July to 61 percent in October, followed by a decline to 45 percent in November. Southern naiad levels, which were 5 percent in late July, increased to 69 percent by November. The occurrence of hydrilla in section 1 increased from 3 percent in August to 24 percent in November.

The 1981 growing season began with Eurasian watermilfoil in 100 percent of all quadrats in both the treatment and the exclosed areas. Sago pondweed occurred in only 28 percent of the quadrats in the treatment area. By June, watermilfoil was declining in percent occurrence, while sago was increasing. That trend continued through August when hydrilla and naiad first appeared. By the end of the season, sago remained the dominant species both inside and outside the exclosure. Hydrilla, watermilfoil, and naiad occurred more frequently in the treatment area than in the exclosed area despite the presence of the hybrid grass carp stocked on September 1, 1981.

Again in 1982, watermilfoil occurred more frequently than the other plant species through July. But as sago and hydrilla steadily increased in occurrence from May to November, watermilfoil decreased after July. Both sago and hydrilla occurred in nearly 100 percent of the mapping quadrats by October.

Section 2. – Hydrilla stands in portions of section 2 had been well established before the initiation of the study; they occurred in 59 percent of the quadrats in the belt transects in May 1980 (fig. 6). This level declined to 41 percent in July, shortly before portions of the canal were cleared in August, to permit passage of water. This decline may be the result of the Komeen treatment of July 17, 1980 (see the discussion in section 4 on Komeen). By November, stands of hydrilla occurred in section 2 in 73 percent of the quadrats. The occurrence of watermilfoil increased from 7 percent in May, to 70 percent in June. It declined to 13 percent in August, before again increasing to 54 percent in October and November Southern naiad peaked at 29 percent occurrence in June, and declined to 7 percent in November. Sago pondweed was sparsely distributed in section 2 and reached a level of 21 percent in November.

In April 1981, hydrilla occurred in 100 percent of the quadrats inside the exclosure and 33 percent of the quadrats outside. Watermilfoil began the season appearing in 67 percent of the quadrats outside the exclosure, but did not appear inside. By June, hydrilla declined by 90 percent, making watermilfoil the dominant species. By August, however, all species had declined to almost zero. Only hydrilla and watermilfoil had reappeared by October, reaching occurrence percentages of 11 and 14, respectively, within the treatment area and 0 and 30, respectively, in the exclosure. The growth pattern of hydrilla varied considerably from 1980 to 1981, but watermilfoil followed its familiar pattern of having a high percent occurrence in the spring, declining dramatically during the summer, then increasing again in the fall.

By March 1982, hydrilla had reappeared. It appeared in 65 percent of the quadrats inside the exclosure and 4 percent outside. Watermilfoil occurred in 75 and 68 percent of the quadrats inside and outside the exclosure, respectively. Both species increased through May, but by July, hydrilla had continued to grow, while watermilfoil declined as usual during the summer months. Sago pondweed occurred every year, especially in March 1982, but its biomass was much smaller than the percent-occurrence data indicate. By the end of the 1982 growing season, section 2 was virtually a pure stand of hydrilla.

Section 3. – Hydrilla showed the greatest increase in occurrence during 1980 in section 3 (fig. 7). Beginning in 3 percent of the quadrats in May, hydrilla reached the 100-percent level by November, while watermilfoil, in its typical pattern, peaked at 51 percent in June, then declined. This decline continued until November, when the watermilfoil was no longer observed. Southern naiad levels ranged from none detected in May, to 21 percent in October, followed by a decline to 4 percent in November. Sago pondweed, similar to section 2, occurred infrequently in July, but its major growth period occurred between October and November 1980.

During 1981 very few plants grew in section 3. This is different from either 1980 or 1982 growth patterns.

A more representative growth pattern emerged in 1982. Hydrilla increased in occurrence to 100 percent by August and remained high inside and outside of the exclosure after hybrid grass carp were removed on May 5, 1982. Watermilfoil reached 100 percent occurrence in June, remained high through

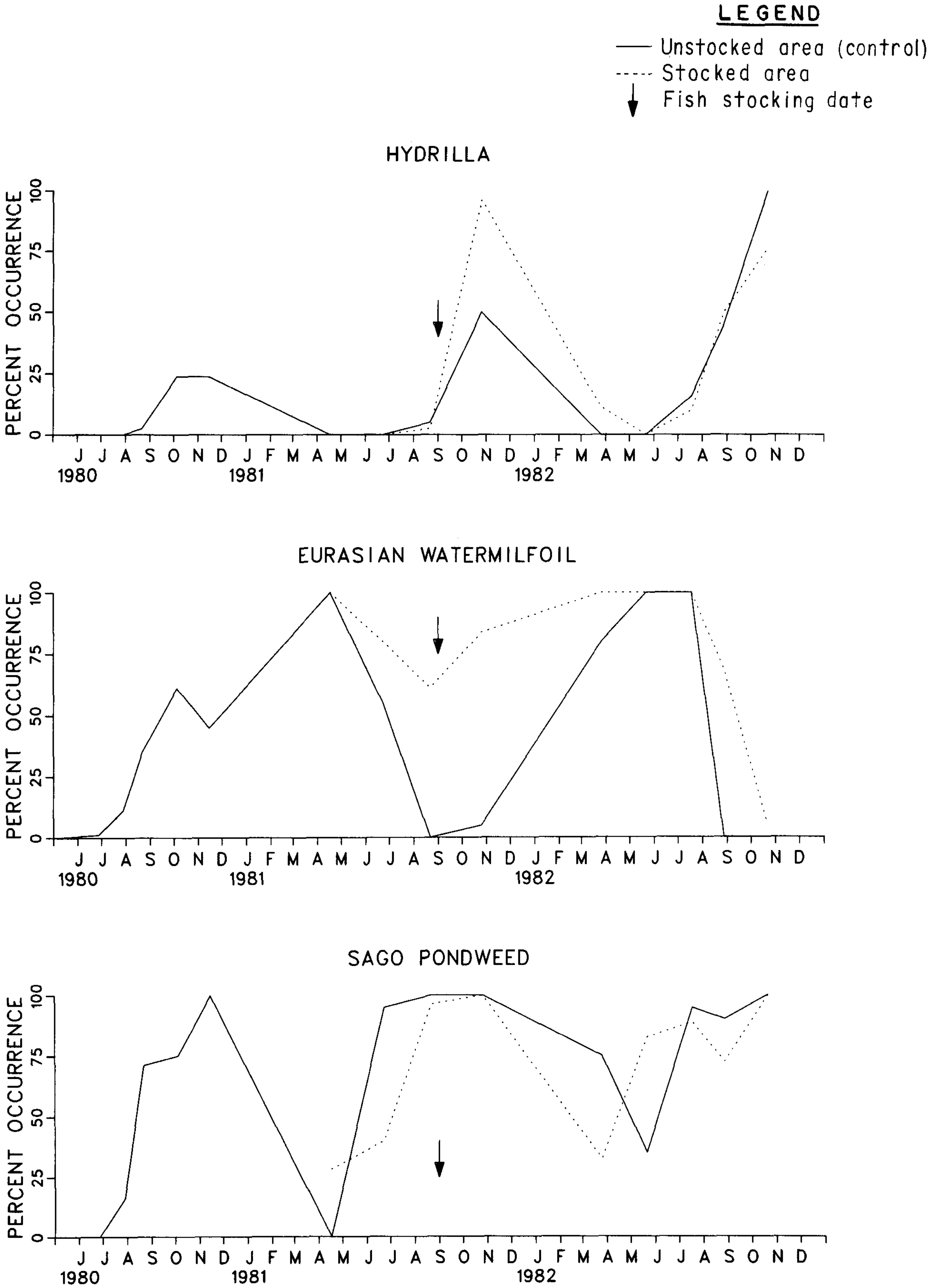

Figure 5. – Percent occurrence of macrophytes in section 1 of Wormwood Lateral 3.

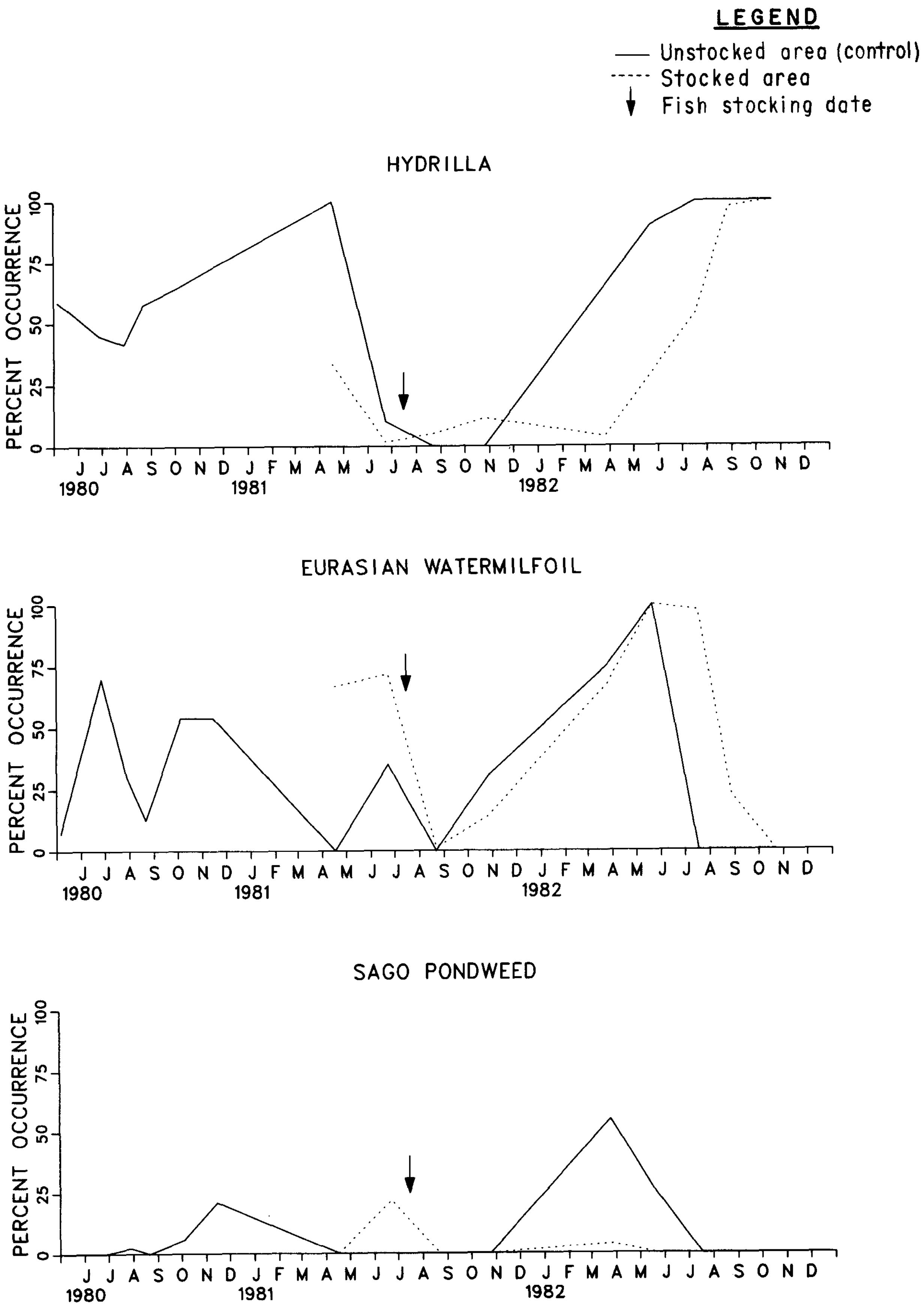

Figure 6. – Percent occurrence of macrophytes in section 2 of Wormwood Lateral 3.

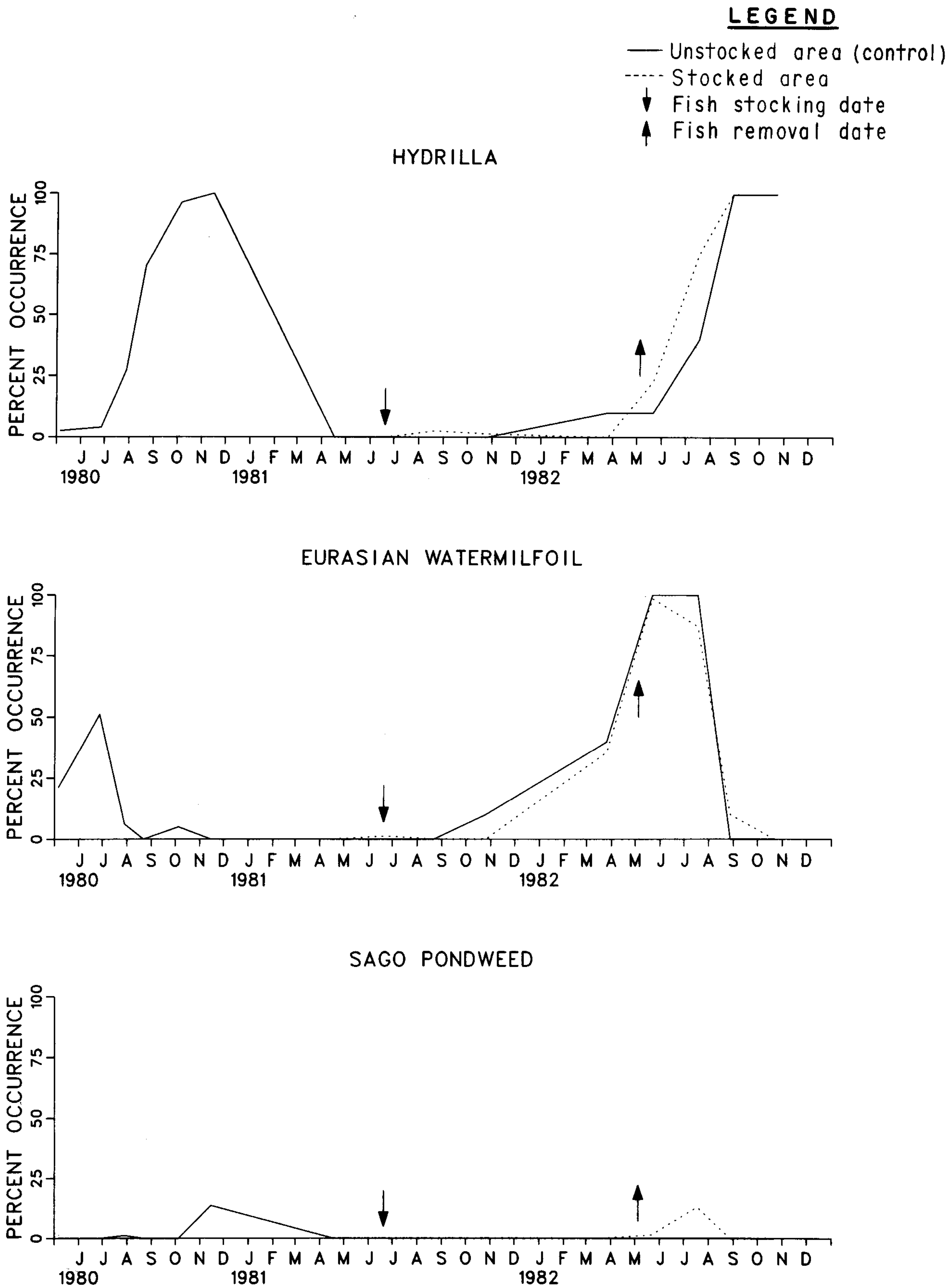

Figure 7. – Percent occurrence of macrophytes in section 3 of Wormwood Lateral 3.

July, and declined to zero and 10 percent in August, inside and outside the exclosure, respectively. In July, only a few sago plants occurred.

Section 4. – Section 4 contained hydrilla in 46 percent of the mapping quadrats during May 1980 (fig. 8), but a decline to 3 percent was observed in July (possibly caused by the July 17 Komeen application). In November, however, the level of hydrilla infestation had again risen to 50 percent. Eurasian watermilfoil declined steadily from 53 percent in May to 9 percent in November. Southern naiad was found in one-half of the quadrats in May, but declined to nondetectable levels by October. Sago pondweed was found in only 5 percent of the quadrats in June and was otherwise undetected in the observations.

During 1981, all macrophytes in section 4 occurred at very low percentages, until the fall. Between August and October, hydrilla grew to 100-percent occurrence inside the exclosure and 91 percent outside the exclosure. This was accomplished because of the planting experiment performed in August.

By March 1982, the occurrence of hydrilla declined to 70 percent, and by May, it was down to 10 percent. The percent occurrence of the plants inside the exclosure followed a pattern similar to that in the treatment area. In July, hydrilla began to make a comeback, and in August it again rose to 100 percent. Watermilfoil rose to 100 percent by May, but began its typical decline in August. Sago was found in the exclosure, only in July and August, and in the treatment area only during July.

The three Komeen treatments applied in 1980 caused some older portions of hydrilla stems to become brittle, take on a reddish coloration, and break into fragments. But healthy, more resistant apical buds remained intact. It should be emphasized that control by Komeen was limited in most cases. The fact that the herbicide induced a response from the vegetation does not necessarily imply that it was successful as a control agent. In some test sections, treatments earlier in the growing season showed a detectable effect. However, in these cases the vegetation made a vigorous recovery.

Coinciding with the decline in the number of quadrats in section 2 containing hydrilla after the first treatment, a dramatic increase in colonization took place in the portion of section 3 immediately downstream from section 2. This increase may have been an adverse consequence of the Komeen treatments. Sites in section 3 showed low occurrences in May and June (3 to 4 percent, respectively), but beginning in July became rapidly colonized by hydrilla (fig. 7). By November, 100 percent of the quadrats surveyed in section 3 had developing hydrilla stands. There are several possible sources of this hydrilla. It may have been produced by germinating tubers, turions, and root stocks that remained from previous growing seasons. However, data from vegetation and tuber sampling in section 3 does not support this premise. It is more likely that this increase in hydrilla resulted mainly from fragments from an upstream source. Fragmentation resulting either from the Komeen treatments or water district dredging activities was probably the mechanism for the hydrilla dispersal. It is quite likely that the large stands of hydrilla in section 2 were the source of these fragments. Further increases in section 4 were less dramatic, possibly because fragments were stopped by the bar screen separating the sections.

Percent Coverage of Macrophytes

Section 1. – Before October 1980, very few macrophytes grew in section 1 (fig. 9). Although percent-occurrence data showed that more plants occurred during this time (fig. 5), they usually occurred singly and did not cover much area. By October, sago coverage had increased to 60 percent throughout the section and by November, had increased another 10 percent. Hydrilla and watermilfoil remained low in coverage (less than 1 percent) throughout the year.

By the spring of 1981, sago had dropped back to less than one percent coverage throughout the section, but watermilfoil had covered 25 to 35 percent of the quadrats (fig. 9). As hydrilla and sago coverage began to increase at midsummer, watermilfoil began to decrease. By October, hydrilla had reached 22 percent coverage outside the exclosure, and sago had reached 100 percent both inside and outside. The hybrids were stocked into this section on September 1, 1981. In October, hydrilla and watermilfoil covered significantly greater areas inside than outside the exclosure.

In 1982, hydrilla covered very little area; it reached a high of 23 percent in the exclosure in October. Watermilfoil coverage was significantly greater outside the exclosure than inside through August, when its annual decline began. Sago began with minimal coverage in the spring. Outside the exclosure, in the treatment area, sago coverage remained low and was significantly less than that inside the exclosure (table 3). This was evidence of good control of hydrilla and sago by the hybrid grass carp.

Section 2. – In 1980, hydrilla grew steadily until November, when it reached 100 percent coverage in the control area (fig. 10). However, in the other transects hydrilla only reached a high of 14 percent, even though this was baseline data collected before the stocking of the hybrid grass carp. Watermilfoil and sago coverage was negligible throughout 1980.

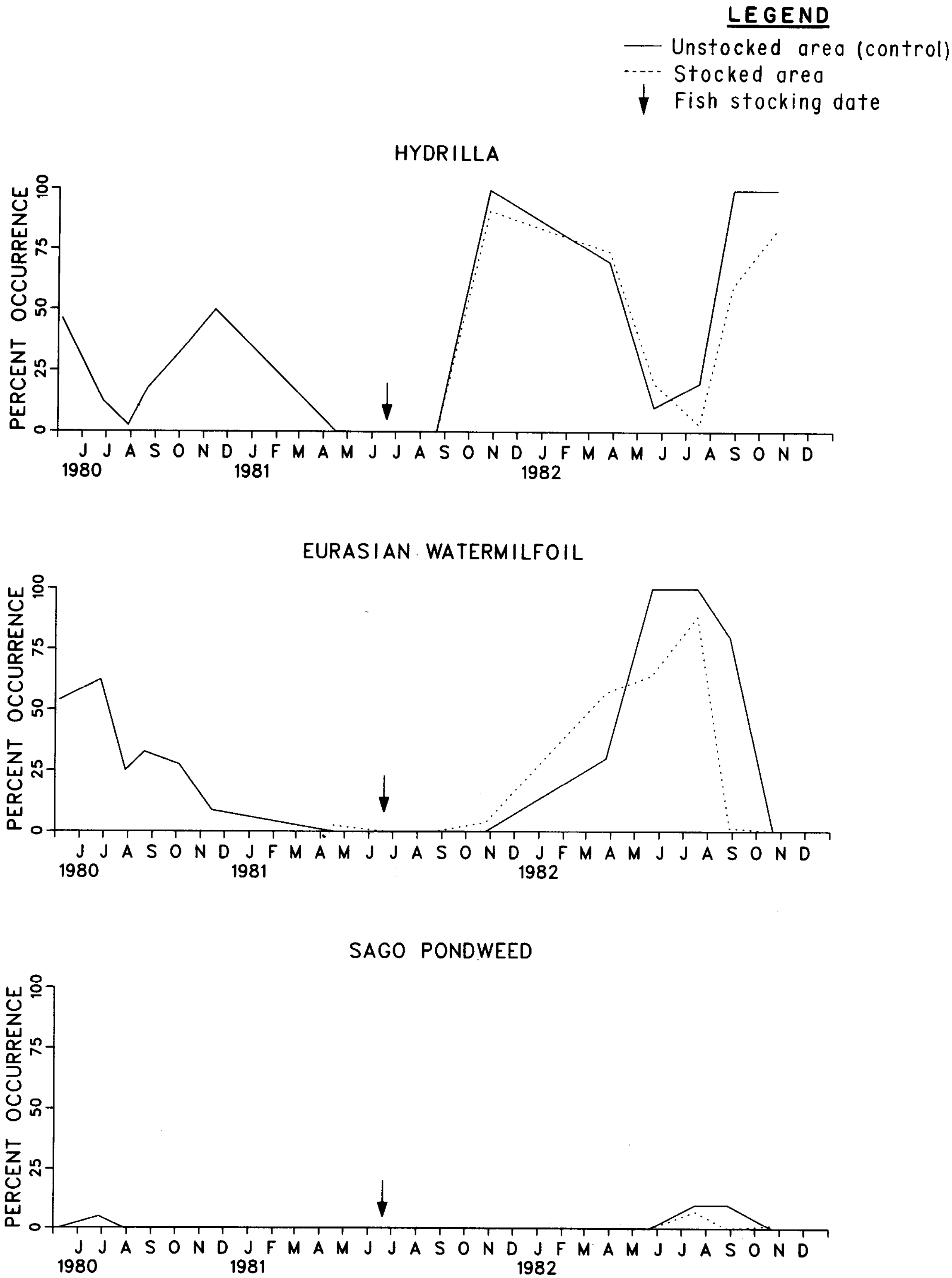

Figure 8. – Percent occurrence of macrophytes in section 4 of Wormwood Lateral 3.

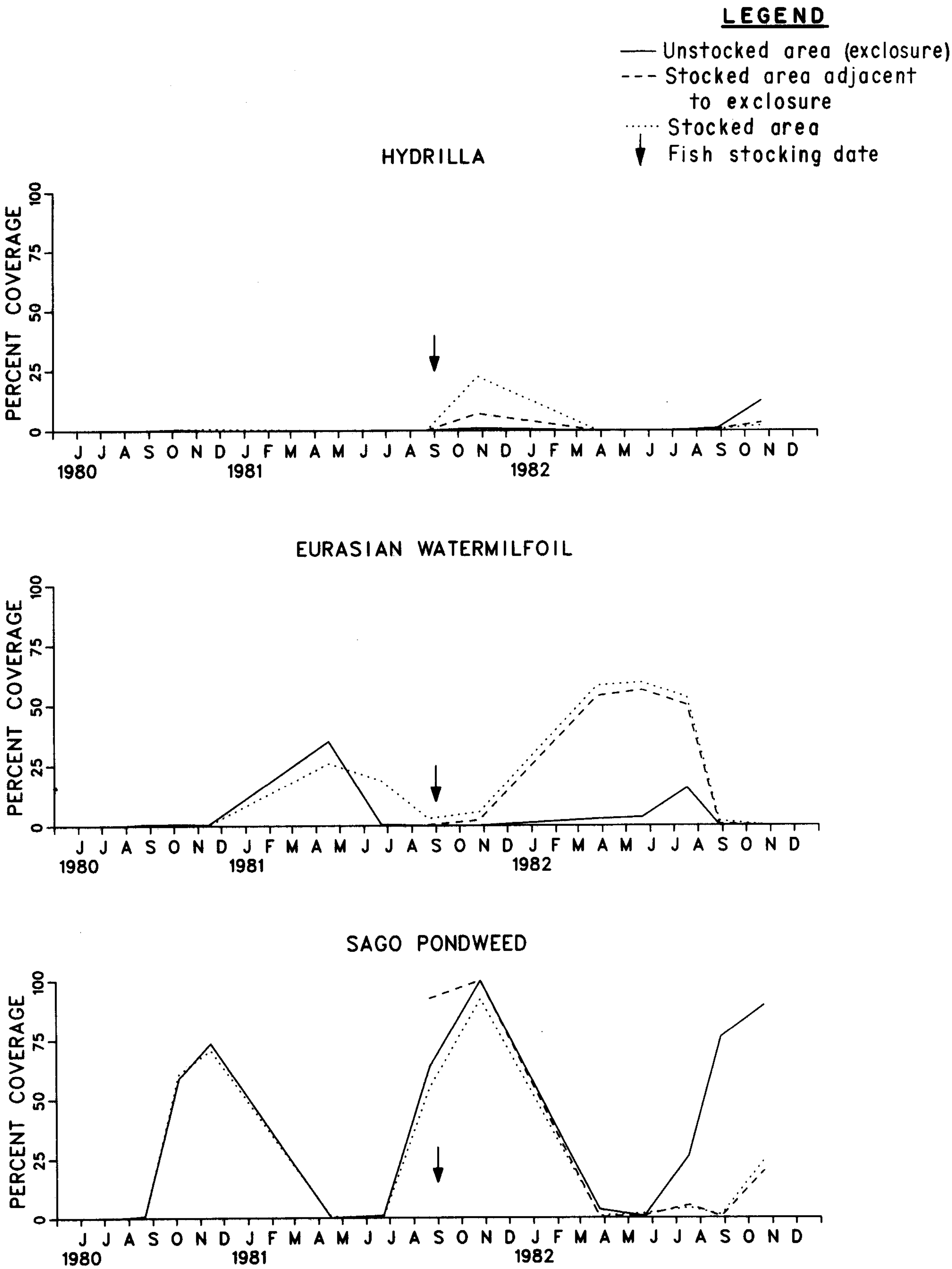

Figure 9. – Percent coverage of macrophytes in section 1 of Wormwood Lateral 3.

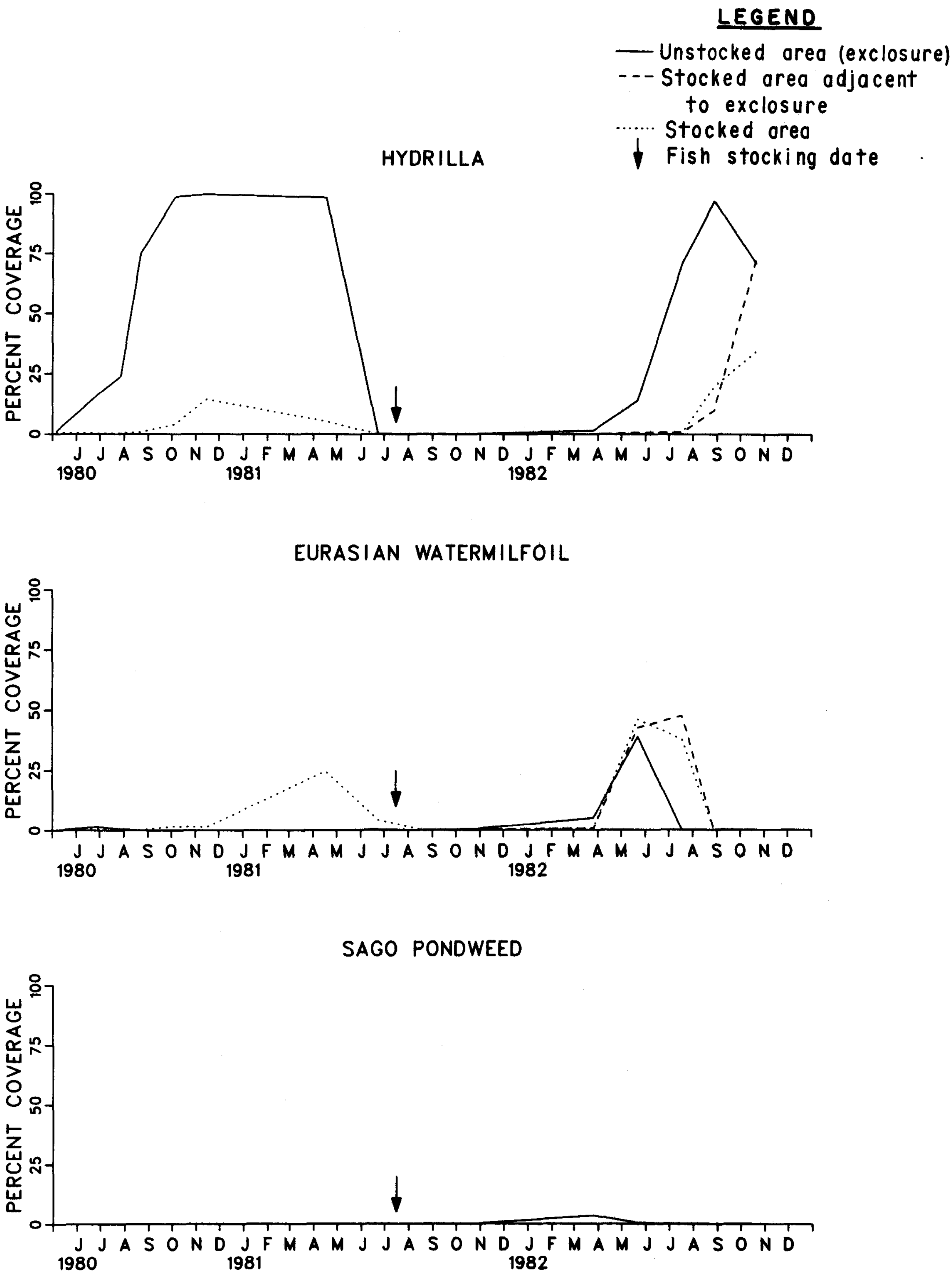

Figure 10. – Percent coverage of macrophytes in section 2 of Wormwood Lateral 3.

In April 1981, residual 1980 hydrilla growth covered 99 percent of the control area. Two months later, hydrilla declined to trace levels; it sloughed off all of the old growth and, essentially, did not regrow all season. Watermilfoil coverage was 25 percent throughout the section in April, but had decreased by June and remained minimal thereafter. Sago coverage remained negligible throughout 1981.

In 1982, the hydrilla growth pattern in the exclosure through August was very similar to the 1980 pattern in the same area (fig. 10). After August, the plants in the exclosure began to die. The treatment area had low macrophyte coverage, significantly less than the exclosure through August, when the hydrilla coverage began to increase. All treatment transects rose to an average hydrilla coverage of 20 percent, while the transect adjacent to the exclosure rose to a coverage of 10 percent. By October, the average for the treatment area of the section was 35 percent coverage, but the line adjacent to, but outside, the exclosure jumped to 74 percent. By that time the control had dropped to 71-percent coverage, which was significantly less than the adjacent line, according to the Kolmogorov-Smirnov nonparametric test [8] (table 3). Fish efficacy in this section is discussed in the section entitled, "Macrophyte Biomass." Watermilfoil followed its usual growth pattern; it reached a peak of 46 percent coverage in the treatment area during July, then essentially disappeared in August. Again, sago was negligible all year.

Secton 3. – Very little macrophyte coverage occurred in 1980 in section 3, until October (fig. 11). Hydrilla then reached 23 percent coverage and, in November, 28 percent. In 1981, there was no macrophyte coverage except for a few scattered sprigs. On May 5, 1982, the hybrid grass carp were removed from section 3. Thereafter, both hydrilla and watermilfoil increased in coverage. Hydrilla steadily increased, reaching 100 percent in October, in all sample areas. Watermilfoil reached its maximum of 11 percent coverage in late May, and declined again by August.

Section 4. – Section 4 had little macrophyte coverage in 1980 (fig. 12). Watermilfoil had the greatest coverage, 17 percent in October, but declined again in November. This is the only Wormwood section where the maximum watermilfoil growth did not occur in the spring.

In 1981, virtually no macrophytes grew in section 4. As an experiment, hydrilla was planted in August, and by October it had covered 38 percent of the exclosure and 60 percent of the adjacent line. This was not a statistically significant difference.

The following spring, most of the 1981 hydrilla plants remained, and watermilfoil began to appear. By May 1982, however, the residual hydrilla sloughed off, leaving only 1 percent new coverage in the exclosure. This new coverage increased steadily after May. Very little hydrilla covered the treated area through the rest of the season and coverage was significantly less than that in the exclosure. Watermilfoil in the exclosure reached its peak coverage of 15 percent in July, and it covered significantly more area there than in the treatment area, from May through August. Virtually no sago grew in section 4 from 1980 through 1982.

Quantitative Sampling

Macrophyte Biomass

Macrophyte biomass is illustrated on figure 13 for sections 1, 2, 3, and 4 in Wormwood Lateral 3; the data include total plant biomass. The predominant species in section 1 was sago pondweed, and in sections 2, 3, and 4, hydrilla. These species were predominant throughout the entire study period (figs. 14, 15, 17, and 19). Eurasian watermilfoil was present in some of the collected samples, but its biomass was a minor component of the total.

Prestocking data collected from all test sections during 1980, and in April and June 1981, were different, not only in aquatic macrophyte species, but also in the amount of biomass. The Komeen treatment of August 4, 1980, may have had a slight effect on hydrilla, causing it to fragment, but produced no lasting impact. In some situations, however, external factors such as system operation and exclosure design affected hybrid grass carp efficacy evaluations.

Section 1. – Macrophyte biomass was very sparse at the beginning of 1980. It was not until the October sampling period, that biomass was collected in section 1, with a total of 14.5 g/m^2 dry weight, 70 percent of which was southern naiad. By November, the sago biomass increased 25 times, to 96 g/m^2, making up 99 percent of the total biomass (fig. 14). Figure 11 illustrates the same pattern using percent coverage.

In 1981, biomass again started out slowly, but by August, sago rose to 40 g/m^2 inside the exclosure and 80 g/m^2 outside. By October, biomass rose even further, to 145.5 g/m^2 inside and 217.7 g/m^2 outside, with hydrilla contributing between 1 and 2 percent of the total.

By April 1982, the biomass in the sampling area was very low again. Outside the exclosure, biomass reached its 1982 maximum of 46 g/m^2, in July. For the rest of the year, biomass did not exceed 1.5 g/m^2 in the treatment area. Inside the exclosure the biomass peak of 58 g/m^2 occurred in December.

Table 3. – Nonparametric Kolmogorov-Smirnov significance test comparing the percent coverage of macrophytes within the control areas (exclosures) with percent coverage in areas stocked with hybrid grass carp in Wormwood Lateral 3.

Sampling date	Section 1			Section 2			Section 3			Section 4		
	Hydrilla	Eurasian watermilfoil	Sago pondweed	Hydrilla	Eurasian watermilfoil	Sago pondweed	Hydrilla	Eurasian watermilfoil	Sago pondweed	Hydrilla	Eurasian watermilfoil	Sago pondweed
1981												
Aug. 22	–	*	*	–	–	–	–	–	–	–	–	–
Oct. 26	*	*	–	–	–	–	–	–	–	–	–	–
1982												
Mar. 26	–	*	–	+	+	+	–	–	–	*	*	*
							Fish were removed May 5, 1982					
May 22	–	*	–	+	*	–	+	+	–	–	+	+
July 18	–	*	+	+	*	–	–	–	–	+	+	+
Aug. 28	–	*	+	+	–	–	–	–	–	+	+	+
Oct. 22	–	–	+	*	–	–	–	–	–	+	–	–

– = Not significant[a]
+ = Macrophyte coverage significantly greater inside the control[a]
* = Macrophyte coverage significantly less inside the control[a]

[a] Confidence limits greater than or equal to 95 percent.

Biomass in August, October, and November was significantly greater in the control area than in the treatment area.

In section 1, dense stands of Eurasian watermilfoil survived periodic drawdowns and accumulated in a deepened trench on one side of the canal, outside the perimeter of the treatment sampling area. This trench, which was created by dredging activities [4], was a more suitable habitat for weeds. By July 1982, it had approximately three times the biomass levels found in the treatment areas. Consequently, the standing crop for the section in May and July was probably much higher than estimated, based on treatment sampling-area measurements. This accumulation of biomass in the trench was not considered when hybrid grass carp stocking took place. As a result, stocking for the section was inadequate for early weed control through July. After removal of the accumulated vegetation in mid-July 1982, the ratio of weed to fish biomass was reduced to a level at which significant weed-control efficacy was maintained (table 4).

Section 2. – Macrophyte biomass in 1980 began low but increased steadily through November, when it reached 228 g/m^2, with hydrilla over 90 percent of the total. However, the majority of the biomass was collected from one sampling area, which contained a very dense stand of hydrilla. By July 25, 1980, a stand just upstream of the sampling area reduced the waterflow in Wormwood Lateral 3 more than 50 percent. This made it necessary for the IID to mechanically remove vegetation from the east side of the lateral and to widen the lateral by approximately 1 m. Because this area was not in the 1980 biomass sampling area, the biomass went unrecorded. As this stand grew, it eventually expanded into the sampling area, resulting in the greater biomass recorded later in the growing season.

Section 2 began, in April 1981, with substantial residual stands of hydrilla from the 1980 growing season. The dense vegetation had healthy growing tips, but older plant tissue showed evidence of senescence and slight herbicidal damage, resulting from the complexed-copper herbicide (Komeen) applications of fall 1980. Between April and June, these dense hydrilla stands disappeared (fig. 15). This may have been the result of a normal annual decline after a mild winter [10]. Although a few widely scattered plants occurred outside the biomass sampling areas (fig. 6) in August and October 1981, no vegetation was harvested from section 2 inside or outside the exclosure. Numerous tubers were all that remained of the dense hydrilla stands. Throughout the 1981 field season, little evidence of either hydrilla root crown sprouting or tuber germination was observed.

Table 4. – Comparison by Student's t-test of dry-weight biomass, stem density, stem length, and tuber density of macrophytes within the control areas (exclosures) with those in areas stocked with hybrid grass carp in Wormwood Lateral 3.

Sampling date	Combined dry weight	Stem density			Stem length			Tuber density	
		Hydrilla	Eurasian watermilfoil	Sago pondweed	Hydrilla	Eurasian watermilfoil	Sago pondweed	Hydrilla	Sago pondweed
Section 1									
1981									
Aug. 22	–	–	*	–	–	–	*	–	–
Oct. 26	–	–	–	–	–	–	+	–	*
1982									
Mar. 26	*							–	*
May 22	*	–	+	–	–	*	–	–	–
July 18	–	–	*	+	–	*	+	–	–
Aug. 28	+	–	–	+	–	–	+	–	–
Oct. 22	+	+	–	+	+	–	+	–	*
Dec. 15	+								
Section 2									
1981									
Aug. 22	–	–	–	–	–	–	–	+	–
Oct. 26	–	–	–	–	–	–	–	–	–
1982									
Mar. 26	–							–	–
May 22	*	+	–	–	+	*	–	–	–
July 18	–	+	*	–	+	*	–	*	–
Aug. 28	+	+	–	–	+	–	–	–	–
Oct. 22	–	–	–	–	+	–	–	–	–
Dec. 15	–								
Section 3									
1981									
Aug. 22	–	–	–	–	–	–	–	–	–
Oct. 26	–	–	–	–	–	–	–	–	–
1982									
Mar. 26									
		Fish were removed May 5, 1982							
May 22	+	–	–	*	+	–	*	–	–
July 18	–	*	+	–	*	–	–	–	–
Aug. 28	–	–	–	–	–	–	–	–	–
Oct. 22	–	–	–	–	–	–	–	–	–
Dec. 15	–	–							
Section 4									
1981									
Aug. 22	–	–	–	–	–	–	–	–	–
Oct. 26	*	*	–	–	*	–	–	–	–
1982									
Mar. 26									
May 22	–	–	–	–	*	+	–	–	–
July 18	–	+	–	–	+	+	–	*	–
Aug. 28	–	+	–	–	+	–	–	–	–
Oct. 22	+	+	+	–	+	+	–	*	–
Dec. 15	+								

– = Not significant[a]
+ = Significantly greater inside the control[a]
* = Significantly less inside the control[a]

[a] Confidence limits greater than or equal to 95 percent.

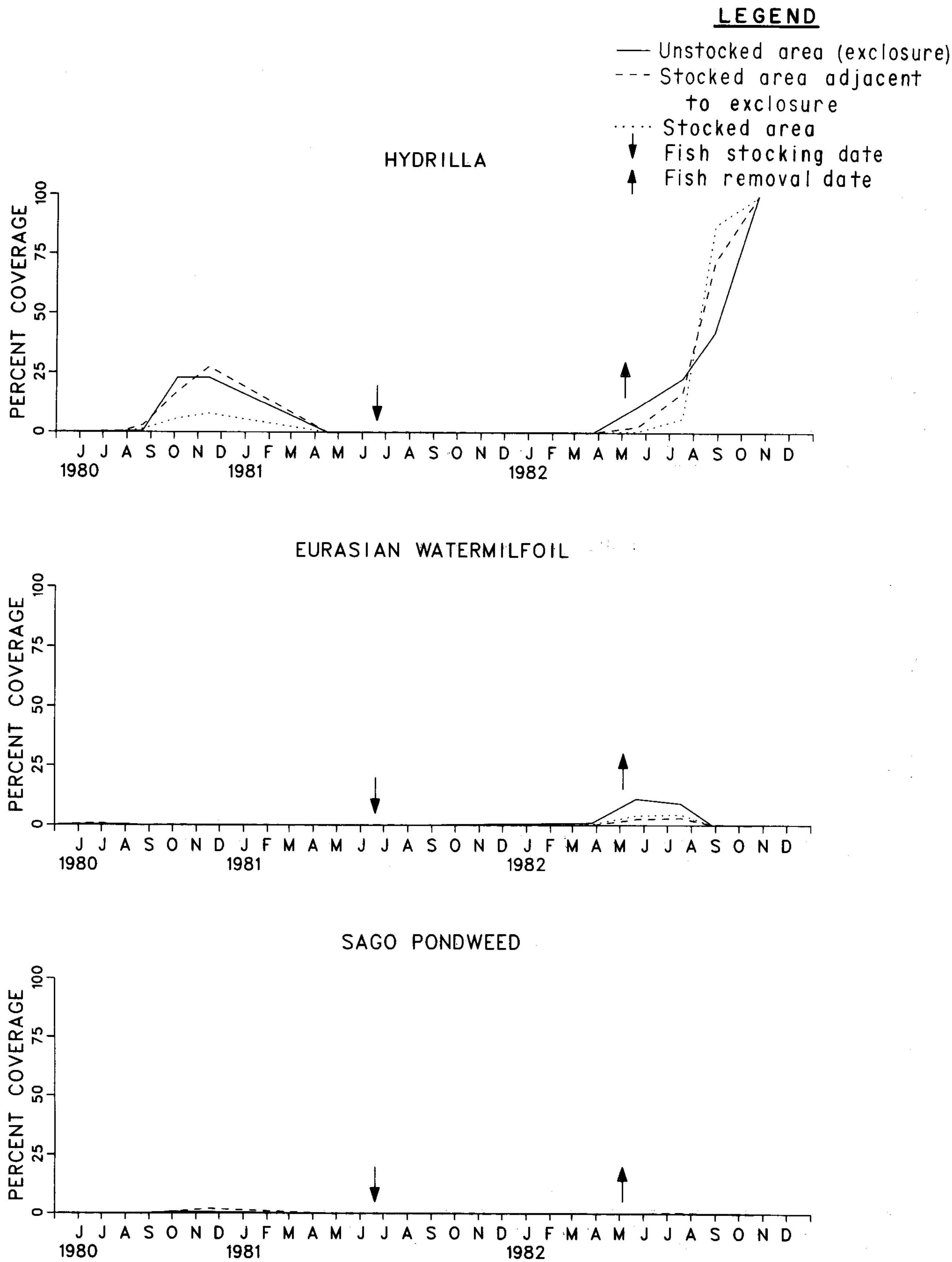

Figure 11. – Percent coverage of macrophytes in section 3 of Wormwood Lateral 3.

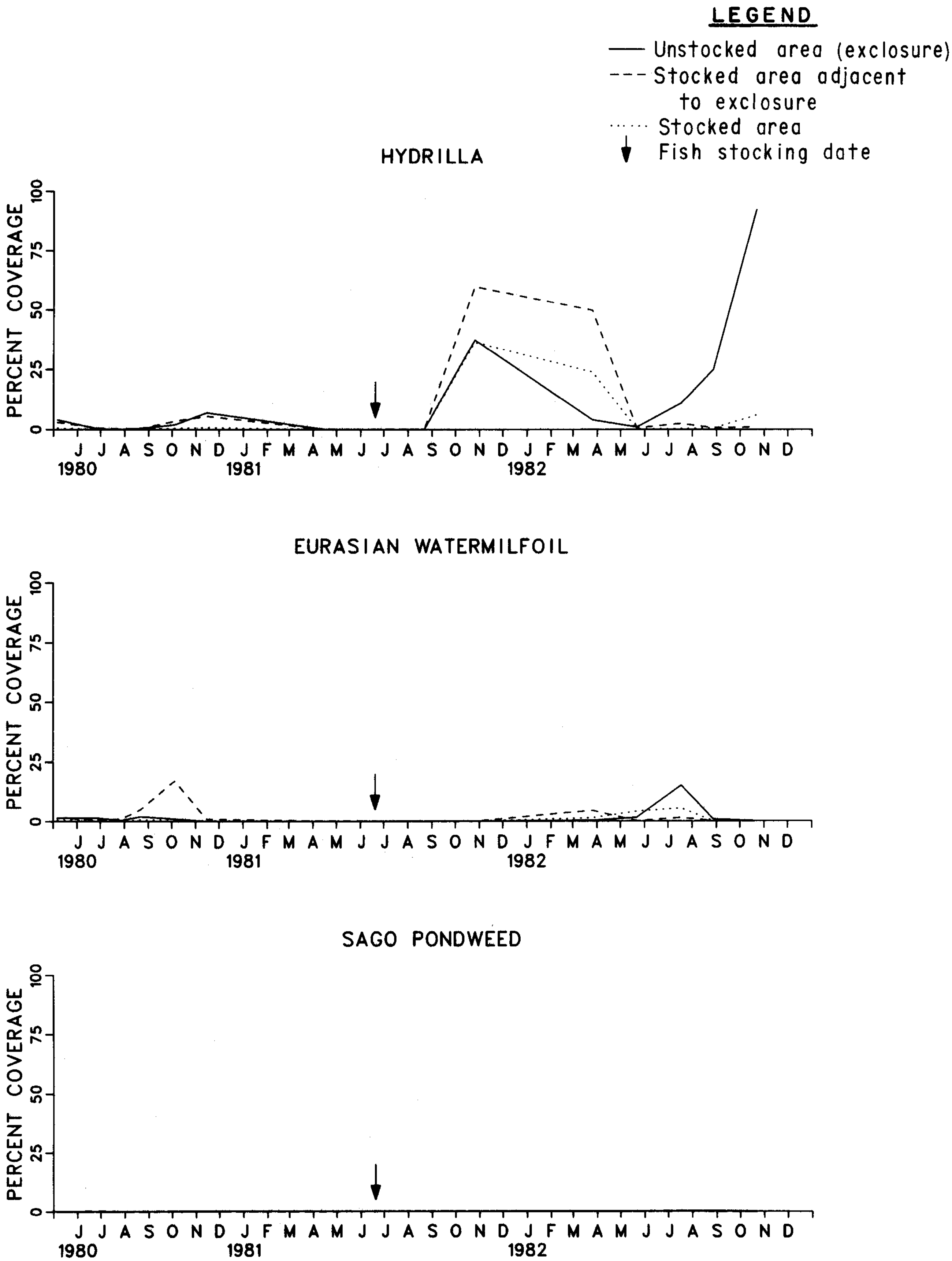

Figure 12. – Percent coverage of macrophytes in section 4 of Wormwood Lateral 3.

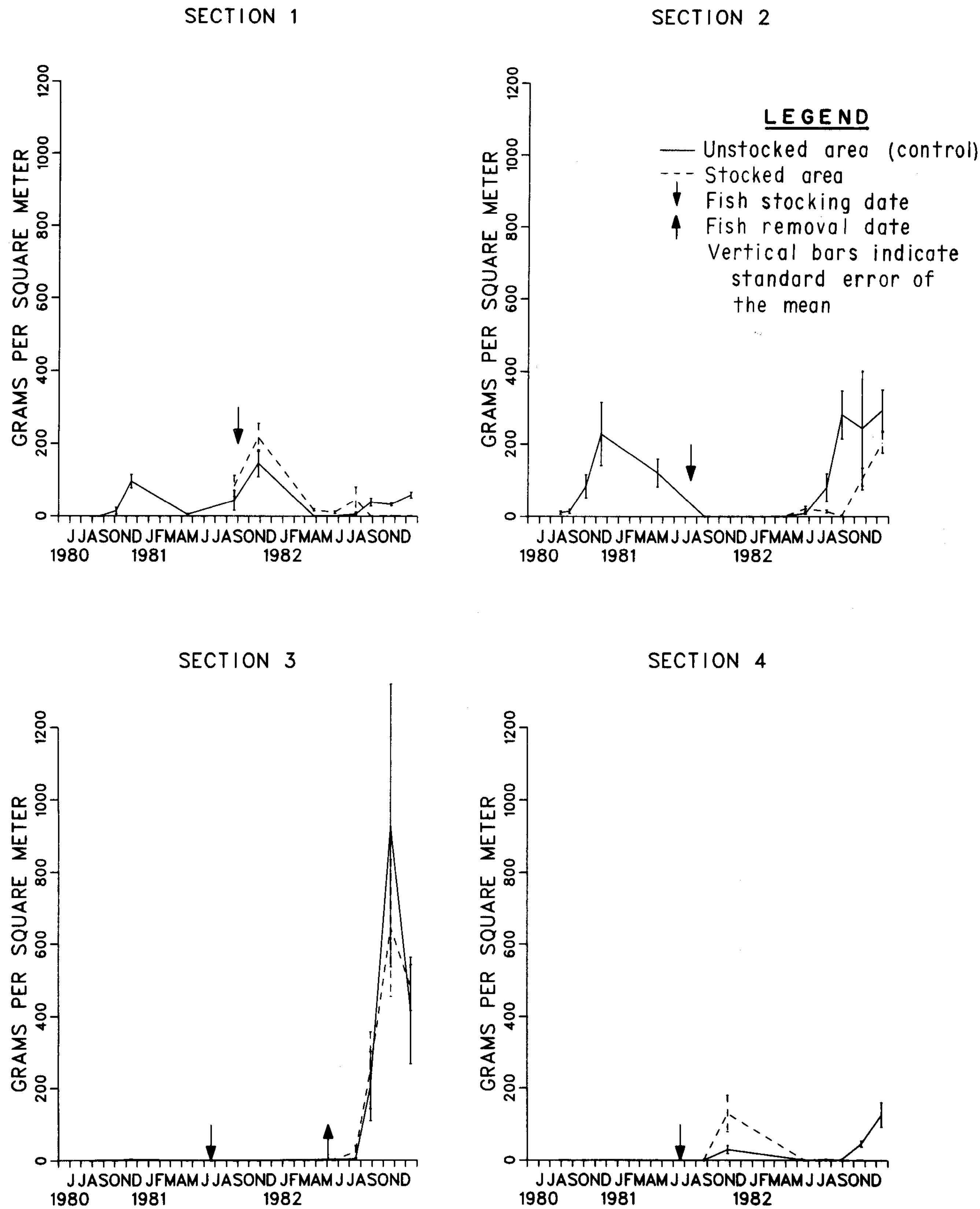

Figure 13. – Combined dry-weight biomass (g/m²) of macrophytes collected in Wormwood Lateral 3.

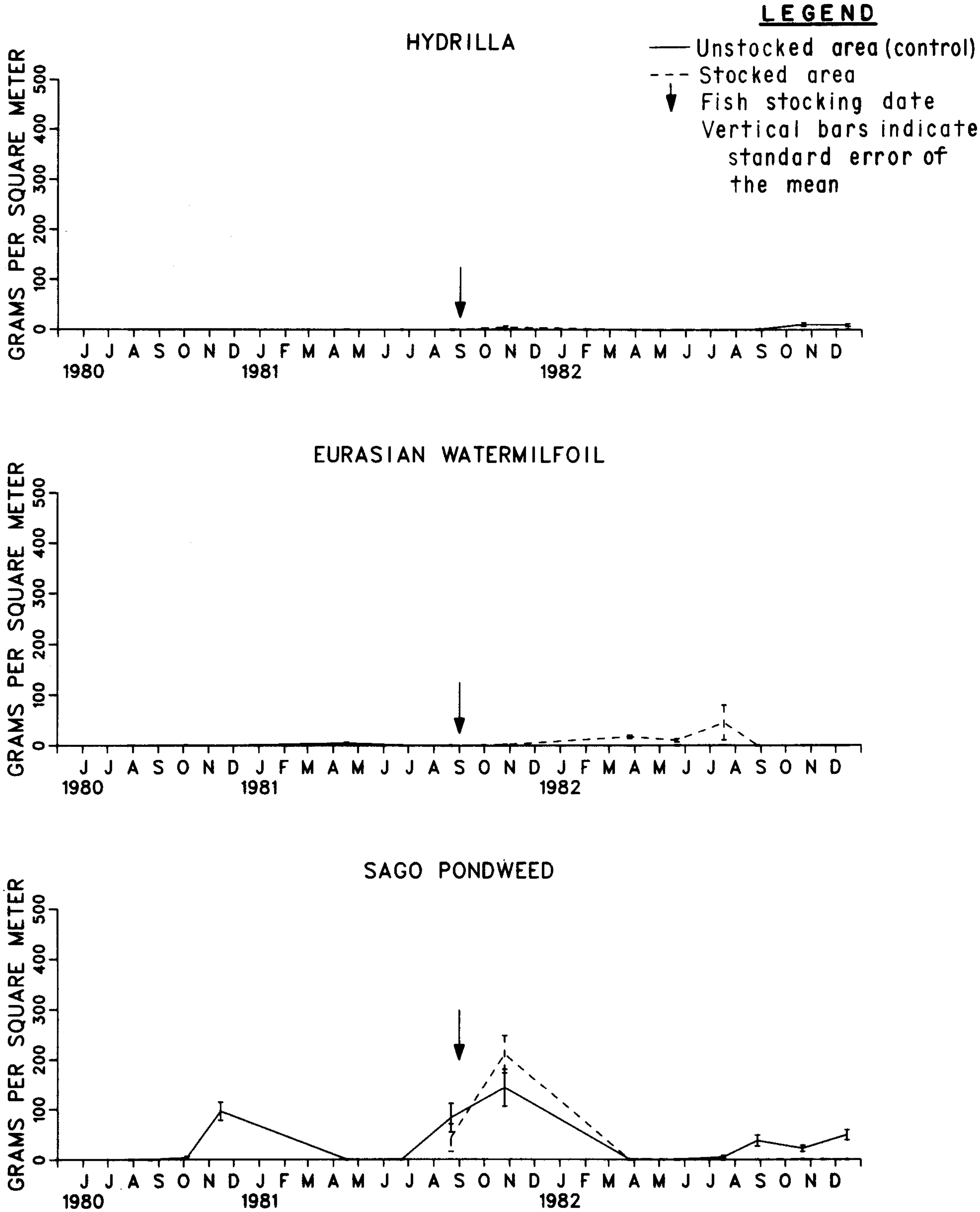

Figure 14. – Dry-weight biomass (g/m^2) of macrophytes collected in section 1 of Wormwood Lateral 3.

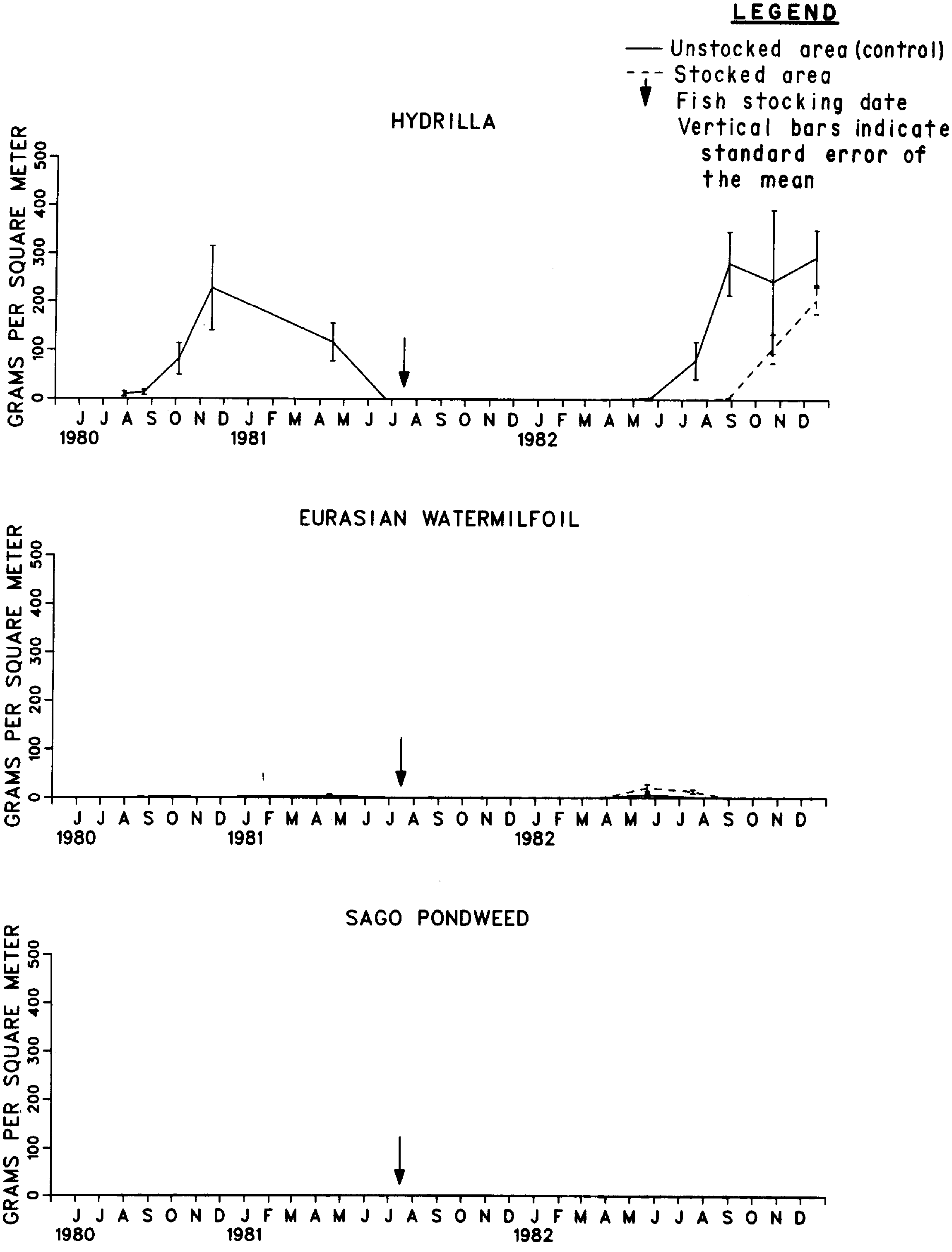

Figure 15. – Dry-weight biomass (g/m²) of macrophytes collected in section 2 of Wormwood Lateral 3.

In 1982, the hydrilla biomass growth pattern was very similar to the 1980 growth pattern, except that in 1982, it occurred earlier in the season, then declined in October. Aquatic weed control was very apparent in section 2 by August, when hydrilla biomass in the treated area was significantly lower than in the adjacent exclosure (2 g/m^2 contrasted with 282 g/m^2). Hydrilla growth was heavy, completely filling the exclosure, while outside aquatic vegetation was sparse (fig. 16). Although it lacked statistical significance, the trend of higher biomass levels within the exclosure continued in October and December. The lack of further weed growth in the exclosure after the August sampling was not representative of hydrilla growth for this period. Hydrilla in Wormwood Lateral 3 typically grows to its maximum biomass during the period from August to October, as occurred in section 3 (figs. 13 and 17). This growth coincides with seasonal high temperatures (fig. 18). Conditions in the section 2 exclosure were probably attributed to effects of the exclosure structure on weed habitat. The mesh (later changed to horizontal bar screens) along the upstream end of the exclosure slowed the water current through the exclosure, especially when algal scum accumulated there. The slow water velocity (0.015 m/s (0.05 ft/s)) altered the normal environmental characteristics of the canal. Dense algal mats accumulated in the exclosure, shaded submerged vegetation, and generally diminished growing conditions. In the slow-moving conditions, the normal influx of nutrients with water currents may have been reduced, causing possible growth-limiting nutrient depletion. Low current velocities have been directly related to lower metabolism in sago pondweed [11]. By October, biomass in the treated area had increased from 2 g/m^2 to 105 g/m^2, and by November had increased to 205 g/m^2. This indicated that biomass was no longer controlled by the hybrid grass carp. A higher stocking density may be necessary to control macrophytes during this time of year.

Section 3. – Very little macrophyte biomass was collected from April 1980 to July 1982, in section 3 (figs. 13 and 17). The fish stocked in July 1981, were removed in May 1982. Biomass began to appear in the next sampling period and rapidly reached a peak of 928 g/m^2 in the exclosure, in October. The only month when there was a significant difference outside and inside the exclosure was May 1982, just after removal of the fish. Relatively uniform growth of hydrilla occurred during the rest of the season both inside and outside the exclosure. By August 1982, biomass had become sufficient to impede water deliveries, and mechanical vegetation removal became necessary.

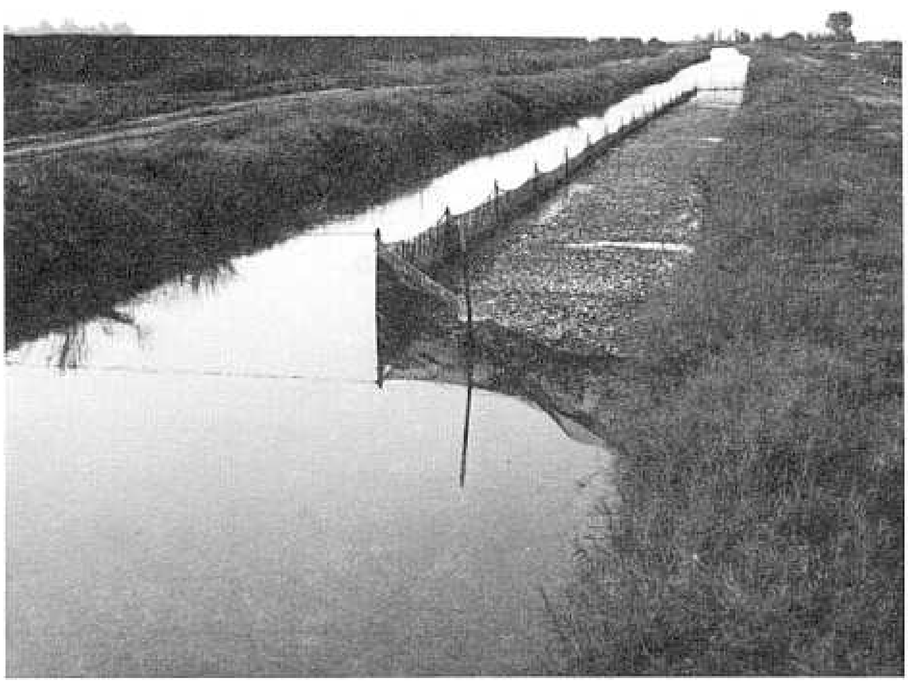

Figure 16. – Dense stand of hydrilla growing in the Wormwood Lateral 3, section 2 exclosure, in August 1982. The area outside of the exclosure had been stocked with hybrid grass carp since July 1981.

WW3

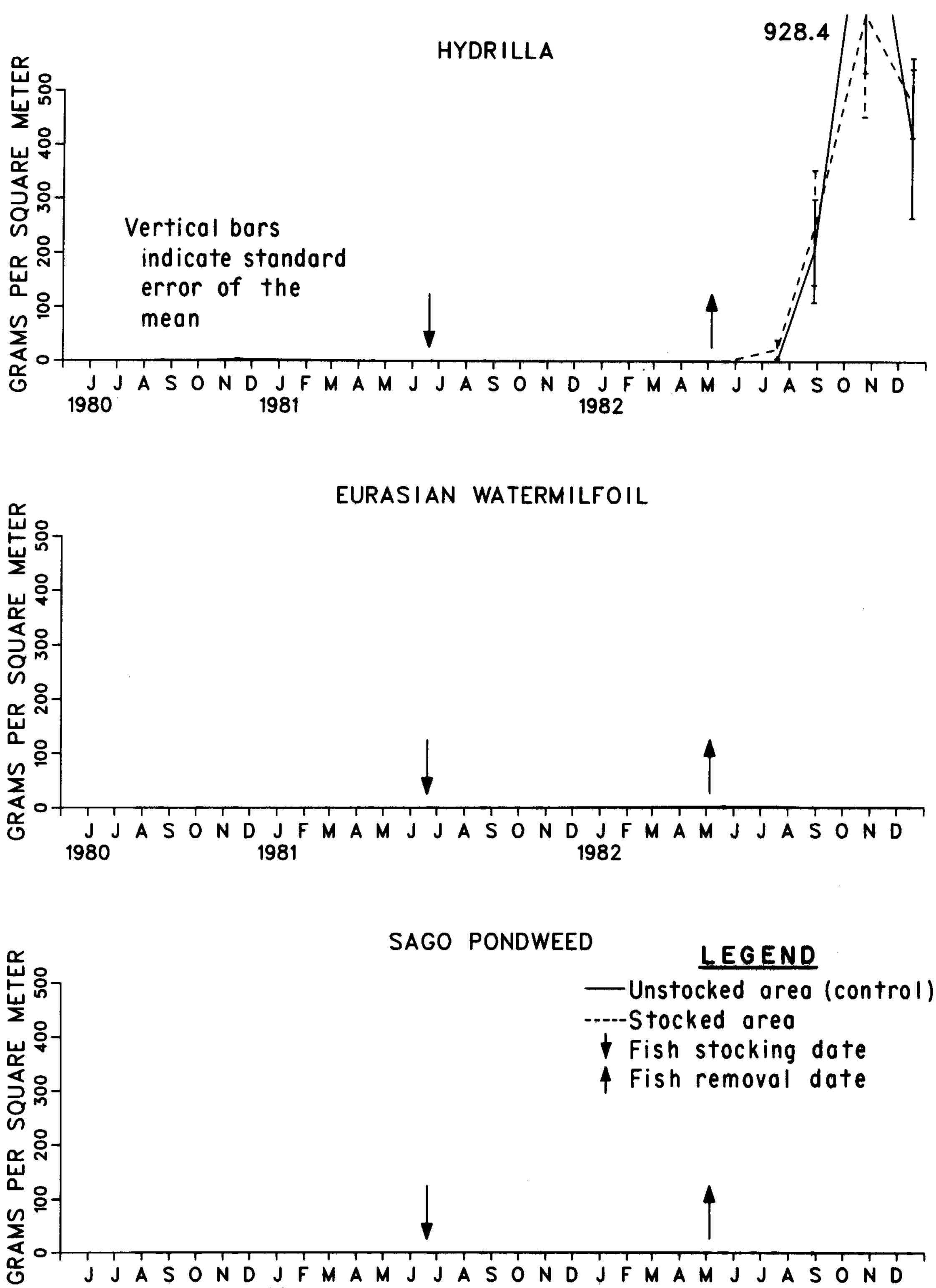

Figure 17. – Dry-weight biomass (g/m²) of macrophytes collected in section 3 of Wormwood Lateral 3.

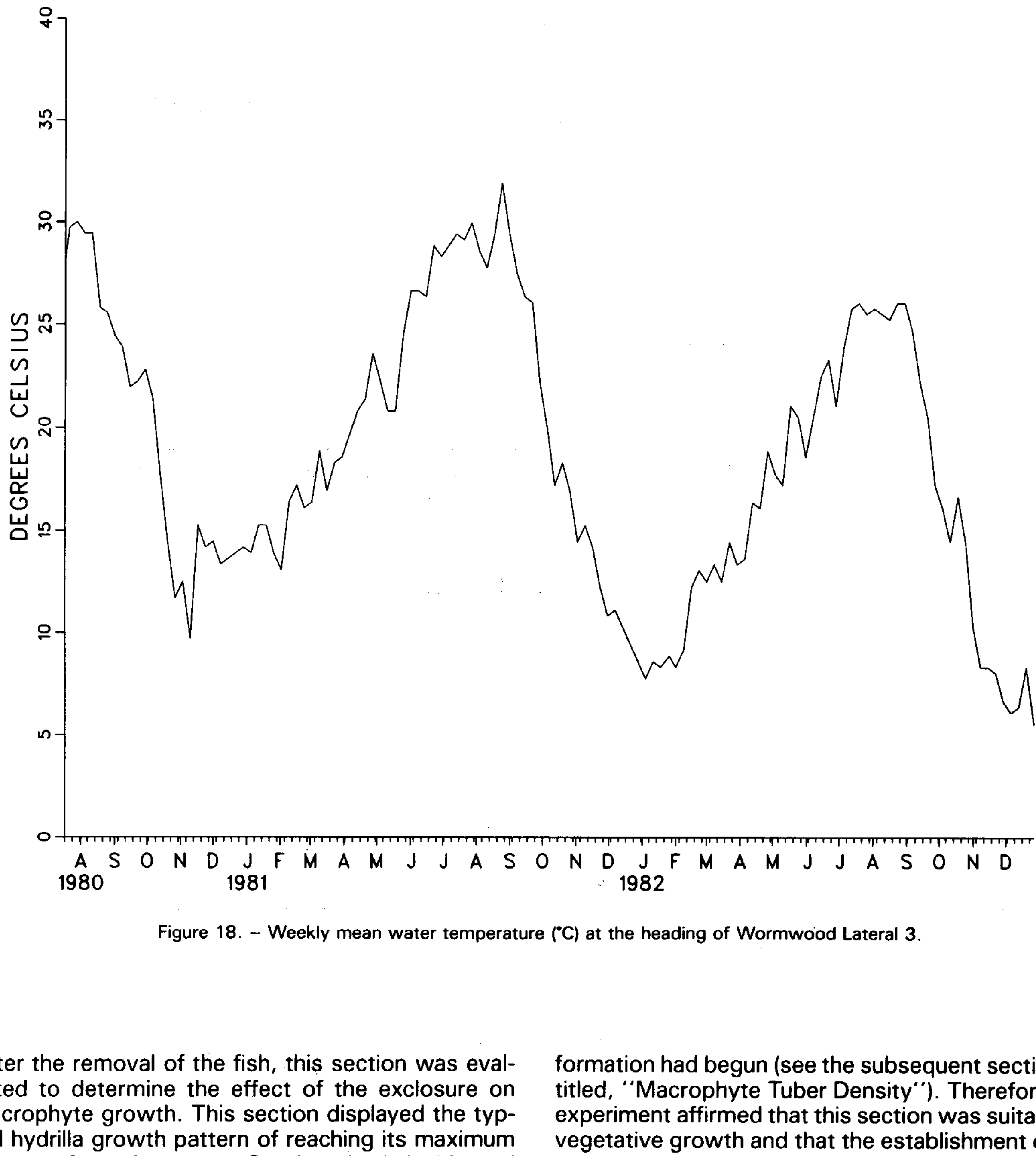

Figure 18. – Weekly mean water temperature (°C) at the heading of Wormwood Lateral 3.

After the removal of the fish, this section was evaluated to determine the effect of the exclosure on macrophyte growth. This section displayed the typical hydrilla growth pattern of reaching its maximum biomass from August to October, both inside and outside the exclosure. The pattern of decline seen in the section 2 exclosure was not apparent in section 3. In fact, hydrilla biomass was greater in the exclosure in section 3. By December, hydrilla had begun to decline.

Section 4. – Section 4 was also virtually macrophyte free from early 1980 through August 1981. A planting experiment was conducted to determine whether a growth-limiting condition existed in section 4. Hydrilla sprigs were planted in August 1981, in the lower two-thirds of the four transect lines. By October, dense stands of hydrilla had grown, and tuber formation had begun (see the subsequent section entitled, "Macrophyte Tuber Density"). Therefore, this experiment affirmed that this section was suitable for vegetative growth and that the establishment of natural hydrilla stands only required adequate introduction of plant material. In October, there was significantly less hydrilla in the exclosure than outside. This indicated little, if any, control by the fish, which had been in the section for four months. The October 1981 plant material declined over the winter and, in the treatment area, did not regrow through December 1982. In the exclosure, hydrilla reached 41 g/m^2 in October, then 127 g/m^2 by December (fig. 19). Development of significantly greater biomass in the control area during October and November 1982, indicated positive fish efficacy. The percent occurrence data confirm this same growth pattern of total biomass (fig. 12).

Comparison of Various Methods

Percent coverage and percent occurrence are both derived from mapping data. However, percent coverage more accurately describes the amount of plant material, whereas percent occurrence indicates the declines or increases in the number of plants. In the study site, percent coverage gives a better idea of the macrophyte situation and is more closely related to total biomass than percent occurrence is.

By comparing the mapping data (qualitative) with the biomass data (quantitative), it is evident that the two methods produce similar estimates of macrophyte growth patterns. In a few instances, mapping data (section 4, during October and November 1980) were more representative of patchy infestations than biomass data were. This is primarily caused by the greater number of samples used in mapping.

Seasonal average dry weights of the macrophytes on Wormwood Lateral 3 composed approximately 10 percent of the average fresh weights, from 1980 through 1982. By species, the dry weight expressed as a percent of the fresh weight was as follows: hydrilla, 9 percent; Eurasian watermilfoil, 15 percent; sago pondweed, 10 percent; southern naiad, 9 percent; and curlyleaf pondweed, 8 percent.

Macrophyte Density and Length

The trend of population, or stem density, expressed as stems per square meter (figs. 20 through 22) is very similar to biomass (figs. 14, 15, 17, and 19) and to the percent-coverage curves by species (figs. 9 through 12). But the objective in sampling density and stem length is to determine the effect of hybrid grass carp on these variables. It has not been determined whether fish eat only the plant tips or the entire plant, or whether their feeding encourages the formation of new shoots.

There is evidence that hybrid grass carp [12, 13, 14] and grass carp [13 through 20], which appear to have similar food habits [13], prefer to eat certain plants. Therefore, the stem density and length of each of the major species is listed and graphed separately on figures 20 through 25.

Section 1. – Data on stem density by species in section 1 (figs. 20, 21, and 22) is very similar to the data on the percent-coverage curves (fig. 9) and biomass curves (fig. 14). Stem length was not as closely related, but usually increased or decreased with density. Generally, the fish did not decrease the number of hydrilla stems or their length in 1981, but by August 1982, the stems had become fewer and shorter in the treatment area. Watermilfoil length decreased after the fish stocking only until July 1982, when stem density and stem length increased dramatically. From these data it appears that fish did not affect the growth of watermilfoil. This may have been caused by the tremendous amount of watermilfoil in the section or the relative lack of interest on the part of the hybrid for the plant [3]. As discussed in "Macrophyte Biomass," heavy stands of watermilfoil grew in the deepened side of the section that was not evaluated in this study. The fish stocked were unable to control such biomass until the deepened side was dredged in mid-July, and the ratio of weed to fish biomass was reduced to a manageable level. Hybrid grass carp were then able to control the watermilfoil in the evaluated portion of section 1; studies have shown they will eat watermilfoil when their preferred species are unavailable [12] (as related to grass carp [13, 15, 17, 18, 20]). In October 1981, sago pondweed, the predominant species in section 1, was significantly shorter in the treatment area than in the exclosure, but stem density was greater (figs. 25 and 22). In May 1982, sago had declined almost completely, but by July, sago stems were significantly shorter and fewer in the treatment area than in the control area. This control continued through the season. However, by October, treatment stem density had increased by 82 times the density in August, with very little increase in average stem length. This indicates a possible stimulation of lateral shoots by the removal of apical growing tips and their inhibiting hormones. This response to the removal of apical dominance is common in many plants [21]. Southern naiad, a macrophyte very much preferred by the hybrids in laboratory studies [12], was significantly shorter in the treatment area, by October 1981. No naiad was sampled after that date.

Section 2. – In this section, virtually all hydrilla declined in 1981, just before the stocking of the hybrid grass carp, and no regrowth occurred the entire year. By May 1982, the hydrilla had begun its reinfestation of both the stocked and control areas. Hydrilla stem length was significantly shorter in the stocked area through the rest of the season, and stem density was significantly less until October. The fish controlled the hydrilla in this section in 1982 until October. By October, the hydrilla in the control area had begun to decline (see "Macrophyte Biomass, Section 2"), but stem density in the stocked area increased from 9 stems/m^2 to 420 stems/m^2, or by 4600 percent, in less than two months. However, within this period the average stem length increased by only 25 percent. The relatively rapid increase in stem density suggests the removal of apical dominance which may occur when hybrid grass carp stocking levels are low. Indications of apical dominance in hydrilla have been noted in a laboratory study by Oechel in 1982 [22]. Cooperating fishery biologists have theorized that as the water cooled in the fall, the metabolism of the hybrid and, thus, its feeding activities began to slow

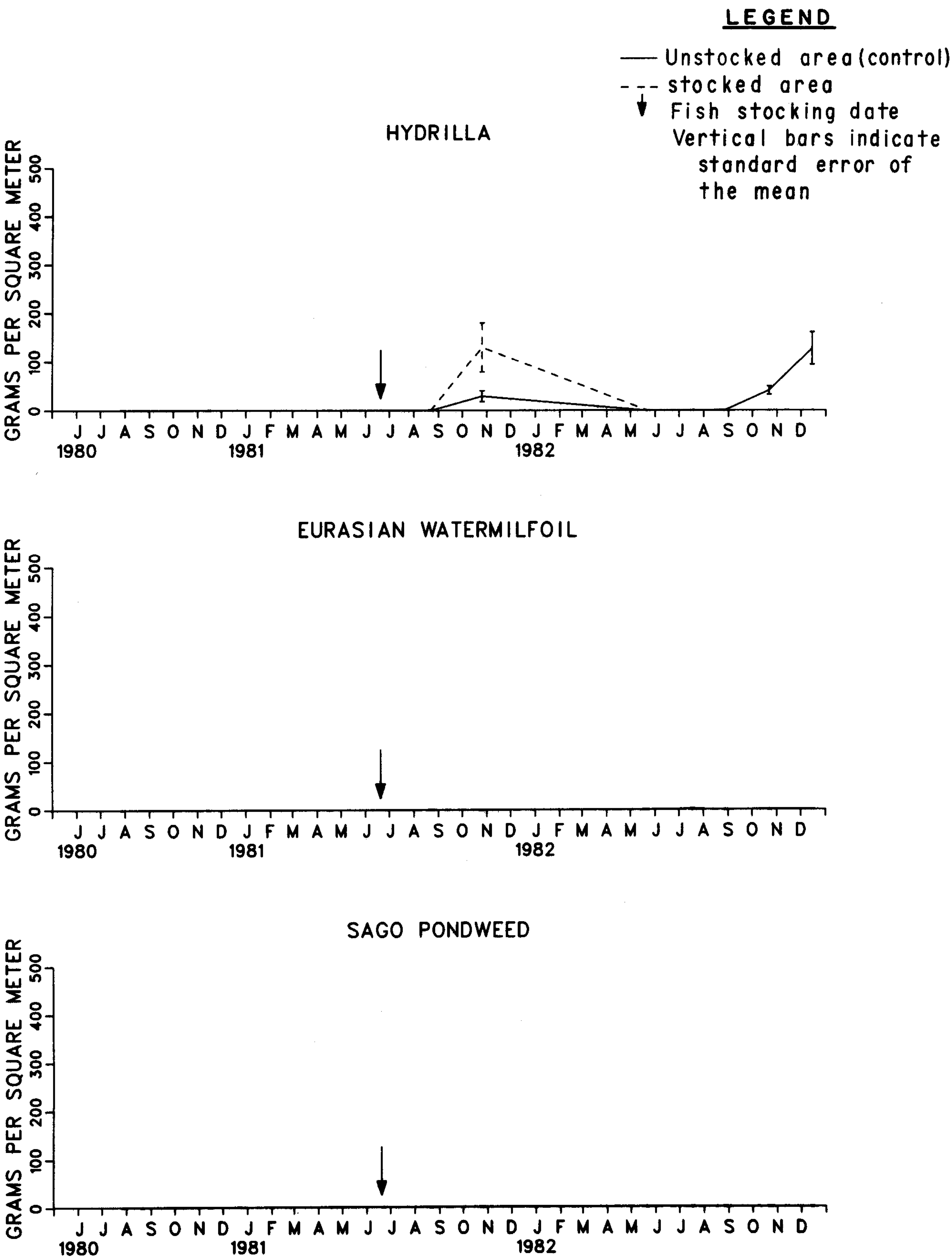

Figure 19. – Dry-weight biomass (g/m²) of macrophytes collected in section 4 of Wormwood Lateral 3.

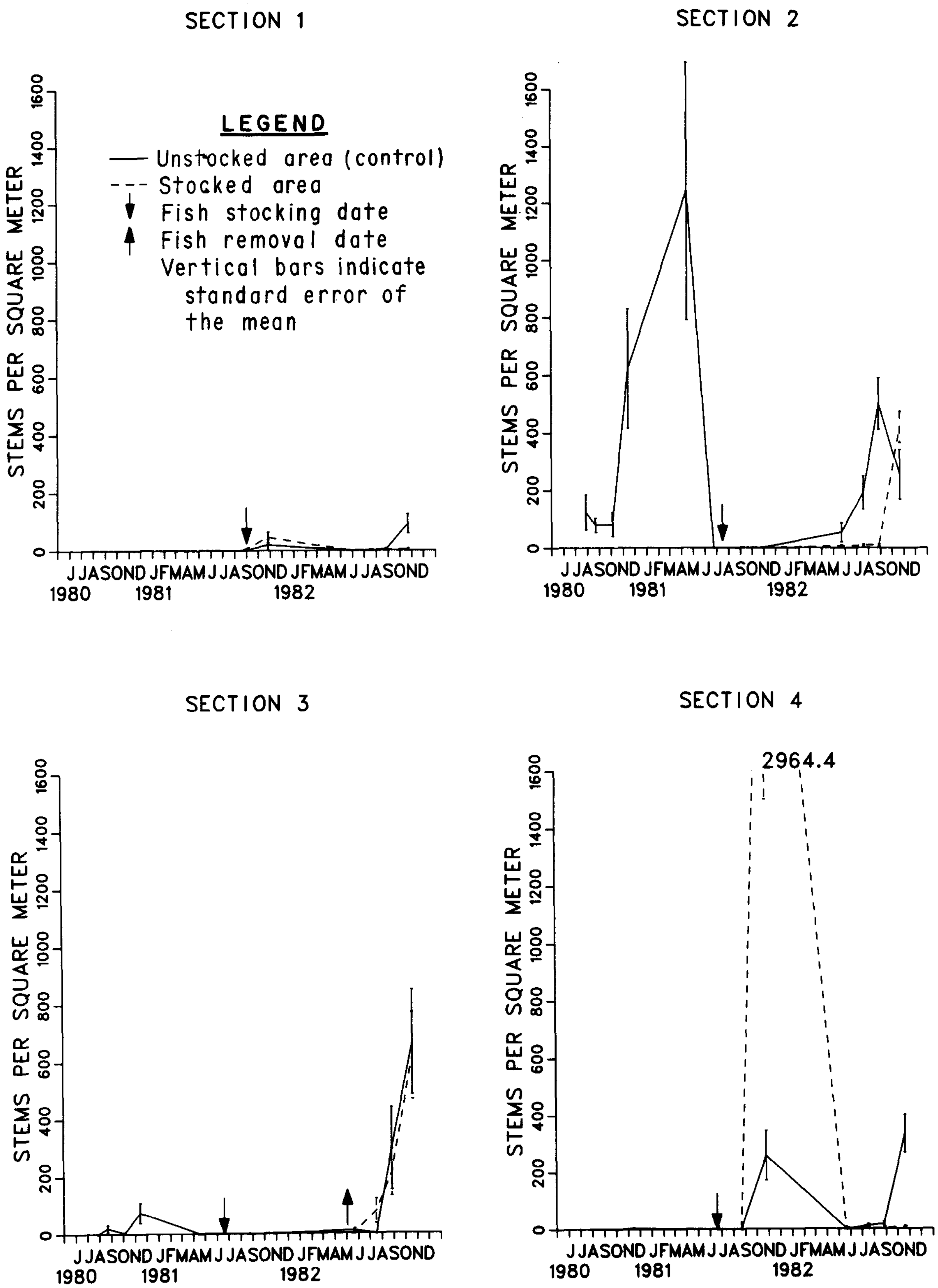

Figure 20. – Mean stem density (stems/m²) of hydrilla in the four test sections of Wormwood Lateral 3.

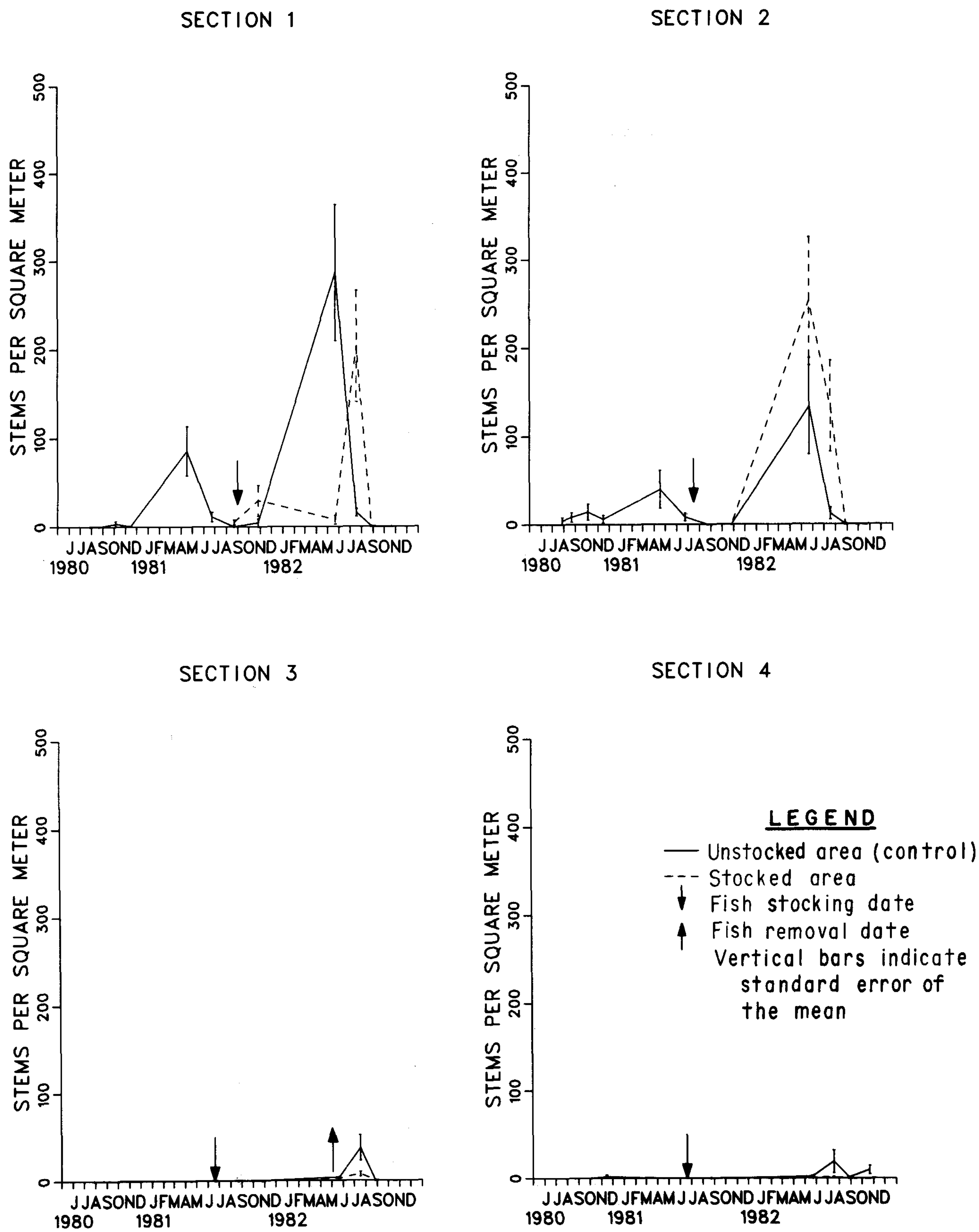

Figure 21. – Mean stem density (stems/m²) of Eurasian watermilfoil in the four test sections of Wormwood Lateral 3.

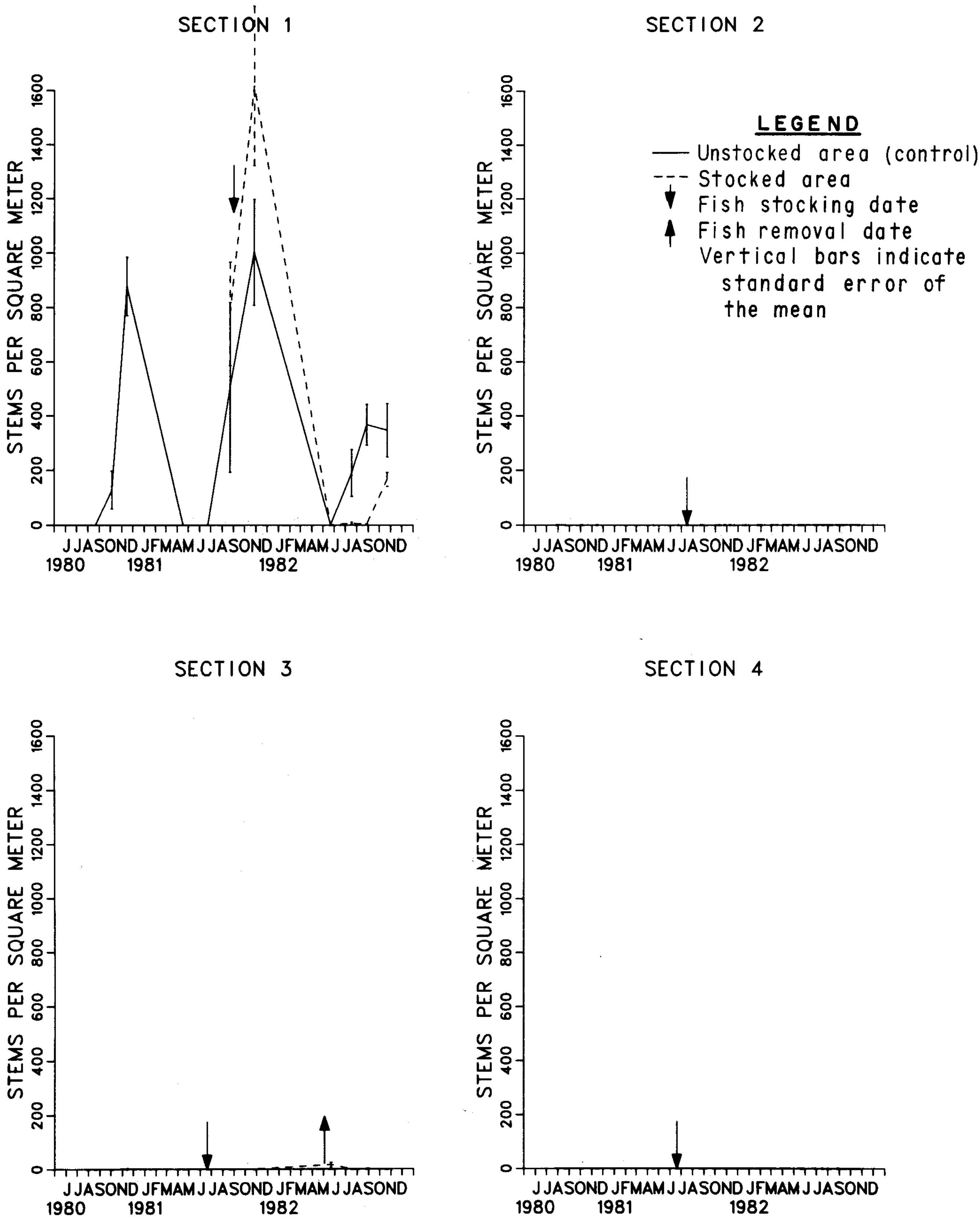

Figure 22. – Mean stem density (stems/m²) of sago pondweed in the four test sections of Wormwood Lateral 3.

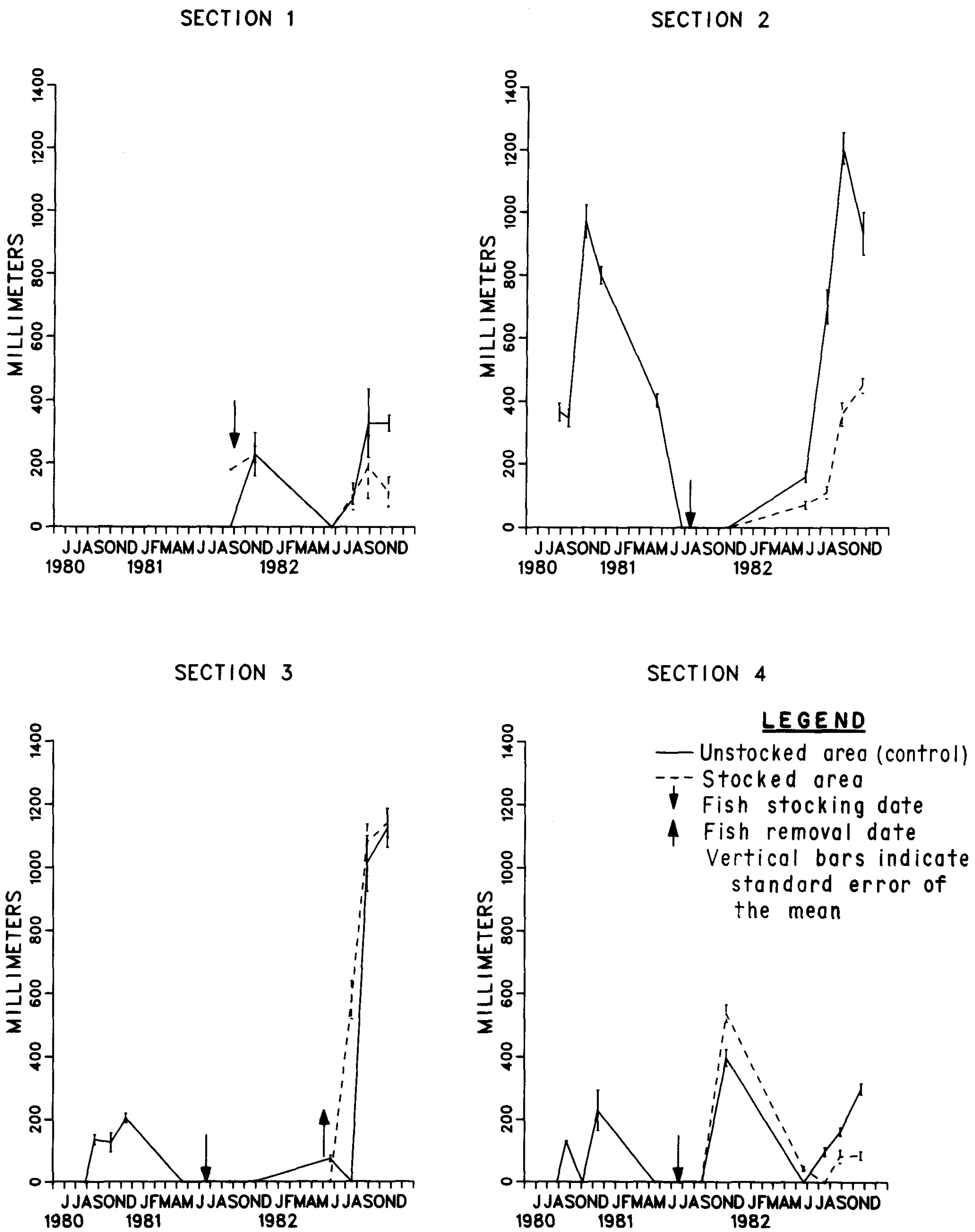

Figure 23. – Mean stem length (mm) of hydrilla in the four test sections of Wormwood Lateral 3.

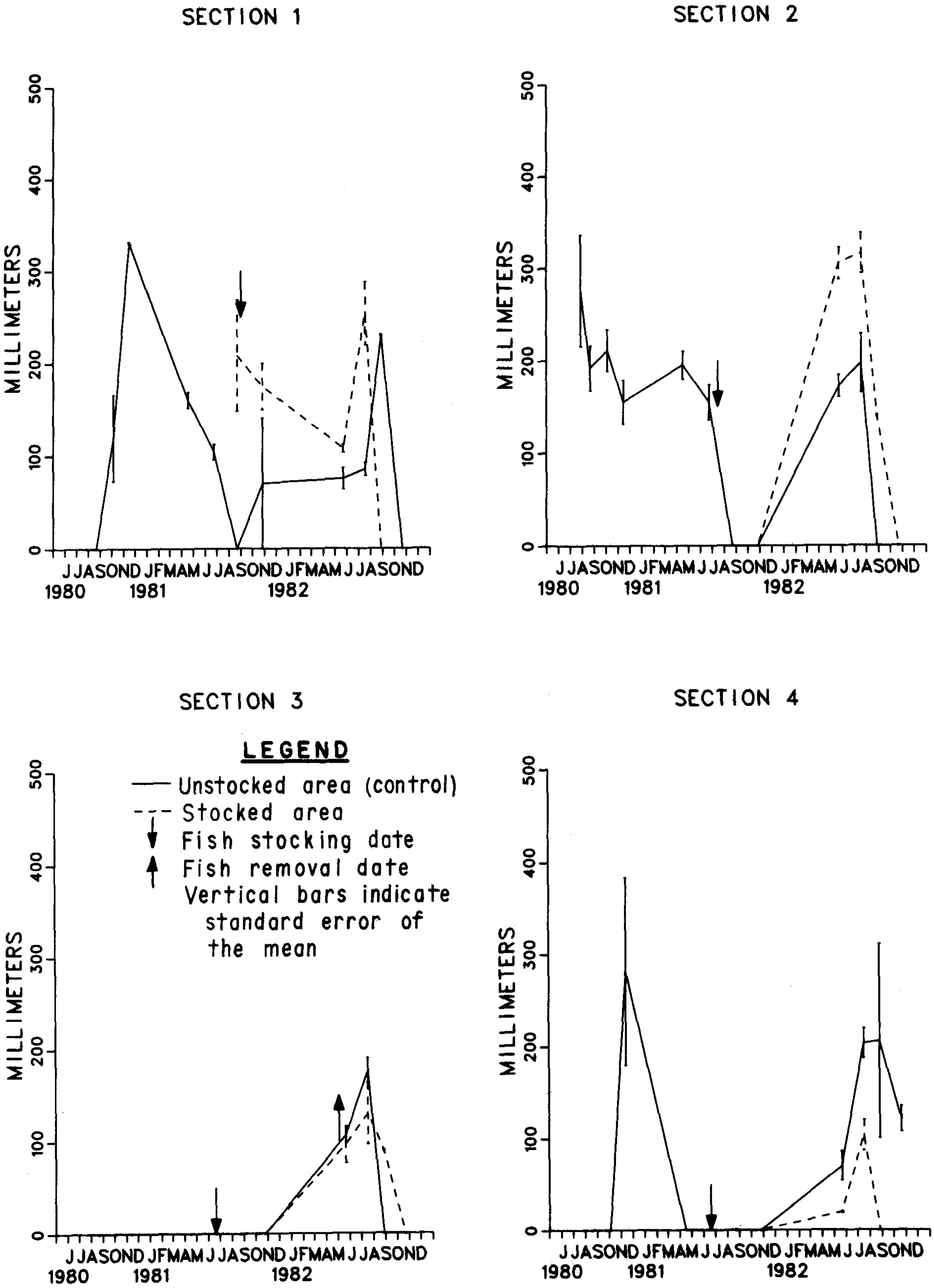

Figure 24. – Mean stem length (mm) of Eurasian watermilfoil in the four test sections of Wormwood Lateral 3.

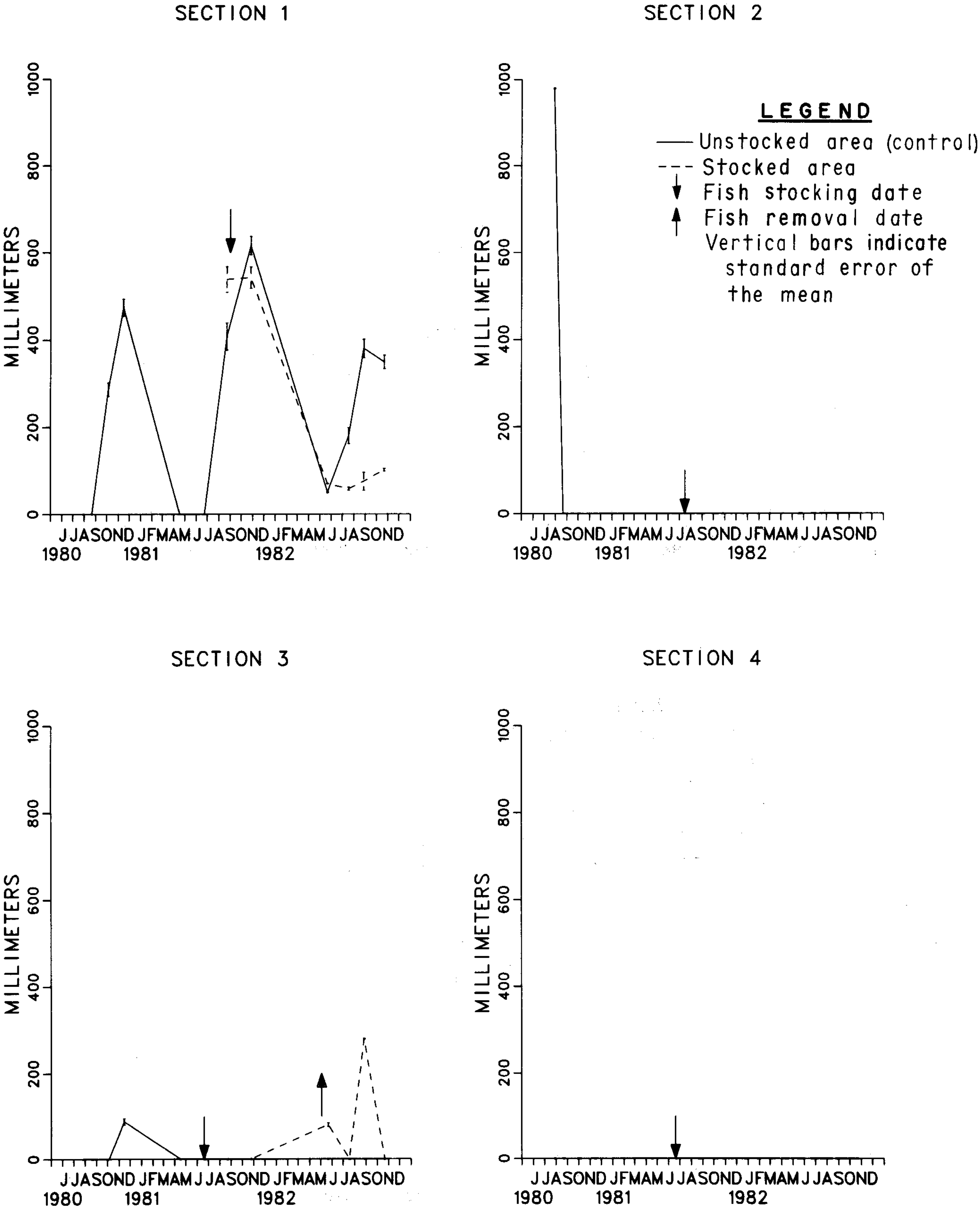

Figure 25. – Mean stem length (mm) of sago pondweed in the four test sections of Wormwood Lateral 3.

before hydrilla growth subsided (personal communication). This indicates the need to increase fish stocking to prevent the rapid increase in stem density.

Watermilfoil seems to follow its own growth pattern regardless of the presence of fish. In the spring of 1982, watermilfoil stems in the treatment area were significantly more numerous and longer than those in the control area, but both declined in the fall. The 1981-1982 data gave no indication that hybrid grass carp controlled watermilfoil in section 2. Only one sago stem was collected in section 2 in July 1980 – no other sago plant was found.

Section 3. – From the time the fish were stocked to the time they were removed from the section, no biomass was collected during sampling, either inside or outside the exclosure. However, by July 1982, macrophytes had begun to reappear. Hydrilla increased dramatically in both density and length through October, both inside and outside the exclosure. The peak in watermilfoil length and stem density occurred in July 1982, followed by a decline similar to its pattern in other sections. Sago grew only outside the exclosure in 1982, where it peaked in May both in number and in length. The second peak shown on figure 25, represents one long stem collected in August.

Section 4. – Hydrilla was planted after the fish had been stocked. By October 1981, hydrilla stem density had increased tremendously outside the exclosure, while average stem length remained similar inside and outside. This may be another example of the influence fish feeding has on apical dominance. That winter, the hydrilla declined inside and outside the exclosure, but began reoccurring in the control area in July 1982. The typical peak occurred in the control in October. This peak was significantly greater than that for the density or the length in the stocked area. Watermilfoil had a small density in 1982, but the average lengths were significantly less in the stocked areas than in the control. The efficacy of the hybrid grass carp was good in section 4 in 1982. No sago was collected in section 4.

Macrophyte Tuber Density

Tuber production varied considerably among the sections, as did macrophyte production. Hydrilla tubers were more numerous in sections 2, 3, and 4, while sago tubers were more numerous in section 1. In general, actively growing stands of plant material are required to produce significant numbers of tubers, which are generally produced in the fall as starch reserves are mobilized and temperature and hours of daylight decrease [23]. No hydrilla turions were observed in Wormwood Lateral 3.

Section 1. – Hydrilla biomass was low in section 1, as was tuber density (fig. 26). However, tuber density was greater in the treatment area after the fish were stocked, indicating a possible relationship to the formation of overwintering structures. Sago tubers in this section were far more numerous outside the exclosure, except in May 1982 (fig. 27). The peak of sago tuber density in the control area in May, is not typical for tuber production, because very little sago vegetation existed at that time. These tubers were probably produced during the previous fall, and were not collected; therefore they went undetected in the March sampling. Fall is generally when macrophytes produce tubers for overwintering [23 through 26], and in 1980 and 1981, sago tubers followed the normal pattern.

Section 2. – Hydrilla tuber production rose in November 1980, in the typical fall pattern, after the rise in biomass. Maximum tuber density recorded in April 1981, probably had been produced the preceding fall and had not yet germinated. Denver laboratory studies have shown a direct relationship between hydrilla tuber germination and warmer temperatures [27]. The decrease in tuber density in June 1981, was probably caused by the germination of the crop from the previous fall. The large increase in tuber density in August 1981, was possibly an outlier resulting from patchy tuber distributions (especially because there was no hydrilla biomass at that time). By October, tuber density had decreased to 15 and 20 tubers/m^2 inside and outside the exclosure, respectively. The following year more tubers were produced in the treatment area even though there was more hydrilla biomass in the control.

Section 3. – No hydrilla tubers were collected in section 3 in 1980 or 1981. A few tubers occurred in May 1982, in the treatment area, after the fish were removed. In October 1982, following the sharp rise in biomass, tubers were formed both inside and outside the exclosure. A few sago tubers were collected within the 3-year study in section 3, but their density was very small.

Section 4. – Hydrilla tubers were collected during the first sampling date of May 1980, which indicated the presence of a good hydrilla stand in the past. This corroborated the findings of Haller [24] on the persistence of tubers. Section 4 displayed the typical pattern of tuber production as the tubers decreased in June, and increased again in the fall. After hybrid grass carp stocking, especially after the planting experiment, tuber density rose sharply in the treatment area. It also increased in the control area but only to approximately one-third of the density in the treatment area. This difference was significant in July and October. Tuber reserves greatly increase the potential for future aquatic plant stands, and it is likely that

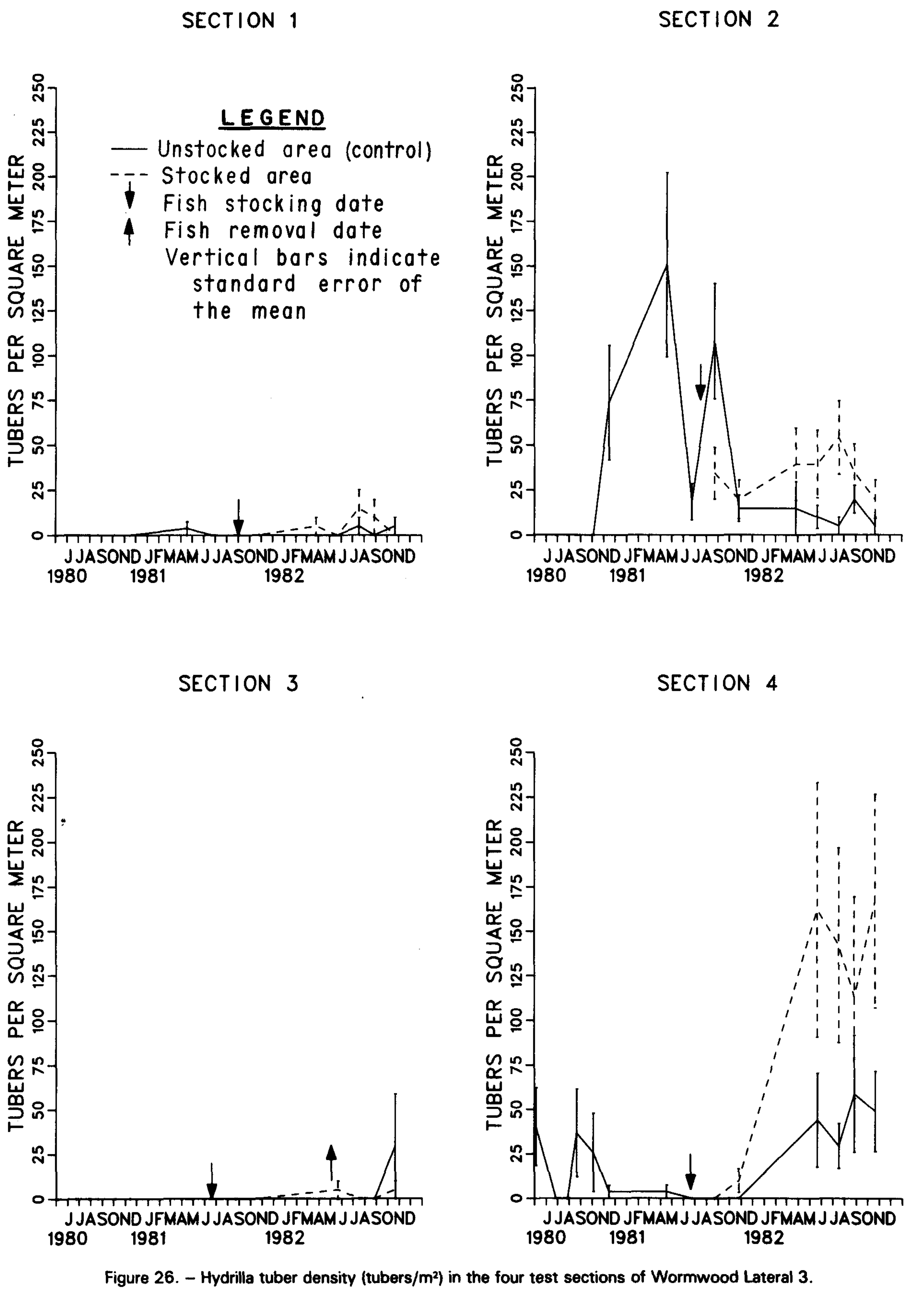

Figure 26. – Hydrilla tuber density (tubers/m²) in the four test sections of Wormwood Lateral 3.

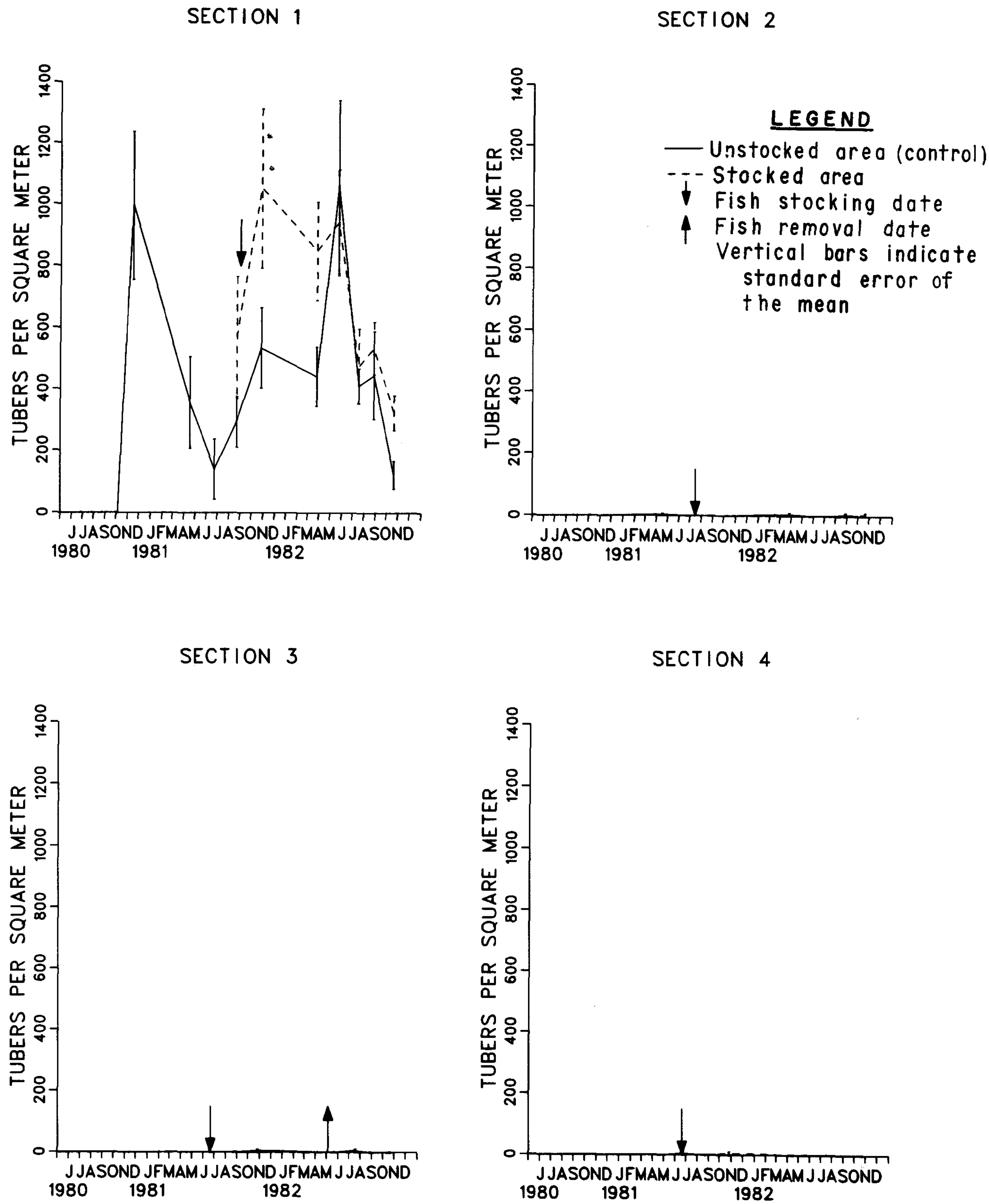

Figure 27. – Sago pondweed tuber density (tubers/m²) in the four test sections of Wormwood Lateral 3.

there will be a large hydrilla stand in section 4 in the future. Sago produced very few tubers in section 4 during the 3-year study.

Water Temperature

Daily water temperatures were recorded at the heading and at the terminal spill of Wormwood Lateral 3, from July 17, 1980, through January 3, 1983 (fig. 18). The high water temperatures of each season occurred during July and August; i.e., 35 °C. Increases in plant biomass usually followed these high-temperature periods (fig. 13), then declined after the cooler temperatures of about 10 °C during January and February. The water temperature followed seasonal air temperature trends. Water-quality samples were collected from the test sections and were reported by Beaty et al. [1, 2, 3].

Soil Composition

Soil classification samples were collected from each test section in November 1980, and analyzed. The soil in sections 1, 3, and 4 contained high percentages of fine material and low percentages of organic material (table 5). Because of the variation in plant communities between the upper and lower ends of section 2, soil was analyzed from each of these areas. The soil from the upper end contained 56 percent fine particles, while the soil from the lower end contained 75 percent fine particles. The percentage of organic material was similar at both ends. This type of soil analysis does not demonstrate an obvious relationship between soil structure and the occurrence of dense macrophyte communities. The two largest plant communities occurred in one area where the soil contained the highest percentage of fine particles (97 percent) and in another area with one of the lowest percentages of fine particles (75 percent).

Summary

Hybrid grass carp stocked late in the 1981 growing season were not effective in controlling the macrophytes in Wormwood Lateral 3 for that year. Percent

Table 5. – Soil analysis[1] of Wormwood Lateral 3 in the hybrid grass carp study sections.

Sites	Gradiation analysis[2] percent	Soil classification[2]	Loss on ignition[3] percent organic material
Section 1	0 gravel 3 sand 97 fine	Lean clay	2.4
Section 2, Upper	0 gravel 44 sand 56 fine	Lean silt	1.3
Section 2, Lower	0 gravel 25 sand 75 fine	Lean silt	1.8
Section 3	0 gravel 7 sand 93 fine	Lean silty clay	2.7
Section 4, Upper	0 gravel 18 sand 82 fine	Lean silt	2.0
Section 4, Lower	0 gravel 9 sand 91 fine	Lean silty clay	2.5

[1] Analyzed by the Soil Testing Laboratory, Geotechnical Branch, USBR, E&R Center, Denver, Colorado.
[2] Procedures and nomenclature are in accordance with the *Earth Manual* 2d ed., USBR 1974.
[3] Samples were dried in a muffle furnace at 550 °C for 2 hours, according to standard American Society for Testing and Materials procedures.

coverage, biomass, and stem density were significantly higher in the stocked areas than the control areas in sections 1 and 4; virtually no plants occurred in sections 2 and 3 throughout 1981. The only evidence of fish feeding during 1981 was in October, in section 1, when significantly shorter sago pondweed stems were noted.

In 1982, the hybrid grass carp effectively controlled hydrilla and sago pondweed in sections 1 and 4. In section 1, hydrilla and sago were controlled after a large amount of macrophyte biomass was mechanically removed from the unevaluated side of the canal. Section 4 macrophytes were effectively controlled throughout 1982. The fish very effectively controlled hydrilla in section 2, during July and August 1982. By October, however, measurement of hydrilla biomass, coverage, and stem density no longer indicated control. Stem density, in particular, increased dramatically, probably encouraged by the fish feeding. The hybrid grass carp were then unable to maintain control of the still rapidly increasing biomass in the cooler water.

The effects of the exclosure on plant growth under controlled conditions were observed in the spring of 1982, when fish were removed from section 3. Data collected in 1982, indicate that macrophyte growth in the exclosure was similar to that of outside areas.

In general, 1982 hydrilla tuber production in sections 2 and 4 was greater in areas stocked with hybrid grass carp, where hydrilla biomass had been suppressed by grazing, than in corresponding control areas. (fig. 26). Whether or not this trend reflects a physiological response of hydrilla to fish feeding to induce a greater rate of tuber formation is not known and requires further study. No apparent seasonal change in tuber formation resulted from fish grazing. Section 1 sago pondweed tuber density followed a pattern similar to that of the hydrilla tuber density in sections 2 and 4. However, the sago tuber density pattern was not as well defined as the hydrilla tuber density pattern and may have resulted from higher plant biomass and tuber density at the time of stocking.

The hybrid grass carp displayed little evidence of Eurasian watermilfoil control in sections 1 and 2, throughout 1982. Instead, the data reveal a typical growth pattern of Eurasian watermilfoil reaching its seasonal peak during July, then declining in August. An exception to this was seen in section 4, where the fish controlled Eurasian watermilfoil, although its coverage was low. From food-preference studies, it was learned that hybrid grass carp consume Eurasian watermilfoil only when preferred food species were unavailble [12].

Figure 28. – Land forms of Eurasian watermilfoil developed shortly after the maintenance drawdown of the Coachella Canal in November 1980.

COACHELLA CANAL

Factors Affecting Vegetation Distribution

Eurasian watermilfoil was the most frequently encountered macrophyte in the Coachella Canal study areas. It was found growing along the side slopes of the canal from the waterline to the base and, on rare occasions, along the canal bottom. In these cases, the plants appeared as small fragments lodged in bottom debris, such as brush or rocks. No significant stands of vegetation were found growing on the bottom of the Coachella Canal.

Apparently, the primary mechanism that affects distribution and abundance of Eurasian watermilfoil in this canal system is fragmentation. No flowering or consequent seed production was observed during the course of the study. The fragmentation of Eurasian watermilfoil falls into two categories: autofragmentation and mechanical fragmentation. Eurasian watermilfoil undergo periods of autofragmentation naturally. In the early spring, axillary shoots, which seem specialized to fulfill the fragmentation process, easily detach from their parent plant. During the growing season, these abscissing fragments often develop roots at the nodes before separating [28]. The second mechanism of fragmentation in irrigation

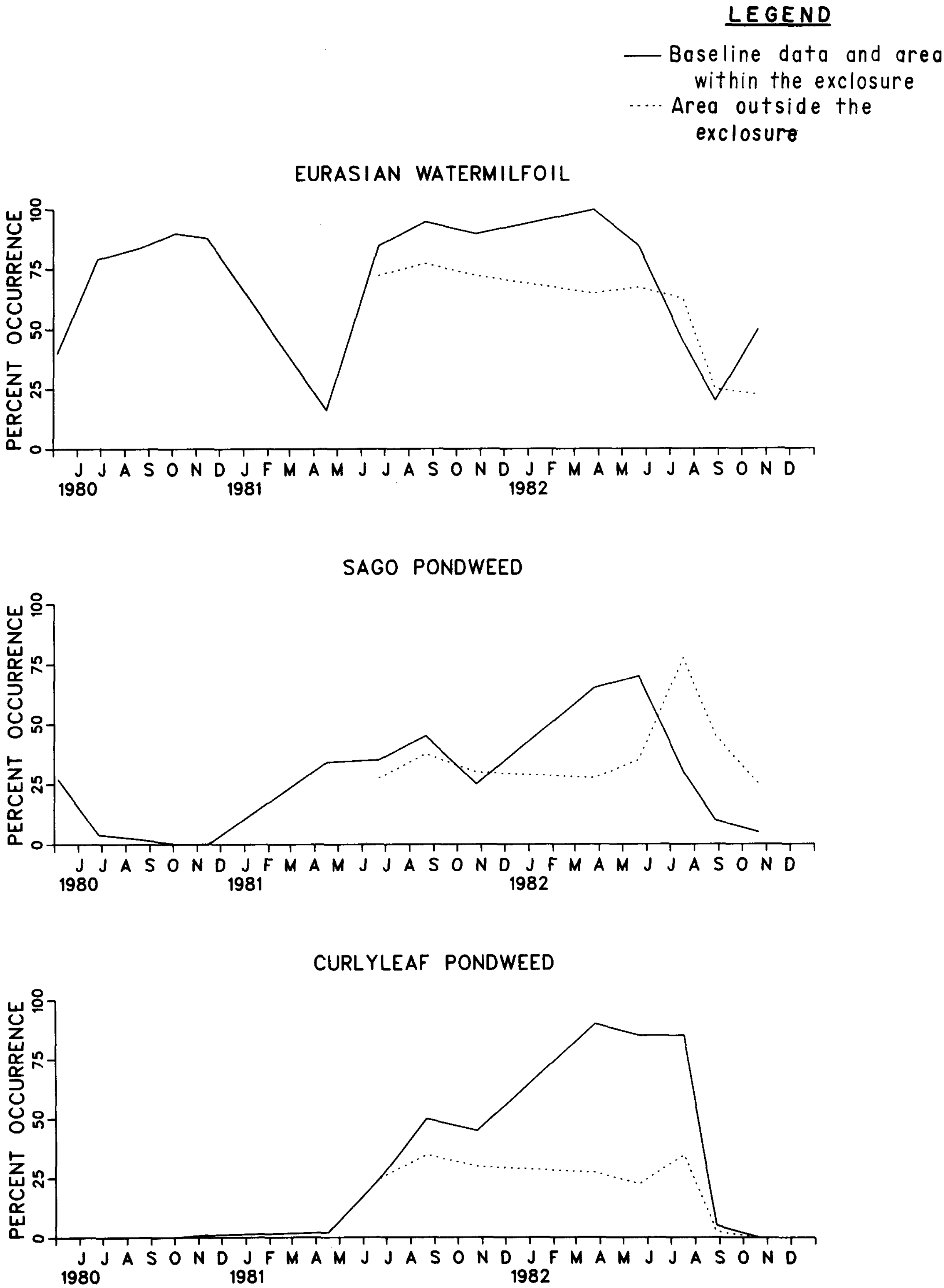

Figure 29. – Percent occurrence of macrophytes in reach 26 (unstocked) of the Coachella Canal.

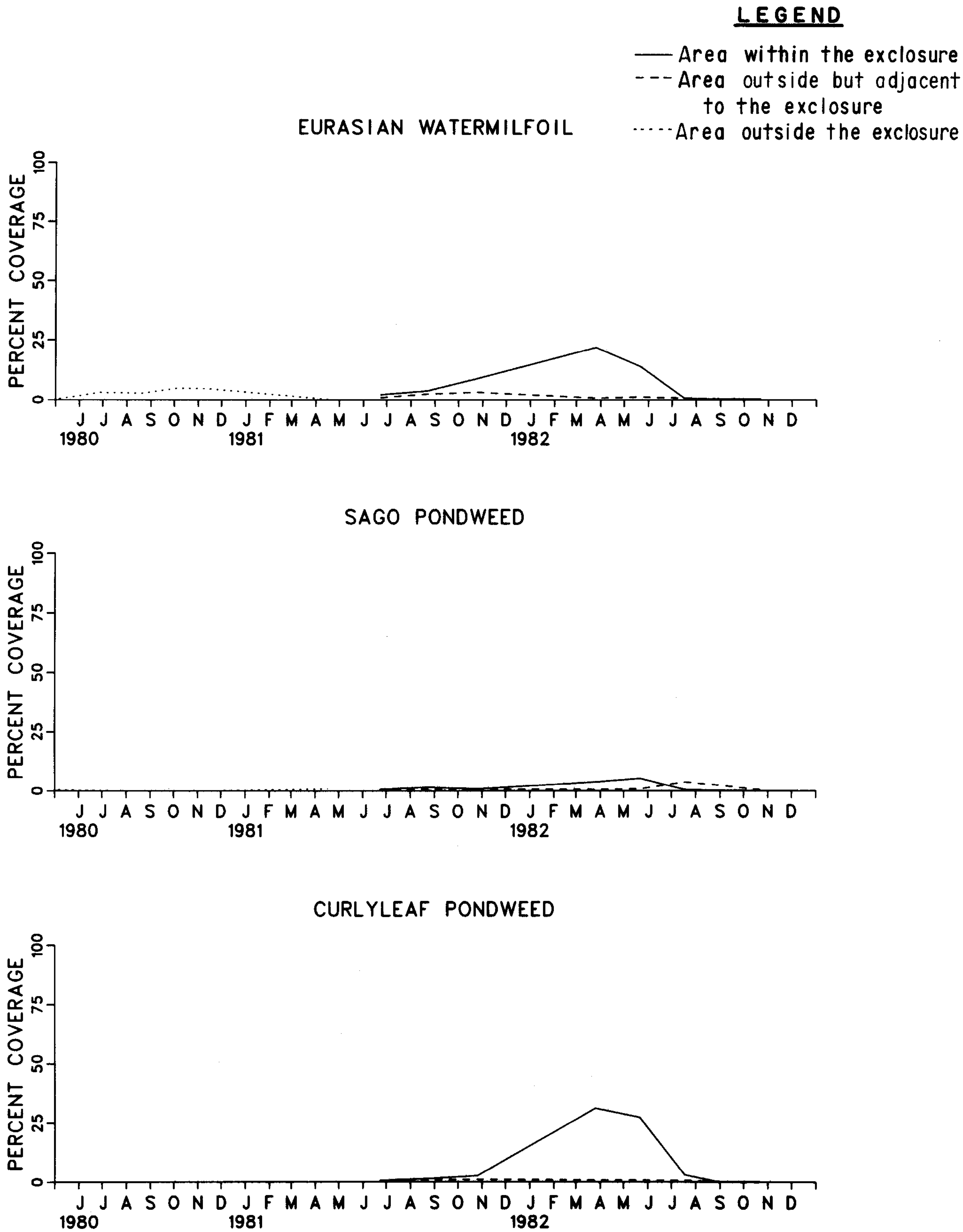

Figure 30. – Percent coverage of macrophytes in reach 26 (unstocked) of the Coachella Canal.

systems is mechanical breakage. Several agents in the canal system can contribute to this process. These agents include mechanical or dredging activities, which are routinely conducted by water districts to clear structures or waterways of vegetation and debris. Water level fluctuations and currents also may cause mechanical fragmentation. The annual introduction of the herbivorous fish, *Tilapia spp.*, into irrigation systems for weed control almost certainly increases fragmentation, through the foraging or nest-building activities of that fish.

Fragmentation was observed in May, and continued throughout the growing season following a pattern similar to that reported by Aiken, Newroth, and Wile [29]. Throughout the growing season numerous fragments were seen drifting in the current with roots already beginning to develop. Although the fragment drift was most obvious when observed on the surface, fragments were also observed at all depths during the scuba-diving activities. Rooting of the fragments in the substrate was most successful where there was some form of debris to snag the fragment and offer shelter from the currents. Fragments were especially plentiful along areas where bermuda grass stolons extended into the water, trapping many of the small, drifting plants.

The primary means by which the numbers of Eurasian watermilfoil plants increased along the mapping transects may be attributed to colonization by fragments. Once established, the spread of the plants along the side slopes of the bank was enhanced by the current flow. Elongated stems were continuously silted over. Excavation of these buried stems revealed old leaf material, extending as much as several meters upstream, still attached to the stem. Along these buried stems, rooted nodes developed axillary shoots, which formed numerous secondary plant groups.

Another survival mechanism of the Eurasian watermilfoil was observed during the November 1980 drawdown of the Coachella Canal. During this period, Eurasian watermilfoil stands were stranded and exposed. Numerous land forms were seen developing from the terminal buds of the stems. Land forms are growth forms of Eurasian watermilfoil specialized for survival in such periods of exposure. Leaves of these land forms are thickened and greatly reduced, and roots develop at points where the stems contact the substrate (fig. 28).

Qualitative Rating – Vegetation Distribution Surveys

Percent Occurrence and Percent Coverage of Macrophytes

Reach 26. – The number of times Eurasian watermilfoil was found in the sampling areas in reach 26 in 1980, was quite high, beginning at 40 percent of the time in May, to 76 percent in October. However, before comparing percent occurrence with percent coverage, it should be noted that they convey quite different information (figs. 29 and 30). Percent-occurrence data indicate the declines or increases in the number of plants, but do not adequately indicate the amount of plant material, which is much more accurately described by percent coverage. Little or no plant coverage does not mean little or no occurrence; however, little or no occurrence definitely means no coverage. In 1980, very little plant material grew in section 26, but by October, over 75 percent of all quadrats contained at least one watermilfoil stem. Sago pondweed occurred in May 1980, but neither sago nor curlyleaf pondweed covered any measureable area throughout that year.

Early in 1981, watermilfoil had low occurrence and low coverage. The occurrence had increased dramatically by June, but the coverage did not. This was also true for sago and curlyleaf pondweed. For the three species, occurrence and coverage was less outside the exclosure than inside; however, no hybrid grass carp were stocked in this section. Reach 26 therefore served as the exclosure control to determine the effects, if any, of the exclosure on the growth of aquatic weeds. These data indicated that the exclosure provided a more suitable habitat for plant growth in 1981.

The year 1982 began with the highest percent coverage for the three years, for each of the three species in the exclosure. However, by July, percent coverage had decreased to low values, and by August, percent occurrence had followed. Coverage outside the exclosures was minimal throughout the year, irrespective of the relatively high percent-occurrence values. The general trend of macrophyte growth enhancement within the exclosure in 1981, and in the beginning of 1982, was apparently caused by the exclosure structure, which reduced current velocities to a level more suitable for plant growth. The decline of vegetative biomass, length, and density in the exclosure after July 1982, may have been caused by openings in the exclosure fabric, which appeared in July, and continued to enlarge. These openings reduced the current flow restriction, and current velocities within the exclosure increased 75 percent. This made growth conditions similar to those of the adjacent areas.

Reach 27. – The development of vegetation in reach 27 during the 1980 growing season demonstrates how rapidly Eurasian watermilfoil can reinfest a stretch of canal after it has been cleared of vegetation (fig. 31). During the winter of 1979 to 1980, propagating root crowns were removed in dredging operations throughout reach 27. Therefore, this reach

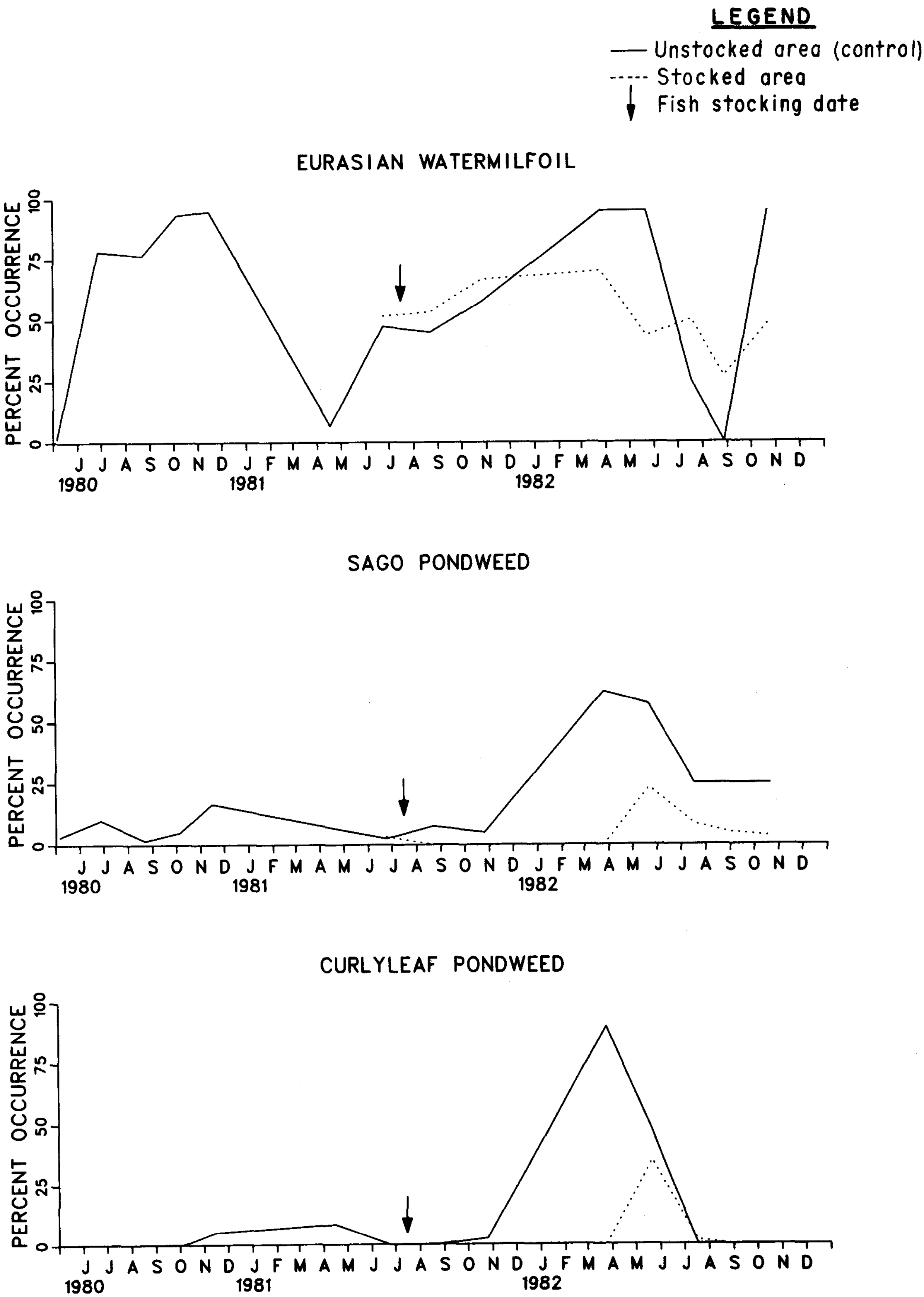

Figure 31. – Percent occurrence of macrophytes in reach 27 of the Coachella Canal.

was essentially in a state of recolonization during the 1980 growing season. Over the growing season of 1980, the number of mapping quadrats in section 27 containing watermilfoil increased from 2 percent in May, to 95 percent in November. The stands of watermilfoil in reach 26 were quite likely the major source of fragments for this recolonization (fig. 29).

In general, occurrence and coverage curves for watermilfoil, sago pondweed, and curlyleaf pondweed in reach 27 are similar to the corresponding curves for reach 26 (figs. 29, 30, 31, and 32). However, there are two important differences: 1. more plants occurred in reach 26 than in reach 27 in 1981 and, therefore, less area was covered by plants in reach 27; and 2. in July 1982, outside the exclosure, sago pondweed occurred in only 8 percent of the sampling quadrats in reach 27, but in 78 percent of the quadrats in reach 26. This, quite likely, is evidence of fish efficacy in reach 27.

Quantitative Sampling

Macrophyte Biomass

Reach 26. – Despite the disruption of the substrate by mechanical control operations before the study, the average macrophyte dry-weight biomass increased steadily in reach 26, from May to October 1980 (fig. 33). By November, biomass had declined, probably because the canal drawdown desiccated much of the plant material. The typical growth pattern for watermilfoil in Wormwood Lateral 3 was different from the typical pattern for watermilfoil in the Coachella Canal. In the Coachella Canal, watermilfoil usually declined in the fall and not during periods of peak water temperatures.

Reach 27. – In 1980, in reach 27 maximum biomass occurred in October, then declined by November, as it did in reach 26. Biomass was very low through 1981, and remained low outside the exclosure in 1982. The exclosure contained good stands of watermilfoil and curlyleaf pondweed, as evidenced by the percentage-coverage curves and the biomass curves (figs. 32 and 34). Comparing the biomass values of sampling areas inside with those outside the exclosures indicates that the hybrid grass carp effectively controlled the aquatic macrophytes (table 6). However, the biomass levels were not high enough to adequately demonstrate the capability of the fish to control aquatic weeds. Environmental conditions in reaches 26 and 27 differed, making direct comparisons unreliable.

Macrophyte Stem Density and Length

Reach 26. – The predominant species in reach 26, based on stem density, changed each year of this study. In 1980, the species with the highest stem density was Eurasian watermilfoil; in 1981, it was sago pondweed; and in 1982, it was curlyleaf pondweed (figs. 35, 36, and 37). There has been no discernible reason for this change in the predominant species. The watermilfoil density peak occurred in early October 1980; the sago density peak occurred in August 1981; and the curlyleaf density peak occurred in March 1982. This growth is typical for sago and curlyleaf but not for watermilfoil.

The stem lengths of species in the Coachella Canal had definite highs and lows (figs. 38, 39, and 40), probably caused by seasonal growth cycles and water operation management. The canal water level fluctuated with irrigation needs, canal maintenance and construction activities, and the installation of mechanical fishscreens. There were sampling periods when remnants of dead plants were observed where live plants had been during the previous sampling period. This probably resulted from fluctuations in the water level. Because the canal water had been drawn down for construction and maintenance activities, before the November 1980 sampling period, the macrophytes were desiccated. This probably contributed to the drastic decrease in dry biomass (figs. 33 and 34). Generally, macrophyte lengths were shorter outside the exclosure than inside.

Reach 27. – The predominant species in reach 27 during 1980, based on stem density, was watermilfoil. It followed the same growth pattern as the watermilfoil in reach 26 (fig. 35), but at about one-third the average stem density. Stem density for sago and curlyleaf pondweeds was almost zero (figs. 36 and 37).

During 1981, watermilfoil density was very low in the control area (less than 3.5 stems/m^2). The treatment area had a density of 17.1 watermilfoil stems/m^2, which decreased during August and increased again to 16.1 stems/m^2 by October. This pattern followed the watermilfoil growth pattern in Wormwood Lateral 3, which declined during seasonal high water temperatures. Again, sago and curlyleaf densities were very low in 1981, in reach 27.

In 1982, macrophyte density was low in the treatment area, never reaching more than 6.6 stems/m^2. In the control area, watermilfoil had a density of 54.4 stems/m^2 in March, and 70.2 in October 1982. The density dropped to less than 1.0 stem/m^2 in August (again following the Wormwood Lateral 3 growth pattern). Sago and curlyleaf had moderate densities in the control area by March. By May, curlyleaf had declined, but sago maintained its density through the growing season.

Although in reach 26, macrophyte stem length was generally shorter outside the exclosure, in reach 27 watermilfoil was longer, sago was shorter, and cur-

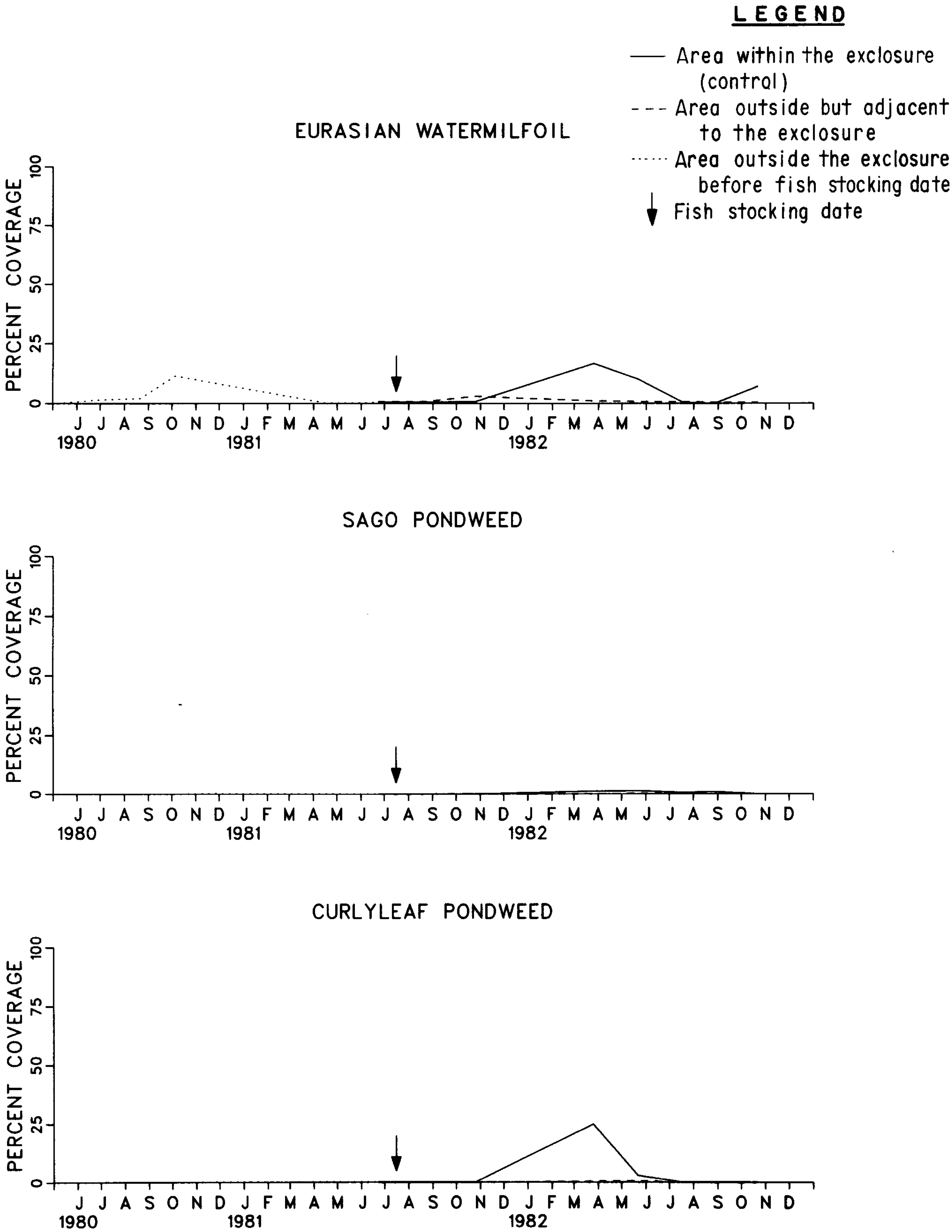

Figure 32. – Percent coverage of macrophytes in reach 27 of the Coachella Canal.

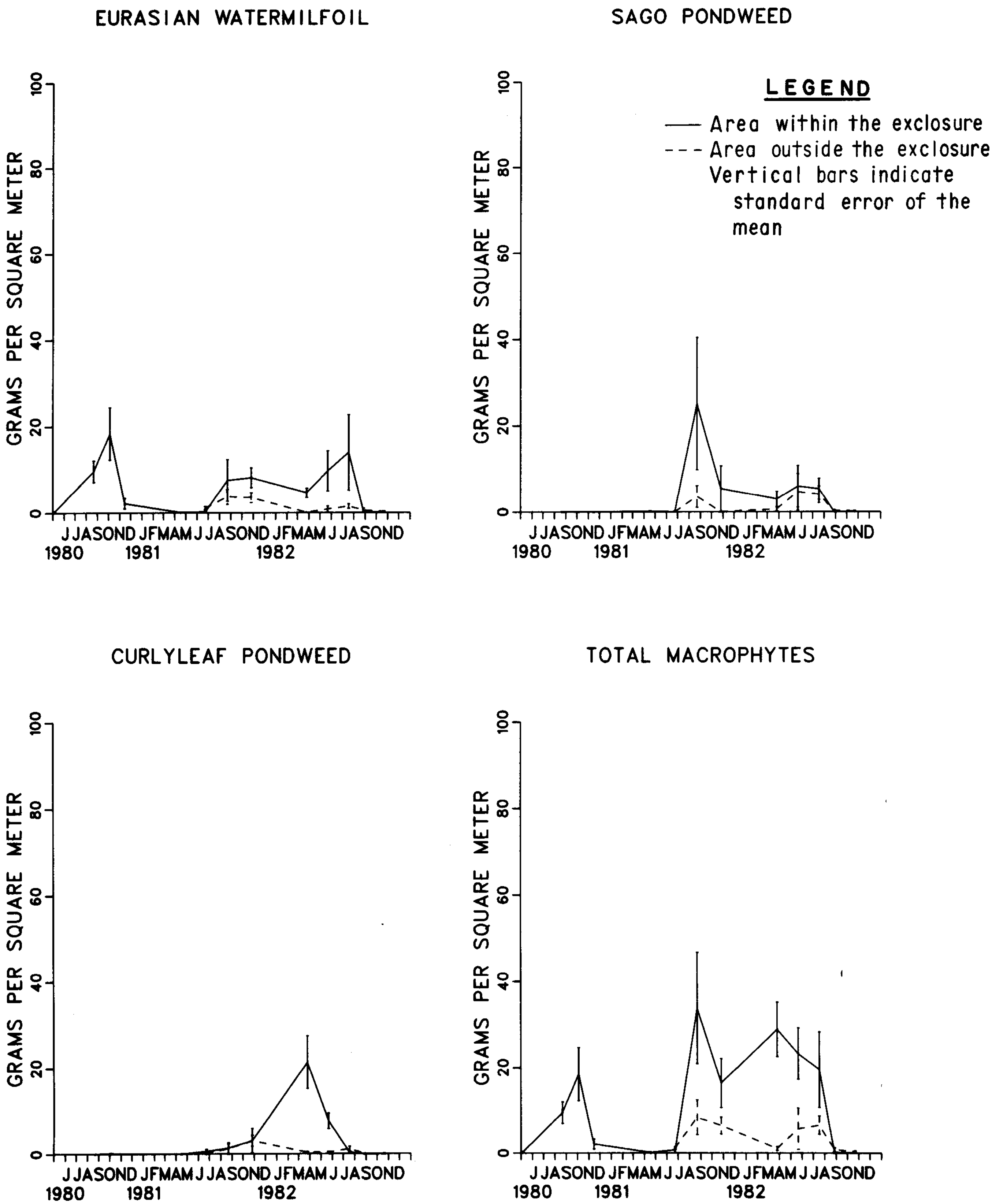

Figure 33. – Dry-weight biomass (g/m²) of macrophytes collected in reach 26 (unstocked) of the Coachella Canal.

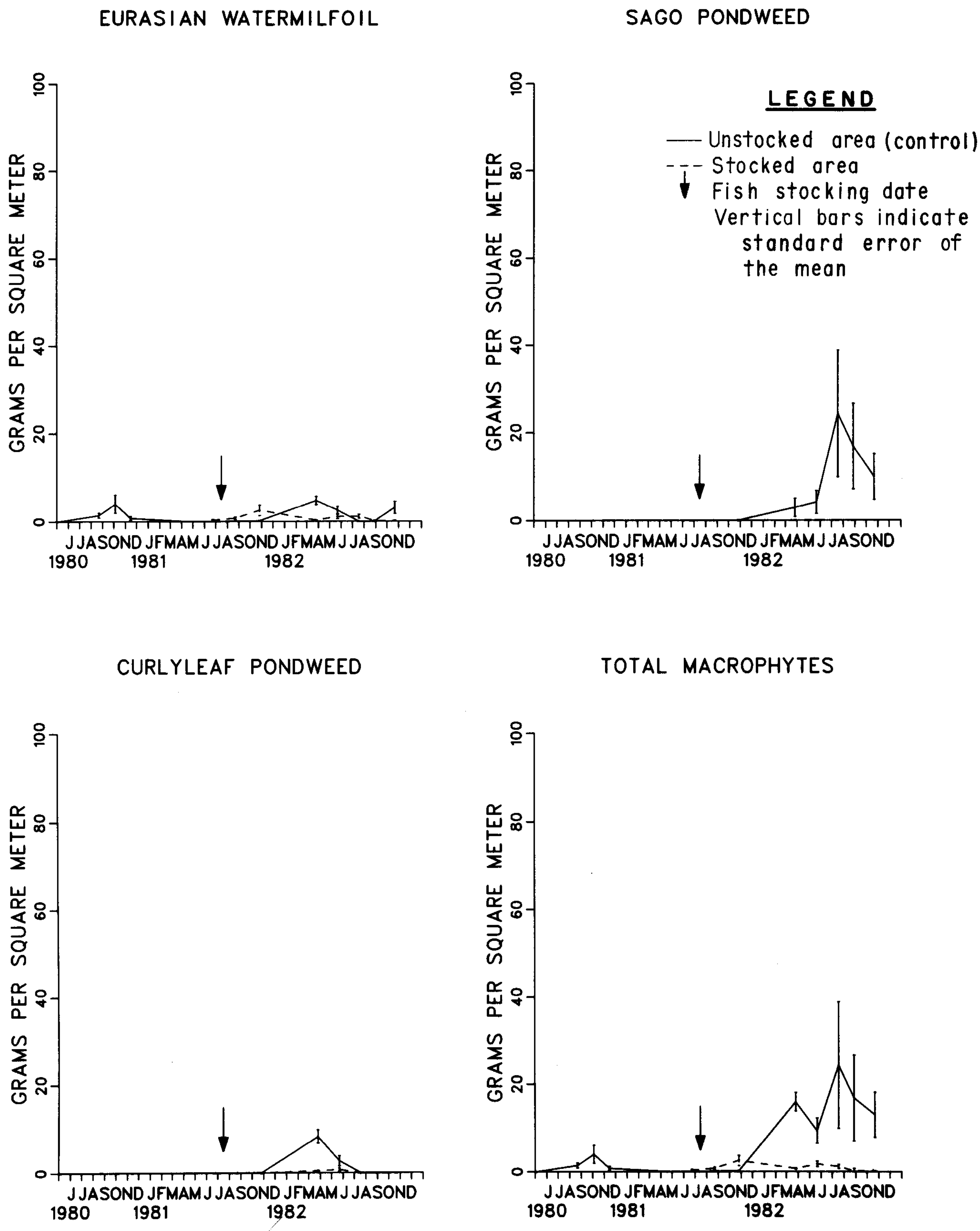

Figure 34. – Dry-weight biomass (g/m²) of macrophytes collected in reach 27 of the Coachella Canal.

Table 6. – Comparison by Student's t-test of dry-weight biomass, stem density, and stem length of macrophytes within the control areas (exclosures) with those in areas stocked with hybrid grass carp in reach 27 of the Coachella Canal.

	Reach 27						
Sampling date	Combined dry weight	Stem density			Stem length		
		Eurasian watermilfoil	Sago pondweed	Curlyleaf pondweed	Eurasian watermilfoil	Sago pondweed	Curlyleaf pondweed
1981							
June 23	–	–	–	–	–	–	–
Aug. 22	*	*	–	–	*	–	–
Oct. 26	–	–	–	–	*	–	–
1982							
Mar. 26	+	+	+	+	–	–	–
May 22	+	+	+	+	+	+	–
July 18	+	*	+	–	*	+	–
Aug. 28	+	–	+	–	*	+	–
Oct. 22	+	+	+	–	–	+	–

– = Not significant[a]
\+ = Significantly greater inside the control[a]
* = Significantly less inside the control[a]

[a] Confidence limits greater than or equal to 95 percent.

lyleaf was the same length outside as inside the exclosure (figs. 38, 39, and 40). The reason watermilfoil was longer may have been that the hybrids preferred the other species [12, 18].

Water Temperatures

Water temperatures, as reported by Beaty et al. [1, 2, 3], peaked during August at about 30 °C and dropped to a low of about 13 °C during February. Water quality samples were collected from the test sections, and the data were reported by Beaty et al.

Soil Composition

Soil samples collected from each test section were analyzed for particle-size distribution and percent organic material (table 7). Particle-size distributions were very similar in each soil sample, and the percent organic matter was consistently low (average of 1.25).

Summary

During the 1981 growing season, the hybrid grass carp stocked in July and September were not effective in controlling the macrophytes in reach 27 of the Coachella Canal.

The data indicate that by 1982 hybrid grass carp were able to control sago pondweed and curlyleaf pondweed in reach 27. The efficacy of the hybrid grass carp was displayed in the percent occurrence, percent coverage, biomass, and stem density of sago and curlyleaf pondweeds, and in the average stem length of sago pondweed. Percent coverage and biomass data from reach 26, the unstocked reach, were very similar to corresponding data collected in reach 27. This similarity indicated the possibility that the reduction of water current velocities within the exclosure structures resulted in a more suitable habitat for plant growth. Fish efficacy determinations for Eurasian watermilfoil were inconclusive.

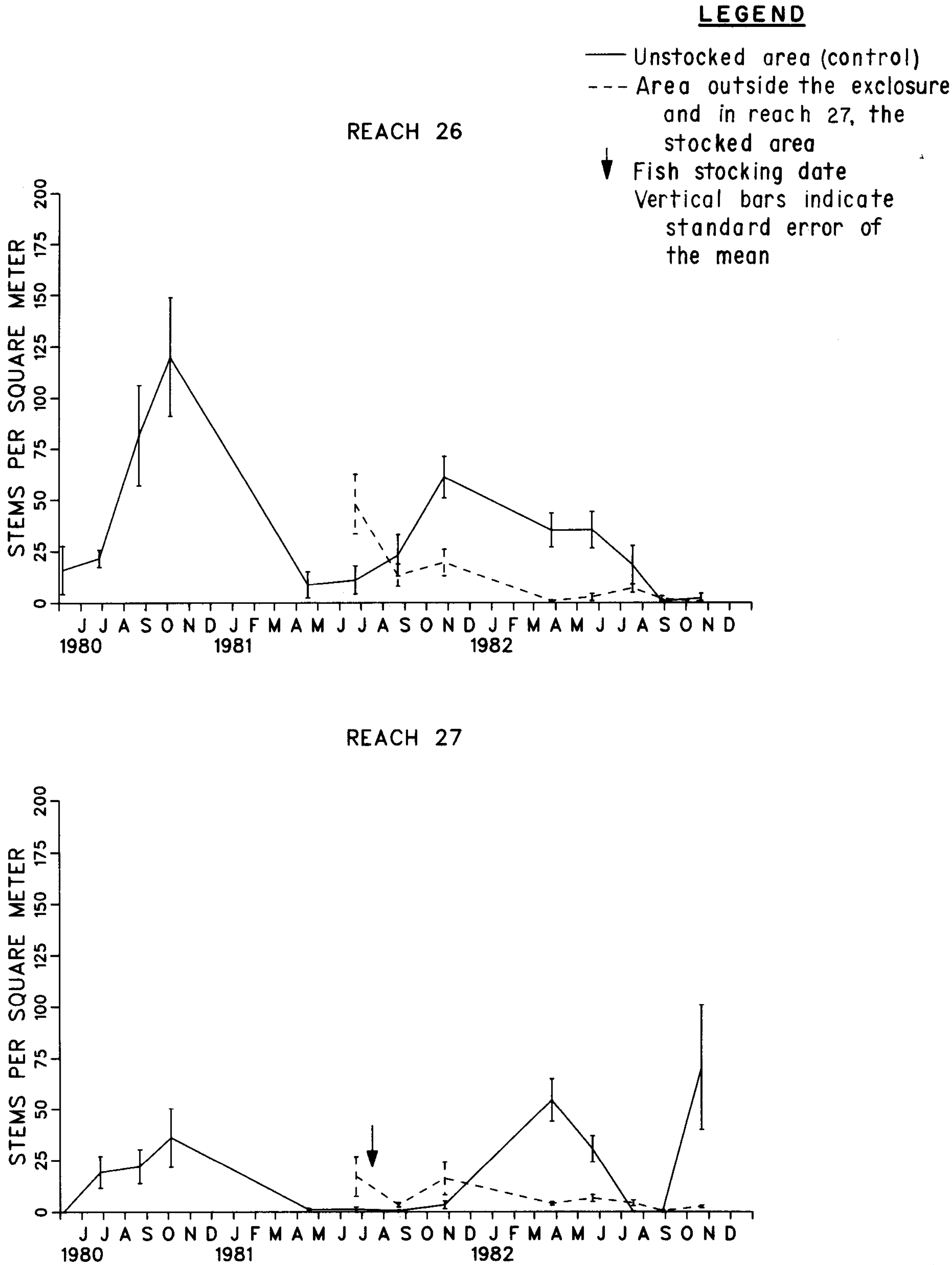

Figure 35. – Mean stem density (stems/m²) of Eurasian watermilfoil in reaches 26 (unstocked) and 27 of the Coachella Canal.

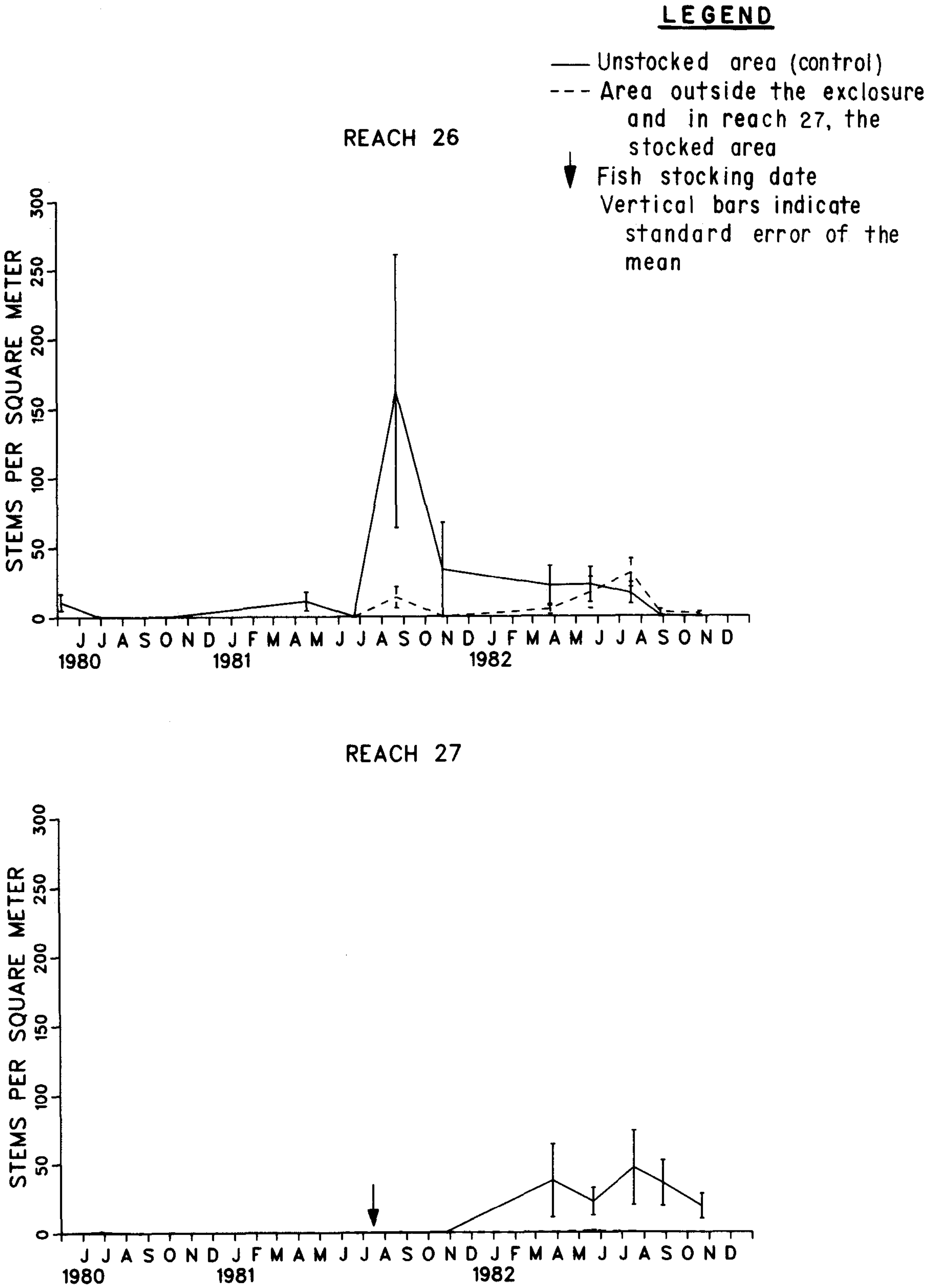

Figure 36. – Mean stem density (stems/m²) of sago pondweed in reaches 26 (unstocked) and 27 of the Coachella Canal.

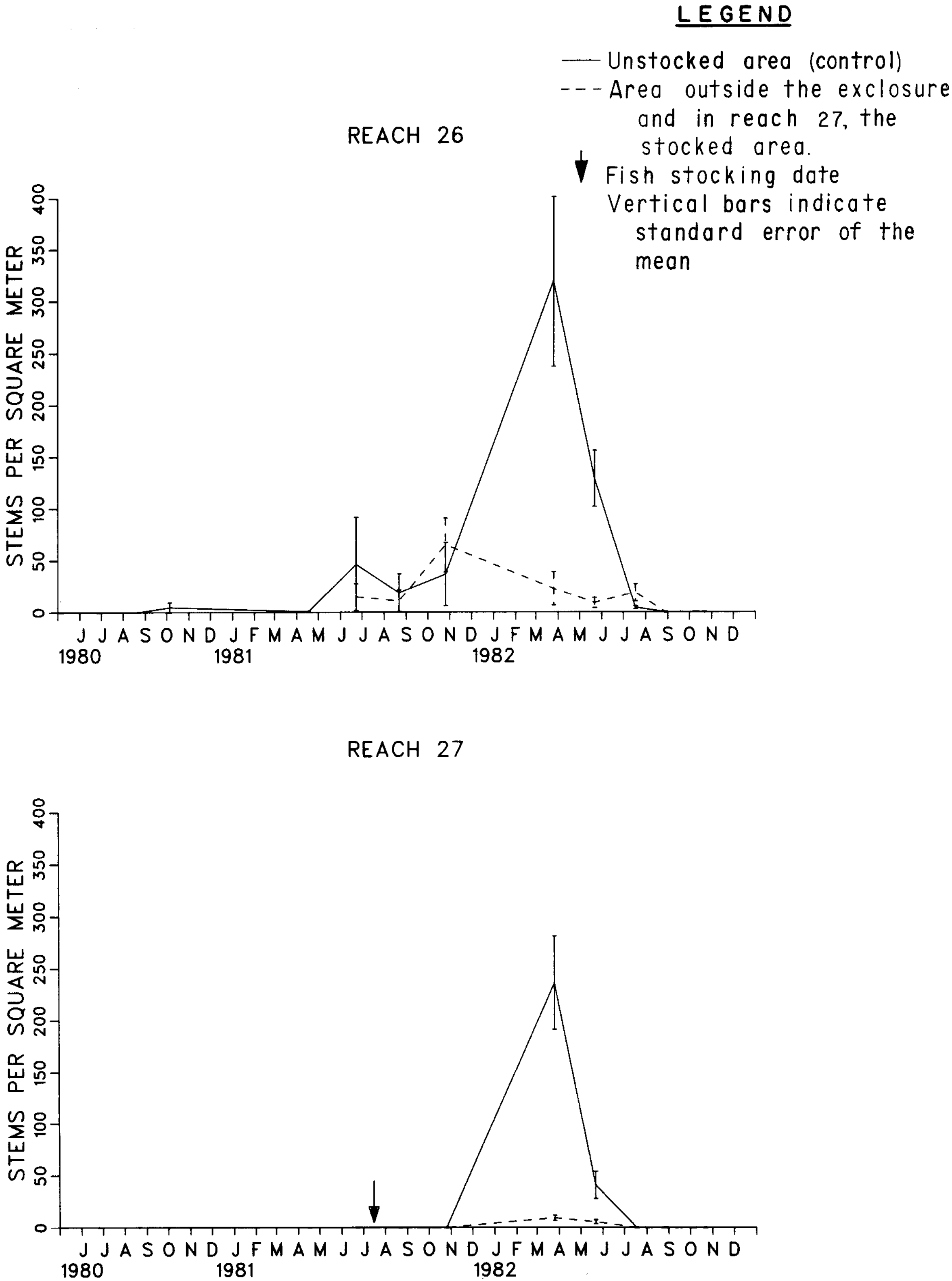

Figure 37. – Mean stem density (stems/m²) of curlyleaf pondweed in reaches 26 (unstocked) and 27 of the Coachella Canal.

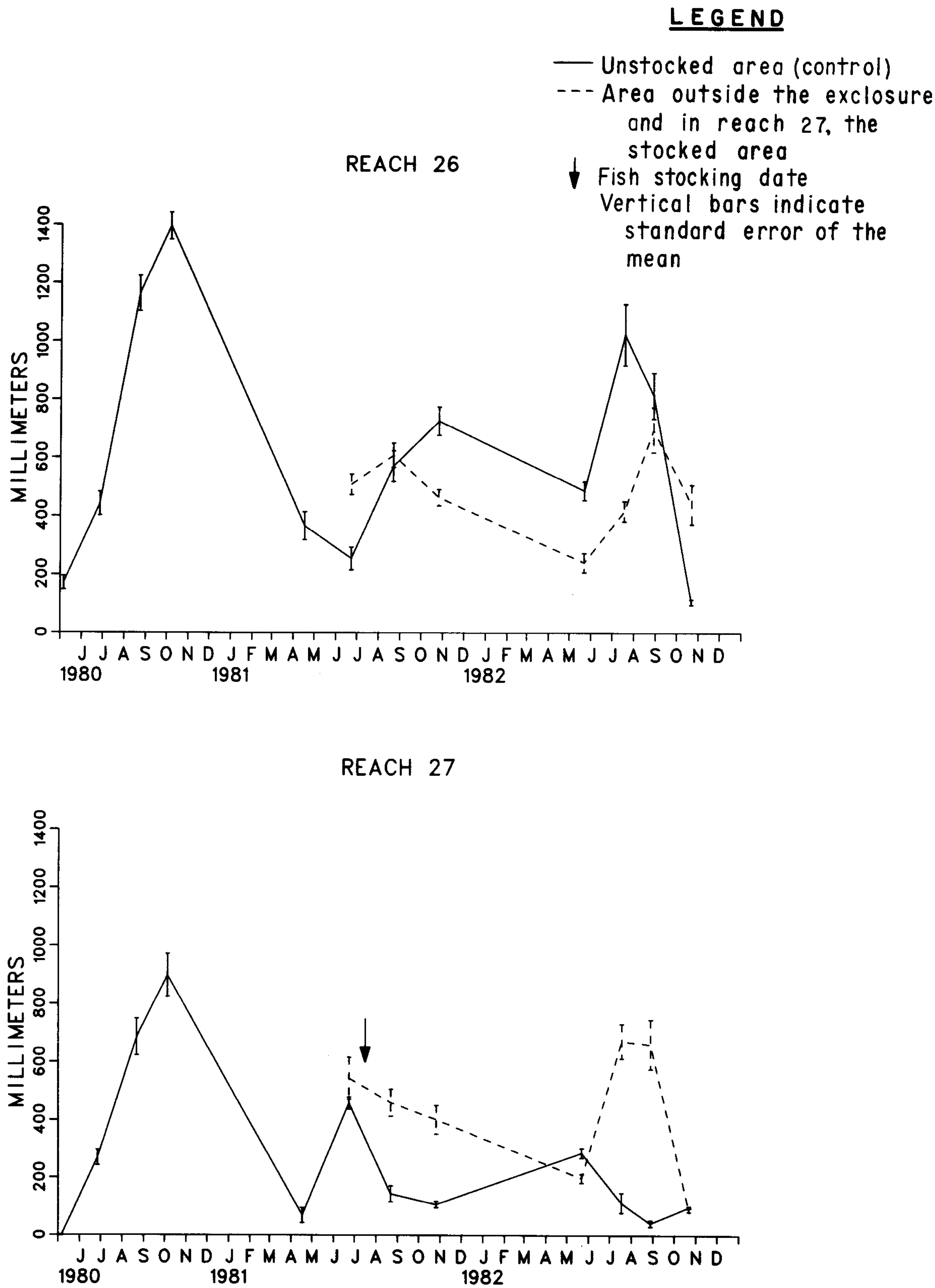

Figure 38. – Mean stem length (mm) of Eurasian watermilfoil in reaches 26 (unstocked) and 27 of the Coachella Canal.

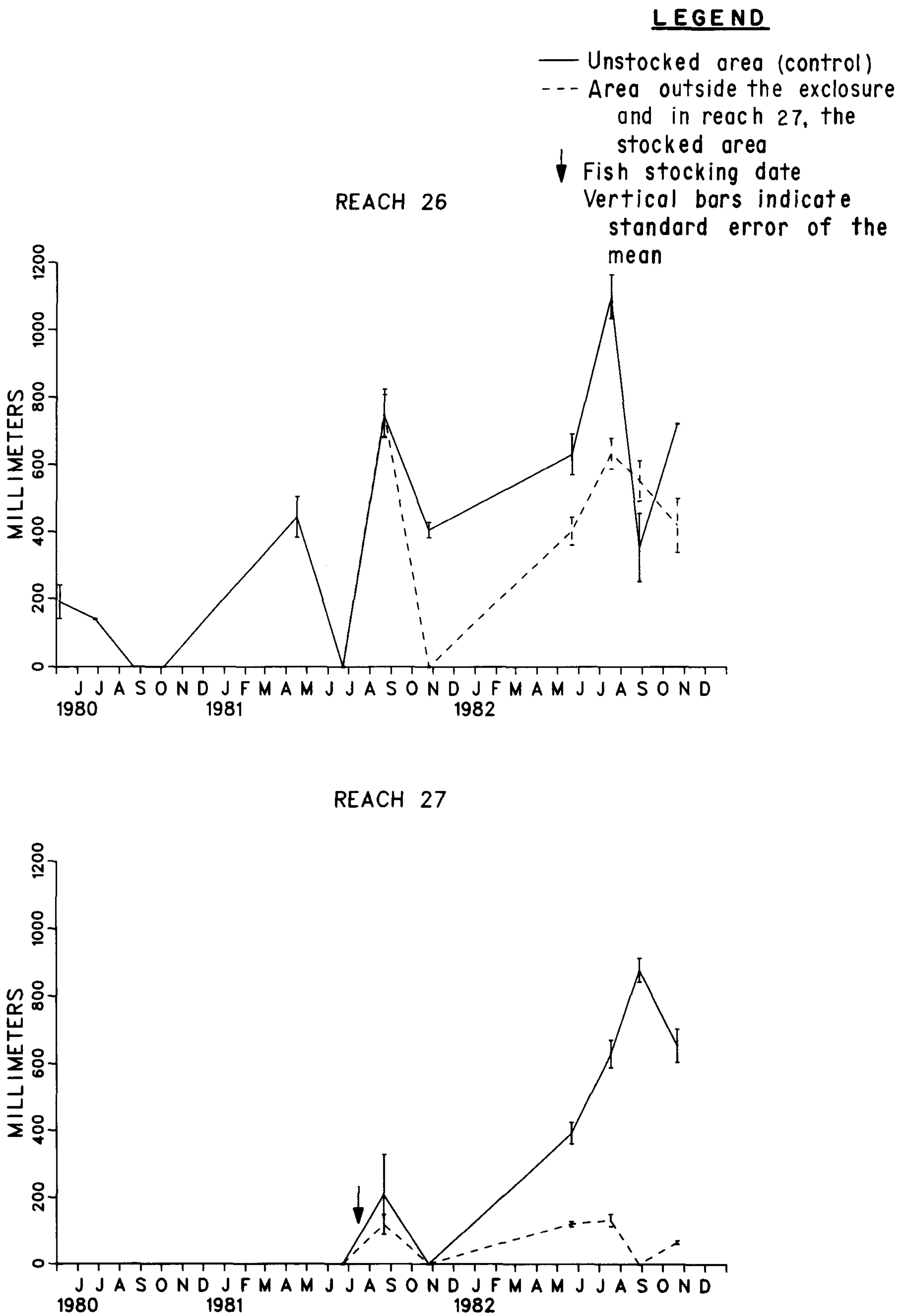

Figure 39. – Mean stem length (mm) of sago pondweed in reaches 26 (unstocked) and 27 of the Coachella Canal.

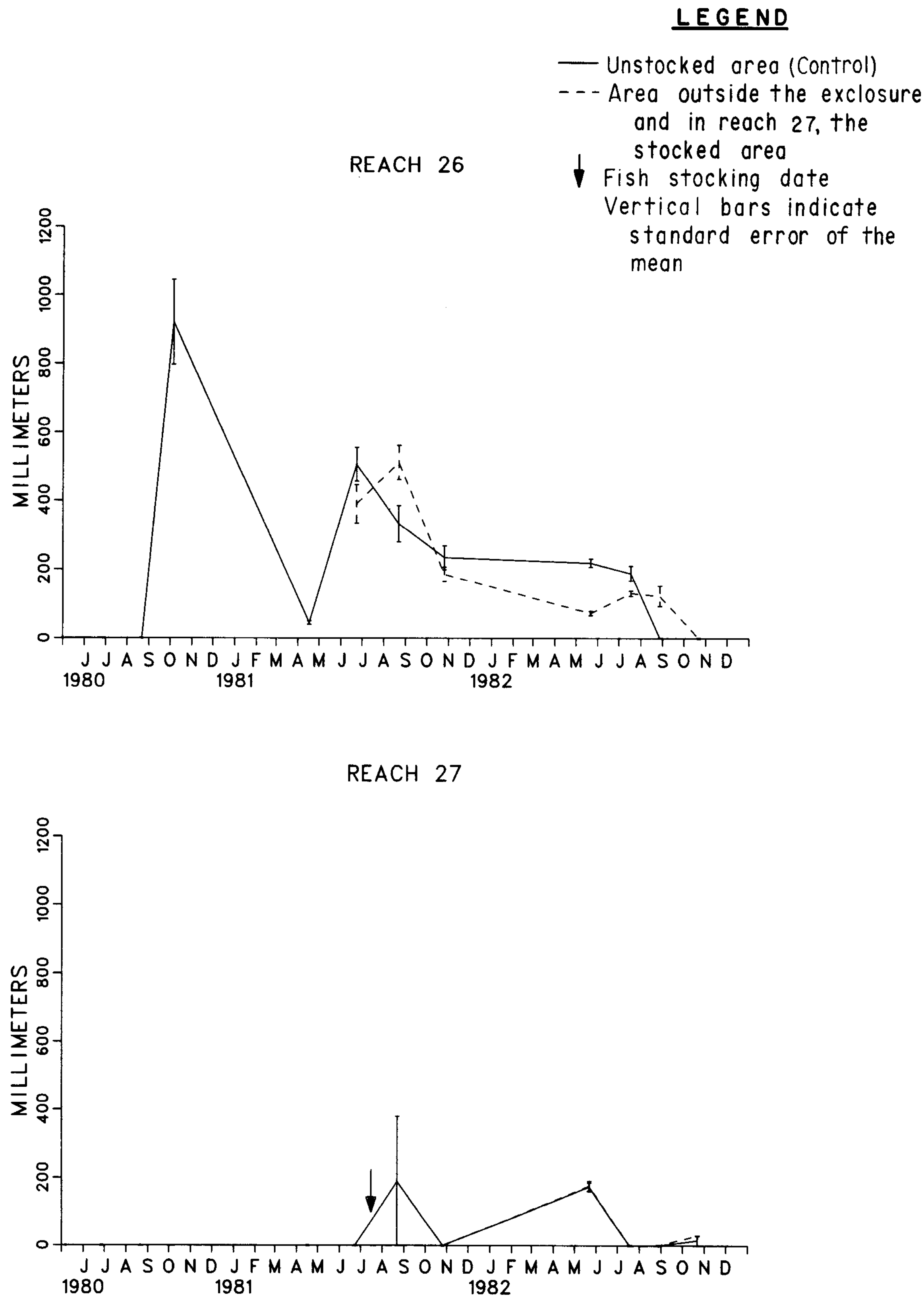

Figure 40. – Mean stem length (mm) of curlyleaf pondweed in reaches 26 (unstocked) and 27 of the Coachella Canal.

Table 7. – Soil analysis[1] of Coachella Canal in the hybrid grass carp study reaches.

Sites	Gradation analysis[2] percent	Soil classification[2]	Loss on ignition[3] % organic material
Coachella Canal			
Reach 25	0 gravel 39 sand 61 fine	Lean silt	1.2
Reach 26	0 gravel 42 sand 58 fine	Lean silt	1.3
Reach 27	0 gravel 37 sand 63 fine	Lean silt	1.1
Reach 28	0 gravel 33 sand 67 fine	Lean silt	1.4

[1] Analyzed by the Soil Testing Laboratory, Geotechnical Branch, USBR E&R Center, Denver, Colorado.
[2] Procedures and nomenclature are in accordance with the *Earth Manual*, 2d ed., USBR, 1974.
[3] Samples were dried in a muffle furnace at 550°C for 2 hours according to standard American Society for Testing and Materials procedures.

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