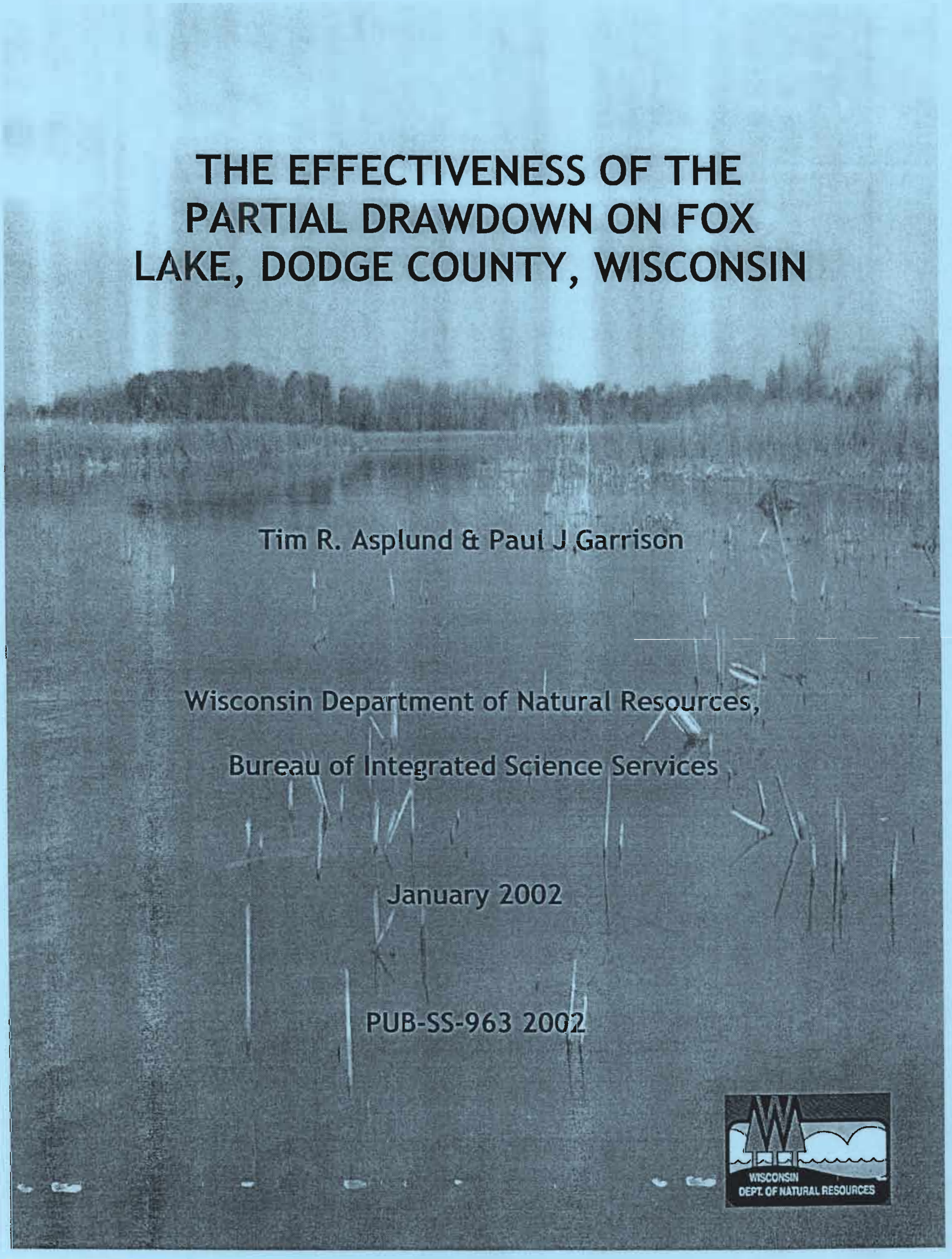

THE EFFECTIVENESS OF THE PARTIAL DRAWDOWN ON FOX LAKE, DODGE COUNTY, WISCONSIN

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Introduction

Lake restoration has typically been based upon reduction in nutrient inputs. While this has worked well with deep lakes, it has not been as successful in shallow lakes. More recently it has been recognized that shallow eutrophic lakes differ from deep ones in many respects (Scheffer, 1998). They can switch between a clear macrophyte state and a turbid algal state without any changes in nutrient inputs (Scheffer et al., 1993; Moss et al., 1996). This is known as alternative stable states, and it has been proposed that when a lake is in one state there are a number of feedback mechanisms that tend to keep it in that state until some major event switches it to the other. There are also forward switches that can move them in the opposite direction (Moss et al., 1996).

Fox Lake is such a shallow lake. Prior to 1950 the lake existed in a clear macrophyte state but from the early 1950's through the mid-1960's the lake was in a turbid algal state. In 1966 the lake was treated with toxaphene to eradicate the fishery, including carp. For at least ten years following this treatment, the lake's water clarity was much improved. However, since the mid-1980's, the lake has existed in an algal turbid state. The one exception was in 1995 when the lake experienced a forward switch to a clear macrophyte state. This only lasted one year.

In an effort to improve water quality and enhance aquatic vegetation, the lake was partially drawdown from February through September 1997. While a 3 foot drawdown was proposed, only a partial drawdown was achieved.

The purpose of this report is to evaluate the effectiveness of this partial drawdown on water quality variables including trophic state variables, phytoplankton, zooplankton, emergent and submersed aquatic vegetation, and the amount of sediment compaction.

Methods

Water Quality

We sampled the lake at the Deep Hole and in the East Basin every two weeks from the end of April through mid-October in 1998 and 1999 (Figure 1). Samples were also collected under the ice in February, just after ice-out in early April, and once in mid-November. Nutrients, chlorophyll, and pH samples were collected from 1m depth with a Kemmerer sampler. In addition, we took Secchi disk readings for water clarity, and profiles of dissolved oxygen, conductivity, and temperature using digital meters. Water samples were also collected from the bottom 1m if the dissolved oxygen profile indicated anoxic conditions. The State Laboratory of Hygiene analyzed the nutrient samples for a variety of constituents including TP, DRP, TKN, NO_3-NO_2, and NH_3. DNR staff at the Research Center analyzed samples for chlorophyll *a* and turbidity. Data were compared to similar data collected in 1994-1996, prior to the drawdown

We also deployed a weather station and automated water-sampling equipment on a raft at the Deep Hole throughout the summer of 1996 and 1998 and at the East Basin in 1999. In all three years, the raft was deployed in late April and retrieved in late October. The weather station recorded average, minimum, and maximum wind speed at hourly intervals, as well as water and air temperature throughout the deployment. A YSI 6000 multi-parameter sonde recorded turbidity, pH, temperature, and conductivity at hourly intervals during most of the time period. During several 2-week periods during the deployment, an ISCO automatic water sampler collected discrete water samples at 6-hour intervals. These samples were subsequently analyzed for suspended solids, turbidity, and total P. We used the water samples to calibrate the turbidity data collected from the YSI sonde.

Plankton

Phytoplankton and zooplankton were sampled biweekly from the Deep Hole and East Basin at the same time as the water quality samples. Phytoplankton were collected from 1-m depth and preserved with Lugol's solution. Monthly samples were scanned to identify species and determine relative abundance. Zooplankton were collected with a 12-cm diameter plankton net with 63-µm mesh in tows from the surface to within 1 m of the bottom. These were preserved in a buffered formalin solution. We determined species composition, numbers of individuals, mean length, and biomass as described in Asplund and Johnson (1996).

Vegetation

We surveyed the submerged aquatic vegetation (SAV) in early August of 1998 and 1999. We used the modified rake method (Deppe and Lathrop, 1992) on 25 regularly spaced transects around the lake, sampling plants at every 1 foot depth interval (Figure 1). A two-headed rake was thrown four times and dragged approximately 2 m along the lake bottom. The SAV on the rake head and each species we found was given a rating on a scale of 1-5, with 5 being most abundant. We then calculated a rake density and individual species densities for each site along the transect. We used the same methodology in 1994, and on a limited number of transects in 1995 (Asplund and Johnson, 1996).

We mapped the occurrence of emergent vegetation in early June of 1998 and 1999 and again in September of both years. A GPS unit with differential was transported around the perimeter of the lake and coordinates recorded at the outside edge of any emergent vegetation encountered. For continuous bands of vegetation, coordinates were recorded at roughly 25m intervals. The GPS unit is accurate within 2 m, meaning that we could detect even small gaps in vegetation coverage. The coordinates were then entered into a GIS framework and laid over a digitized orthophoto of Fox Lake. The area of emergent vegetation was mapped manually by filling in the area between the coordinates and the lake shoreline. In areas where the lake shoreline is defined by cattail marsh, the existing marsh edge in the orthophoto was used as the baseline. Total area and length of shoreline covered by new emergent growth were calculated from the resultant GIS map.

Stem density and species composition of the emergent vegetation were determined at ten selected sites in June of 1998 and six of these sites in 1999 (Figure 1). At each site, 3 parallel transects were laid out extending from the outside edge of the emergent growth to the shoreline or 50 m, whichever came first. Where vegetation was sparse, we counted all the stems that occurred along the transect within 20 cm of the transect line. Where stems were more dense (such as the West Jug, Lower Cambra, and

West Landing), we counted all stems within a 20 by 20 cm quadrant at 5 m intervals along the transect.

Sediments

Sediment thickness and bed elevation were measured at four sites through the ice in February of 1997, prior to the drawdown, and again in 2000 (Figure 1). Site 1 was located at the north end of the lake and consisted of a single transect running N-S from the west end of Devils Island to the north shore of the lake, behind private home W10919 Blackhawk Trail Rd. Site 2 is located west of site 1, where Cambria Creek opens into the lake. A series of five transects originating behind 11083 Blackhawk Trail Rd. was run perpendicular to the northern shore. Site 3 is located in the southern portion of the lake, in the water area known as "The Jug". Four transects originating behind private home 10468 Kuno Trail were run perpendicular to the northern shore. Site 4 is located at the far east end of the lake, in the backwater slough formed by Alto Creek. A series of 10 random samples were taken in this area, with water levels referenced to a staff gage placed on site.

After establishing a set of shore-based survey control points at each of the sites, a geodetic total station (Pentax PTS-V) was used to stake out a series of transect endpoints. Taped distances were then used to mark locations for point sampling along each transect, at 50 to 100 m intervals. After augering through the ice, a sediment sounding probe was used to measure bathymetry and sediment thickness at each sample point. The sounding probe is a 2.5-in. diameter aluminum pole, incremented in tenths of feet. The tip of the pole is fitted with an aluminum cap, gently beveled to facilitate penetration into the sediment. After measuring water depth, the probe is manually pushed through the sediment until firm refusal to obtain a measure of sediment thickness, accurate to 0.1 ft. The total station was then used to measure the relative X and Y coordinate of each sampling location, referenced to true north. The relative elevation (Z) of the water surface was also measured. The resulting data was used to generate cross-sectional and surface-contour plots of each of the study sites, and determine if any sediment compaction occurred as a result of the drawdown.

Results and Discussion

Water Quality

Water quality has not improved since the drawdown. Secchi disk readings averaged less than 50 cm in 1998 and 1999 at the Deep Hole, comparable to the pre-drawdown years of 1986-1989 (Figure 2). Water clarity was slightly worse in 1990-1994, but better in 1995 and 1996. Chlorophyll *a* concentrations averaged just under 90 µg/L, and followed similar patterns to water clarity. Total P averaged 180 µg/L in 1998, but dropped to 140 µg/L in 1999. The 1998 value was the third highest average total P since 1986, but the 1999 value was lower than all years from 1990-1998, with the exception of 1996.

Fewer years of record were available for nitrogen constituents (Figure 3). Total N was fairly high in both 1998 and 1999 compared to the other years for which we have data. As total P values were similar or less than in previous years, the N:P ratio in 1999 was the highest recorded at 18. Spring nitrate-nitrite concentrations were relatively high in 1998 and 1999, with only 1992 and 1993 having higher values. Spring nitrate concentrations were much higher in 1998 and 1999 than in 1995 and 1996 (Figure 4), which likely contributed to the higher chlorophyll *a* concentrations and much earlier blooms. N:P ratios were relatively similar among the 4 years, with generally declining values from spring to late summer. The dominance of blue-green algal blooms, especially in late summer in Fox Lake, can be explained by these low N:P ratios. These increasing nitrogen values likely reflect increased runoff from farm fields, and reflect a national trend in freshwater.

More detail about the water quality trends exhibited in Fox Lake can been seen by comparing seasonal patterns from the two years prior to the drawdown (1995 -1996) to the two years following the drawdown (1998-1999). Total P showed similar patterns among the four years, with relatively low values in spring and fall and peaks in June or July (Figure 5). Differences among years mainly lie in terms of timing of the summer peak. This pattern is quite different from the expected pattern seen in many lakes, where total P peaks in spring with snowmelt and runoff events. Higher P levels during the summer are a result of the high internal loading that occurs in Fox Lake. Chlorophyll *a* generally follows the same pattern, with low values in May and peaks occurring in June and July. However, the two post-drawdown years achieved these peaks in early June while in 1995 and 1996 these peaks did not occur until July. In addition, chlorophyll *a* values were much lower in 1995. These patterns are further reflected in the Secchi disk readings with relatively clear water in 1995 and 1996 through June. In contrast, Secchi disk readings were uniformly low throughout 1998 and 1999.

Dissolved reactive P was only present in any significant amount in 1995. This one parameter, in combination with the zooplankton data, is the best evidence that we have that the unusually high water clarity in 1995 was a result of intensive zooplankton grazing on the algae (Asplund and Johnson 1996). In all other years, the algae appear to be able to take up P as soon as it is made available.

The East Basin generally followed similar patterns to the Deep Hole (Figure 6). No data were collected in 1996. The East Basin tended to have slightly worse water clarity, but lower chlorophyll *a* concentrations, likely due to the greater influence of the sediments at this shallower site. However, over the three years that we collected data at both sites, there was more variability seasonally and among years than there was between the Deep Hole and East Basin.

Plankton

Algal blooms continued to be frequent and dominated by the blue-green alga *Microcystis aeruginosa* following the drawdown (Table 1). Samples were not analyzed explicitly in 1999, but visual inspection of the water column and observations from the zooplankton tows indicated that *Microcystis* was ubiquitous throughout 1999. Species composition has remained relatively uniform since the late 1980's, with the only exception being the shift in dominance to cryptophytes and diatoms in 1995.

Table 1. Phytoplankton species composition at the Deep Hole site (1 m) from 1988 to 1998. D = Dominant, C = Common, S = Somewhat common, R = Rare, P = Present. Only June though August samples are included. Data from 1988-1991 are from the LTTM program (unpublished data). Dashes indicate that the species was not found. Post drawdown year is shaded.

		1988	1990	1991	1994	1995	1998
Blue-greens							
	Anabaena spiroides	P	--	--	--	S	--
	Aphanizomenon flos-aquae	P	P	P	S	--	S
	Aphanocapsa sp.	D	--	C	--	--	R
	Microcystis aeruginosa	D	D	D	D	S	D
	Microcystis incerta	--	--	--	D	S	--
	Other bluegreens	S	--	--	P	P	R
Cryptophytes							
	Chroomonas acuta	--	--	--	--	C	R
	Cryptomonas erosa	C	P	P	P	C	P
	Cryptomonas ovata	--	--	--	--	C	--
	Other cryptophytes	--	--	P	--	R	--
Chrysophytes							
	Mallomonas sp.	--	--	--	--	--	R
Diatoms							
	Aulacoseira granulata	R	--	P	S	D	S
	Aulacoseira italica	--	--	--	S	C	--
	Cyclotella sp.	--	--	--	--	S	P
	Stephanodiscus niagare	--	P	C	R	R	--
	Other diatoms	S	--	P	R	P	P
Dinoflagellates							
	Cerratium hirudinella	S	--	--	P	P	S
	Gymnodinium sp.	--	--	--	--	--	R
	Peridinium umbonatum	C	--	--	--	--	--
Greens							
	Chlamydomonas sp.	--	--	--	--	--	R
	Asterococcus limneticus	--	--	--	--	R	--
	Oocystis sp.	--	--	P	P	P	R
	Staurastrum sp.	P	--	--	P	P	R
	Pediastrum sp.	R	P	--	R	R	--
	Sphaerocystis schroeteri	--	--	--	R	S	--
	Other greens	--	--	P	P	P	P

Zooplankton species composition has undergone some changes since the drawdown, though it is not clear whether this is a direct result of the drawdown. In most years, the zooplankton assemblage was dominated by copepods and smaller-bodied cladocerans (Table 2). However, there was a shift in the dominant copepods from *Leptodiaptomus siciloides* to *Skistodiaptomus oregonensis* and *Acanthocyclops vernalis* to *Diacyclops thomasi* in 1998 and 1999. *Daphnia* species have become slightly more abundant in recent years since the dominance of *D. schödleri* in the 1995 clear year. These shifts may be indicative of changes in the fish assemblage that have occurred in the past two years as a result of intensive carp eradication and northern pike stocking (Congdon pers. comm.). These fish management programs may be reducing the biomass of the planktivorous fish in Fox Lake, which may be reducing planktivory on the larger zooplankton.

Table 2. Species composition and relative abundance of the Fox Lake zooplankton community, 1974 - 1999. 0 = absent, 1 = present, 2 = occasional, 3 = common, 4 = very common, 5 = abundant. Post drawdown years are shaded.

	1974[1]	1986[2]	1987[2]	1988[2]	1994	1995	1998	1999
CLADOCERANS								
Daphnia schodleri	**0**	**0**	**0**	**0**	**3**	**5**	**3**	**3**
D. retrocurva	**3**	**3**	**2**	**5**	**2**	**3**	**3**	**4**
D. pulicaria	**0**	**2**	**0**	**0**	**0**	**2**	**0**	**1**
D. galeata mendotae	**2**	**3**	**0**	**2**	**5**	**4**	**3**	**4**
Diaphanosoma sp.	**3**	**4**	**3**	**4**	**0**	**2**	**1**	**2**
Ceriodaphnia sp.	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**1**
Chydorus sphaericus	**4**	**3**	**5**	**4**	**0**	**4**	**5**	**5**
Eubosmina coregoni	**2**	**4**	**4**	**5**	**0**	**1**	**2**	**2**
Bosmina longirostris	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**3**
Leptodora sp.	**1**	**2**	**0**	**1**	**0**	**1**	**0**	**1**
COPEPODS								
Leptodiaptomus siciloides	**3**	**3**	**2**	**1**	**5**	**5**	**0**	**2**
Skistodiaptomus oregonensis	**0**	**2**	**0**	**2**	**0**	**0**	**3**	**3**
Diacyclops thomasi	**1**	**1**	**0**	**1**	**1**	**1**	**4**	**4**
Acanthocyclops vernalis	**3**	**3**	**2**	**5**	**4**	**4**	**0**	**2**
Mesocyclops edax	**3**	**2**	**1**	**1**	**0**	**1**	**1**	**1**
Eucyclops speratus	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**
Macrocyclops albidus	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**
Orthocyclops modestus	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**

[1] Data from Torke 1979.

[2] Data from LTTM program (WDNR unpublished).

As previously mentioned, the extremely clear water that occurred in 1995 can largely be attributed to the zooplankton dynamics. *Daphnia* populations often peak in late spring, leading to a clear water phase that has been described in many lakes (Lambert et al. 1986). This clearwater phase usually occurs before the onset of warmer temperatures when fish populations begin grazing on the zooplankton and algal populations begin to grow rapidly. In 1995, this clearwater phase began under the ice in February and tracked a large and extended peak in *Daphnia* biomass that persisted until June (Figure 7). In 1994, 1998, and 1999, the *Daphnia* population declined from under the ice to spring turnover, and achieved a much smaller and shorter duration peak sometime in May. In all 4 years, the *Daphnia* populations crashed by the beginning of July, before building up their numbers to a secondary peak in late July-early August. This secondary peak usually corresponded with a decline in chlorophyll *a* concentrations and the presence of other species of phytoplankton. Thus in most years, the zooplankton appear to be responding to the phytoplankton dynamics, rather than keeping the water clear as in 1995.

Vegetation

Submerged aquatic vegetation (SAV). The SAV in Fox Lake were initially set back by the drawdown, but appeared to have rebounded to pre-drawdown levels by 1999 (Table 3). In 1998, SAV covered only 36% of the littoral area (defined as the area between the shoreline or cattail fringe and the maximum depth at which plants were found). Densities peaked at 2 feet with a mean density rating of 0.47 (Figure 8). These values were much lower compared to 1995, when the clear water allowed plants to reach greater densities and depths. The macrophytes we did find in 1998 appeared to be confined to a few pockets near the cattail fringe in the Jug, in Cambra Creek, and some scattered clumps in the middle of the East Basin and off the north side of Brushwood Island (Figure 9). It appeared that submerged plants were not growing in areas exposed by the drawdown, which instead had more emergent vegetation. In addition, the poor water quality/clarity in 1998 limited the growth of submerged plants in deeper waters.

Table 3. Summary of submerged plant characteristics in Fox Lake from surveys performed in 1994, 1995, 1998, and 1999. Post drawdown years are shaded.

	1994	1995 (7 transects)	1998	1999
Maximum rooting depth	5 feet	7.5 feet	6 feet	6 feet
% cover in littoral area	46%	65%	36%	51%
# species	14	7	7	7
Simpson's Diversity Index	0.80	0.75	0.73	0.72
Peak Density (0-5 scale)	0.78	1.52	0.47	1.27
Depth of peak density	2 feet	2.5 feet	2 feet	3 feet

In contrast, in 1999 we found SAV in most areas of the lake where it had been documented prior to the drawdown (Figure 9), with greatest densities in the Cambra Creek area (transects 2-6). SAV covered 51% of the littoral area, with higher densities particularly in the 3-4 foot depth range (Table 3). In fact, densities at three feet were similar to those found during the clear water year of 1995. While not achieving the coverage and density of 1995, the SAV in 1999 were better established than in 1994 (Figure 8).

Table 4 compares the species composition in 1994 and 1995 to that found in 1998 and 1999. Coontail, sago pondweed, and Eurasian water milfoil (EWM) continued to predominate, though they exhibited very different patterns between 1994 and 1999. Coontail frequency more than doubled in response to the clear water in 1995 and then dropped off dramatically after the drawdown in 1998. In 1999, coontail returned to similar levels as in 1994 with the biggest changes occurring in the Cambra Creek area (Transects 2-6) (Figure 9). Sago pondweed appears to be declining relative to the other 2 species, at about half the frequency recorded in 1994. EWM, in contrast, did not respond to the clear water, but after declining in 1998 has reached a higher frequency than in 1994. Interestingly, a large patch of EWM and sago was found in the East Basin at water depths of 5-6 (transects 17-19) (Figure 9), which appears to be expanding. These species tend to do better in turbid conditions and will develop growth forms that allow them to utilize the available light (Nichols 2000). We did not find any curly-leaf pondweed (*Potamogeton crispus*) in 1998 and found only a small amount in 1999. The area just to the east of the town landing has had dense coverage of this species in the past, but it was much reduced in both 1998 and 1999. Numbers of species continue to be poor relative to 1994.

Thus it appears that the poor water quality/clarity in 1998 limited the growth of submerged plants in deeper waters, while the drawdown likely limited re-growth of plants in the shallower waters over sediments that were exposed. In 1999, many of the shallow areas had regained their SAV, perhaps due to declines in emergent growth and more favorable growing conditions than in the first year after the drawdown. However, SAV also appears to be expanding in deeper water, despite the continued poor water clarity. This phenomenon may be the result of the expansion of EWM in the lake, which tends to grow in deeper water and may be able to sustain itself despite the poor light conditions. In addition, the carp eradication and no-wake areas instituted in the East Basin may be helping the SAV to expand in deeper waters.

Emergent vegetation survey. Prior to the drawdown, emergent vegetation was very sparse, except on the north side of Brushwood Island. During the drawdown (1997), emergent plants such as soft stem bulrush and narrow-leaved cattail grew quite abundantly on the exposed mud flats (Sesing, pers. comm.). In June of 1998, emergents occupied about 200 acres, or 8% of the total lake area, and were found along 63% of the shoreline. Cambra Creek Inlet, the Jug, Drew Creek Inlet, the east side of Elmwood Island, the perimeter of Brushwood Island, and the outlet were the areas with the most notable emergent growth (Figure 10). Narrow-leaved cattail and soft-stem bulrush were the most common emergents found in 1998, with arrowhead, reed canary grass, and two other species of bulrush also somewhat common (Table 5). Cattails were most common along the northern shoreline near the town park landing, Cambra Creek, and the West Jug (Figure 11). Bulrushes were common around Brushwood Island, Cambra Creek, and especially along the north shore of the Jug (Figure 12).

By September of 1998, some losses had occurred, particularly around the islands and at the Drew Creek inlet (Figure 13). Emergent coverage dropped to 184 acres and 53% of the shoreline (Table 6). In 1999, the areal extent of the emergent growth continued to decline, with only 36% of the shoreline vegetated and 5% of the lake area covered by Sept. 1999. Wind and wave exposure likely wiped out the vegetation along the northern end of the lake (see arrow in Figure 13). However, riparian removal also contributed to the decline along populated shorelines, such as in the northern Jug, and near the town landing (see arrows in Figure 13). In those areas that were more protected from wind and riparians, the densities appeared to be similar between 1998 and 1999, or actually

Table 4. Percent plant cover and relative frequency of macrophytes in Fox Lake. Post drawdown years are shaded.

Corrected 11/2/99

		% Plant Cover				Relative Frequency			
		Whole lake	7 transects	Whole Lake	Whole Lake	Whole lake	7 transects	Whole Lake	Whole Lake
Plant species	**Common name**	**1994**	**1995**	**1998**	**1999**	**1994**	**1995**	**1998**	**1999**
C. demersum	Coontail	21.7	51.2	13.8	25.3	22.3	39.8	37.3	37.2
E. canadensis	Elodea	2.8	7.0	--	12.1	1.2	4.1	--	9.2
N. flexilis	Naiad, slender	<1	--	--	--	0.4	--	--	--
Nuphar sp.	Pond lily, yellow	<1	--	1.1	4.0	--	--	3.4	3.1
P. crispus	Pondweed, curly leaf	7.5	4.7	--	2.0	6.7	4.1	--	1.5
Z. palustris	Pondweed, horned	<1	--	--	--	0.4	--	--	--
P. foliosis	Pondweed, leafy	1.9	--	--	--	1.2	--	--	--
P. pectinatus	Pondweed, sago	31.1	11.6	9.2	16.2	29.9	7.3	22.0	14.3
C. echinatum	Prickly coontail	10.4	34.9	--	--	10.8	19.5	--	--
V. Americana	Water celery	1.9	--	1.1	--	0.8	--	1.7	--
Nymphaea	Water lily, white	6.6	--	3.4	3.0	8.3	--	6.8	2
M. spicatum	Water milfoil, Eurasian	20.8	23.2	12.6	31.3	15.9	19.5	27.1	32.7
Z. dubia	Water stargrass	4.7	9.3	--	--	2	5.7	--	--
Nelumbo lutea	American lotus	--	--	1.1	--	--	--	1.7	--
All species		46.2	65.1	35.6	51.0	100	100	100	100
Diversity						0.81	0.75	0.73	0.72

Table 5. Emergent plant species found in areas previously exposed by the drawdown in Fox Lake in June of 1998.

Species	Common name	Percent of Transects
Scirpus validus	Softstem Bulrush	96.7%
Typhus angustifolia	Narrow-leaved Cattail	86.7%
Phalaris phalaros	Reed Canary Grass	43.3%
Scirpus fluviatilis	River Bulrush	43.3%
Sagittaria latifolia	Arrowhead	36.7%
Nuphar sp.	Yellow Pond Lily	20.0%
Nymphaea sp.	White Water Lily	20.0%
Scirpus acutus	Hardstem Bulrush	20.0%
Typhus latifolia	Broad-leaved Cattail	20.0%
Leersia oryzoides	Rice Cut-grass	6.7%
Zizania aquatica	Wild Rice	6.7%
Polygonum sp.	Water Smartweed	3.3%
Pontederia cordata	Pickerel Weed	3.3%

Table 6. Emergent vegetation coverage in Fox Lake in 1998 and 1999 as determined by GIS.

	June 1998	Sept. 1998	June 1999	Sept. 1999
Vegetated Area (acres)	200	184	152	132
% Lake Area	8	7	6	5
Vegetated shoreline (m)	18,651	15,690	12,730	10,504
% Shoreline	63	53	43	36

expanded (Figure 10). Thus the drawdown appeared to effectively encourage emergent plant growth, mainly cattail and soft-stem bulrush, which has persisted in areas protected from wind exposure and human disturbance.

Sediment Compaction

There is some evidence for sediment compaction in shallow areas as a result of the drawdown, but the results were hampered by the increase in emergent vegetation and 0.2 ft. lower water levels in 2000. Site 1 (east of Town Park landing) exhibited no net change in bed elevation or sediment thickness, although these varied dramatically across the transect (Figure 14). Site 2 (Cambra Inlet) experienced a dramatic expansion of the cattail bed, such that few sampling points could be re-occupied in 2000. However, soft sediments appeared to have decreased by about 0.25 ft. in thickness in the re-sampled areas. Site 3 (Jug) demonstrated the most evidence for compaction, with an average drop in bed elevation of 0.3 ft (Figure 15). In Site 4 (Alto Creek Inlet), the ice cover extended all the way to the sediment surface in 2000, in contrast to 1997 when there was at least 1.5 ft. of water. Lower water levels, thicker ice cover, and more sediment deposition in the Alto Creek inlet than in 1997 are likely explanations for this finding.

Wind resuspension

In order to determine whether the drawdown compacted the sediments enough to decrease sediment resuspension during wind events, a raft was placed in the Deep Hole during the years 1996 and 1998 and the East Basin in 1999. This raft was used as a platform to collect near continuous data for wind speed and turbidity. Maximum daily wind speed was somewhat similar all 3 years (Table 7, Figure 16). Peak values were somewhat higher in 1998, especially during late May to early June. Suspended solids (as inferred from turbidity) were higher after drawdown in 1998, but this was largely a result of the higher wind speeds in late May and early June. Wind generated turbidity was higher in the East Basin compared to the main lake basin. Even though peak wind speeds were higher in 1998 than 1999, the average turbidity was higher in the East Basin in 1999 (Table 7, Figure 17). The reason for this is the East Basin is shallower than the main basin (17 ft vs 6 ft) and thus waves are better able to resuspend the bottom sediments. Sediment resuspension is only indirectly responsible for the turbid conditions in the lake. Much of the turbidity is not sediment but is instead suspended algae. Figure 18 shows that there is a poor relationship between maximum daily wind speed and suspended solids.

Table 7. Wind speed and turbidity as measured from the raft before and after the drawdown.

	1996 (Deep Hole)	**1998 (Deep Hole)**	**1999 (East Basin)**
April - Oct.			
Avg. Maximum Daily Wind Speed (m/s)	9.40 ±2.76	9.98 ± 3.59	9.62 ± 3.18
Maximum Wind Speed (m/s)	20.9	25.9	20.0
Average Turbidity (NTU)	32.4	63.9	74.0
May-June			
Avg. Maximum Daily Wind Speed (m/s)	9.73 ± 2.80	11.27 ± 4.31	10.02 ± 3.18
Maximum Wind Speed (m/s)	18.6	25.9	20.0
Average Turbidity (NTU)	11.2	84.9	73.2
July-August			
Avg. Maximum Daily Wind Speed (m/s)	8.21 ± 2.05	7.83 ± 1.52	9.47 ± 3.38
Maximum Wind Speed (m/s)	12.9	11.8	18.3
Average Turbidity (NTU)	39.2	52.8	70.3
Sept. - Oct.			
Avg. Maximum Daily Wind Speed (m/s)	9.92 ± 2.72	9.40 ± 2.47	9.34 ± 2.86
Maximum Wind Speed (m/s)	20.9	15.4	18.6
Average Turbidity (NTU)	62.2	62.8	88.6

Conclusions

The most significant change in the lake as a result of the drawdown has been the emergent vegetation response. Almost all of the mudflats that were exposed during the drawdown grew lush stands of cattail and soft-stem bulrush that persisted throughout 1998. Sites that were protected from wind-wave exposure (Cambra Creek Inlet, the Jug, and the Outlet) maintained fairly dense and healthy stands of emergent growth. The submerged macrophyte response was disappointing, with very low densities throughout the lake. The poor response is likely due to a combination of poor light conditions and competition from emergent growth in areas that had dense submerged vegetation historically. In addition, light conditions during the drawdown were very poor due to increased wind mixing under shallow water conditions. Very few submerged plants were able to take hold, despite the decreased amount of water between the surface and sediments.

Water quality did not improve during the two post-drawdown years, and in fact was worse than the two years preceding the drawdown. It was hoped that the drawdown would contribute to sediment compaction and improve both emergent and submerged vegetation growth, which would in turn, reduce sediment resuspension and improve water quality. Sediment compaction only appeared to occur in the Jug and not the other sites that were evaluated. A combination of factors contributed to the lack of water quality response. First, climatic conditions in spring and early summer may have confounded our efforts. A wet spring refilled the lake fairly rapidly and may have brought a load of nutrients in from the watershed, as indicated by the high TP concentrations in April (Figure 2). Also, the very windy and stormy conditions in May and June 1998 (Figure 16) likely resuspended the bottom sediments and contributed to pulses of nutrients from the lake bottom. Second, the zooplankton community composition indicates that planktivory was high, with very few large zooplankters to keep the phytoplankton in check. Finally, it is possible that the drawdown was not severe enough to cause a shift in water quality. A relatively small percentage of the lake bottom was actually exposed during the drawdown. While the emergents did respond, there may not have been enough new growth to have a significant impact on preventing sediment resuspension. The failure of the submerged vegetation to take hold further contributed to a lack of a water quality response.

In order to improve the water quality of the lake it will be necessary to perform other measures. Improving water clarity will require reducing nutrient input into the water column. This includes both reducing nutrient runoff from the watershed as well as reducing the internal loading of nutrients from the bottom sediments. A reduction of nutrients from the sediments could best be done by fostering the growth of submerged vegetation. This vegetation would reduce sediment resuspension which provides nutrients as well as provide a refuge for large zooplankton. The presence of large numbers of these zooplankters can dramatically reduce algal blooms as was demonstrated in 1995. Increased growth of vegetation would also help protect emergent vegetation, especially on the east shore of the East Basin. At the present time this vegetation is significantly eroding on an annual basis. While the partial drawdown of 1997 did not result in increased growth of submerged vegetation, there may be other ways to foster this growth. One possible technique would be to perform complete fish eradication. This would greatly reduce the carp population, which may enable the submerged vegetation to become better established. A more extensive drawdown that exposed a significant portion of the lake bed may also be warranted, though this may be prohibitive in practice. Other groups have had success with this method (Pool 8 drawdown on the Mississippi River, Big Muskego).

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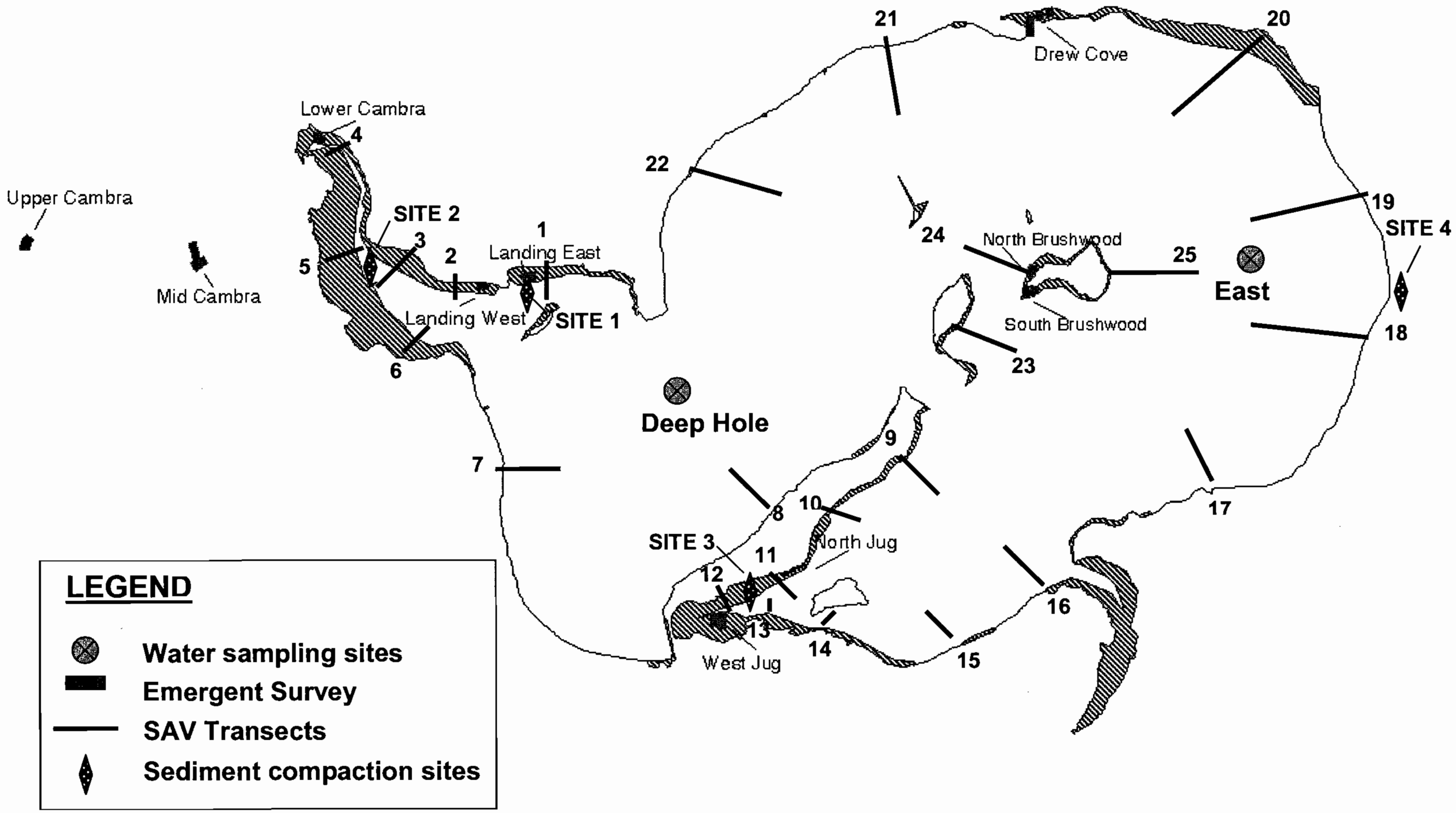


Figure 1. Map of Fox Lake showing macrophyte transects, emergent vegetation sampling sites, sediment compaction sites, and water sampling sites.

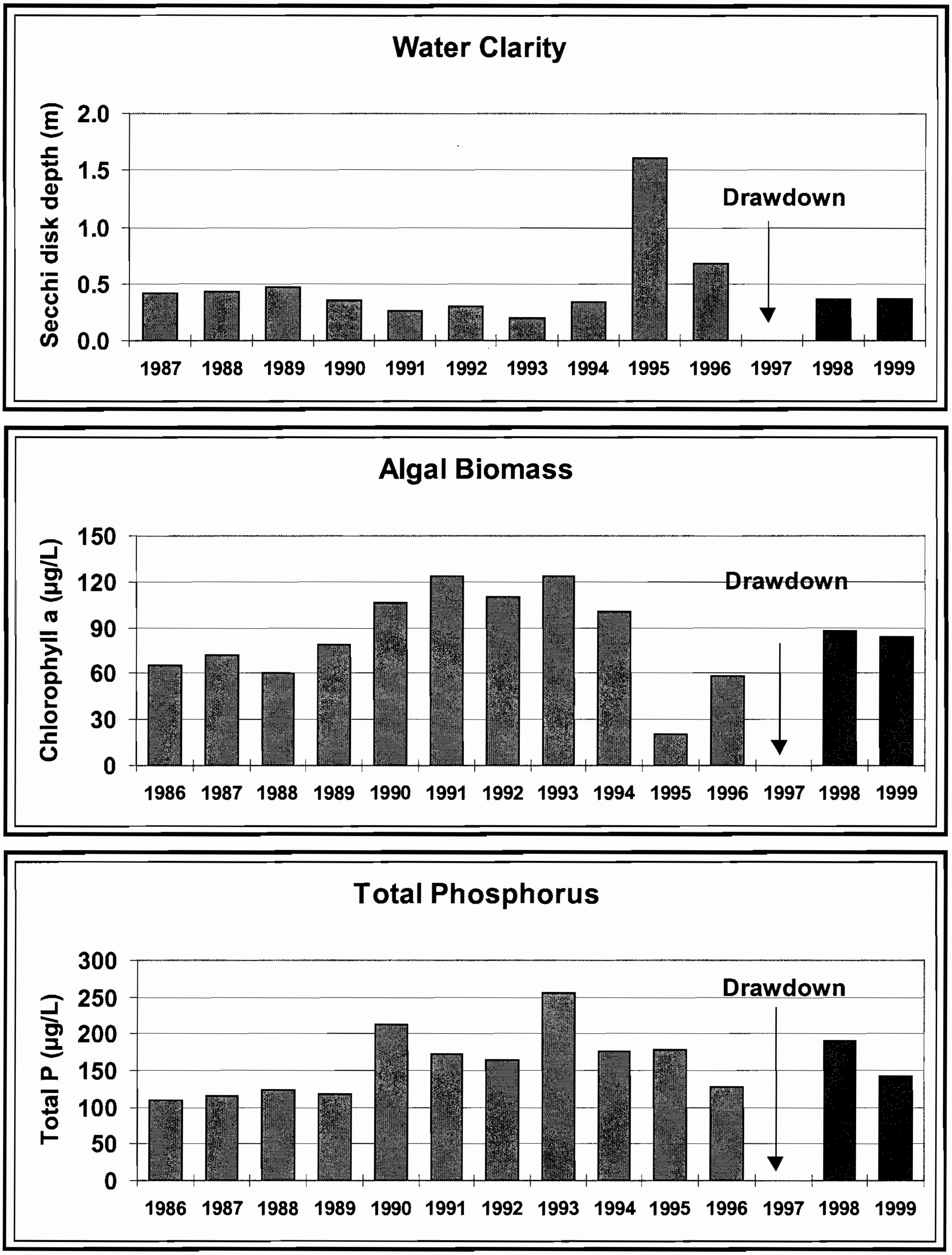


Figure 2. Thirteen year trends of a) Secchi depth, b) chlorophyll *a*, and c) total P in the top 1 m at the Deep Hole in Fox Lake. No data was collected during the drawdown in 1997.

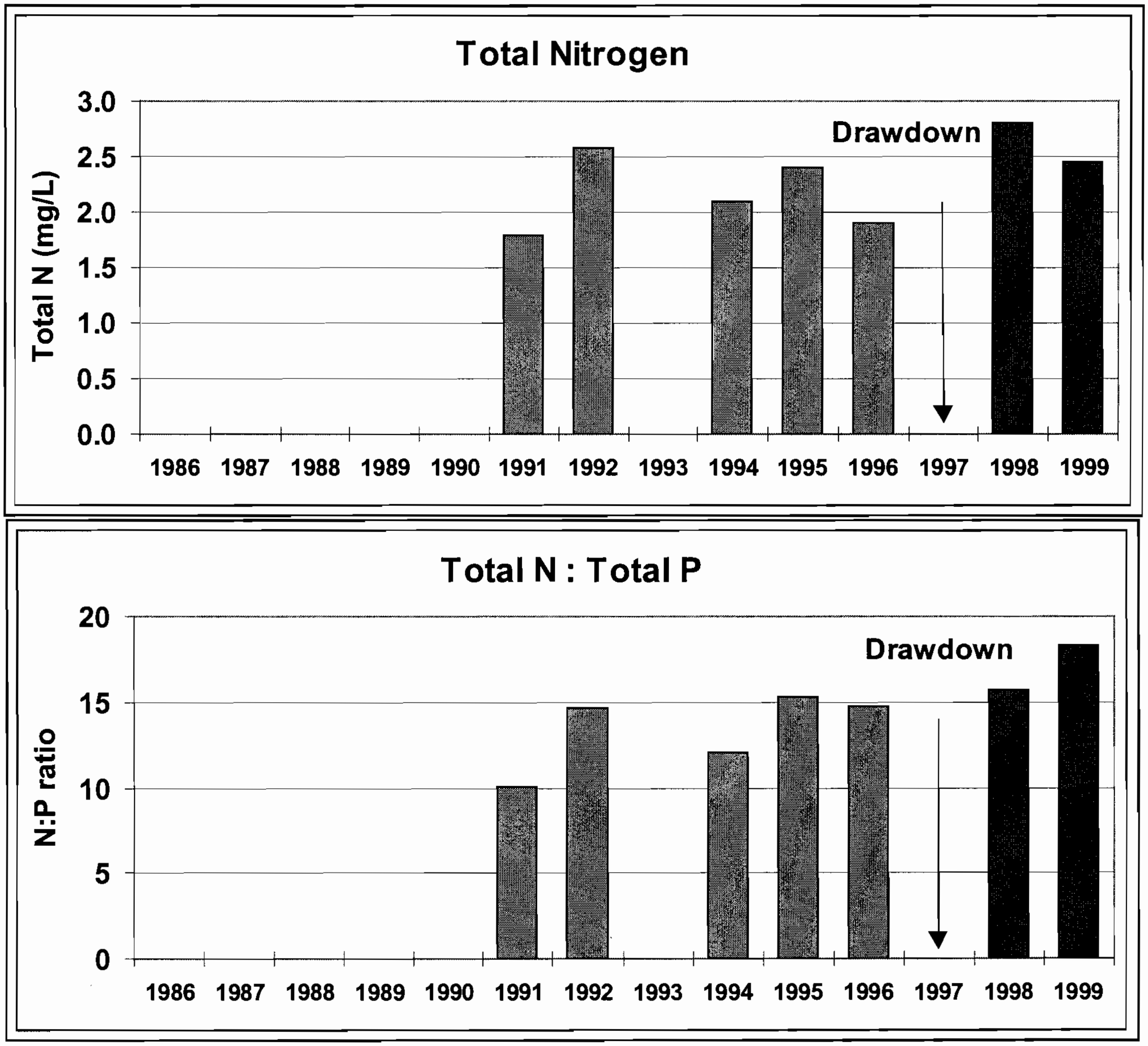


Figure 3. Annual trends for Total N and N:P. Data was not collected in 1997 during the drawdown.

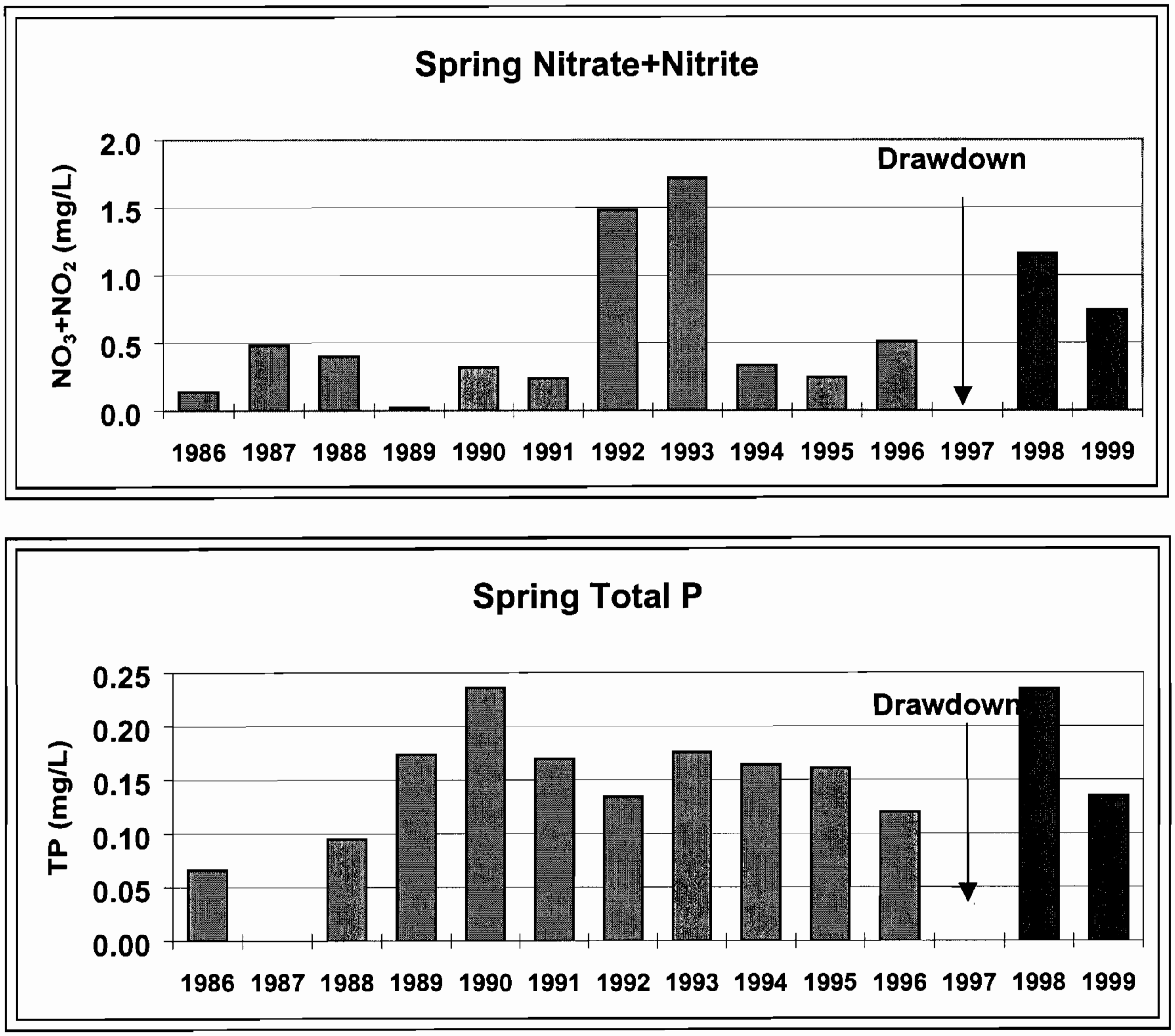


Figure 4. Annual trends of spring concentrations of NO_3-N and total P. Samples were not collected in 1997 during the drawdown.

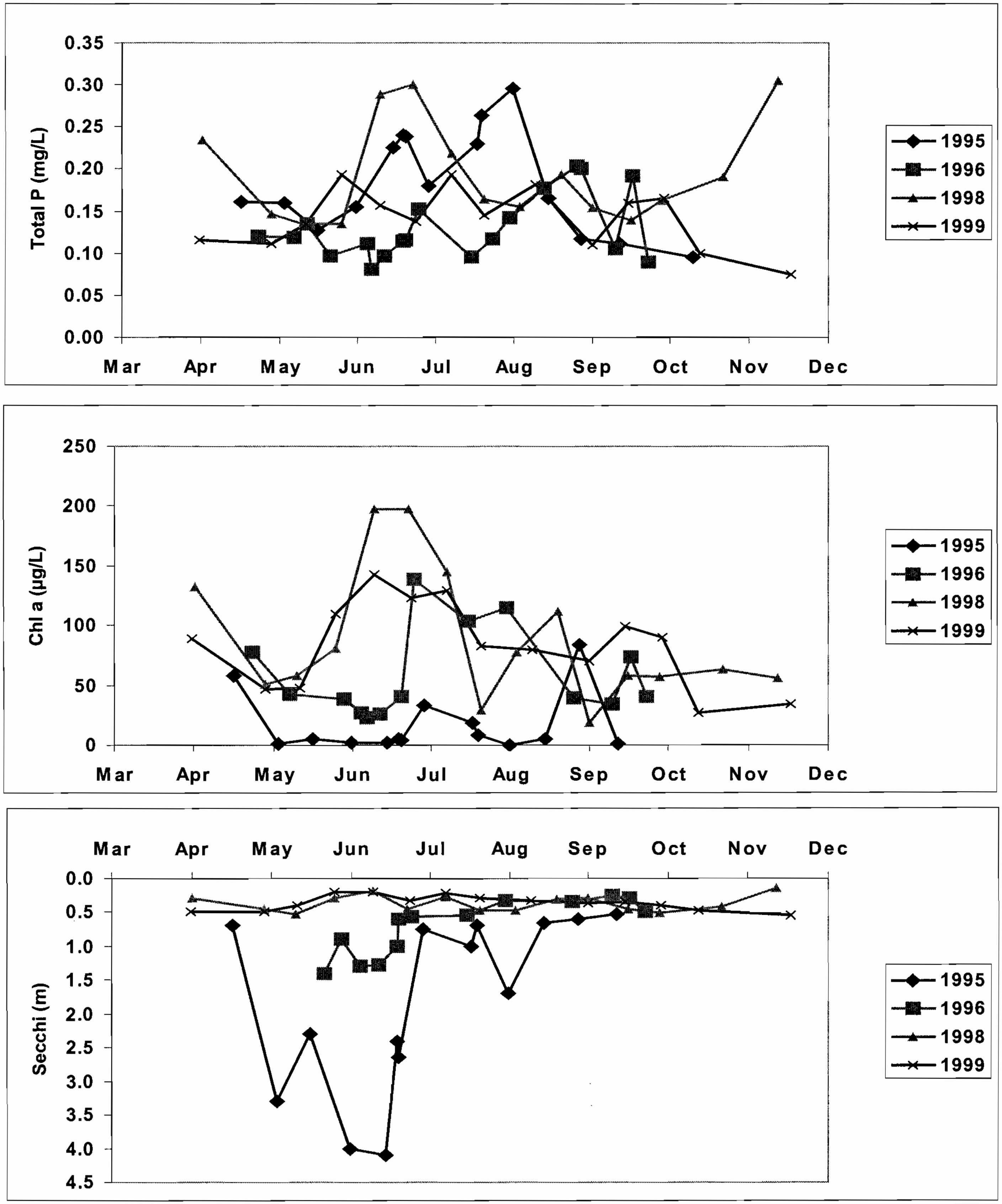


Figure 5. Seasonal trends in a)Secchi depth, b) chlorophyll a, and c) total P in the top 1m of the Deep Hole of Fox Lake. Samples were not collected during the drawdown in 1997.

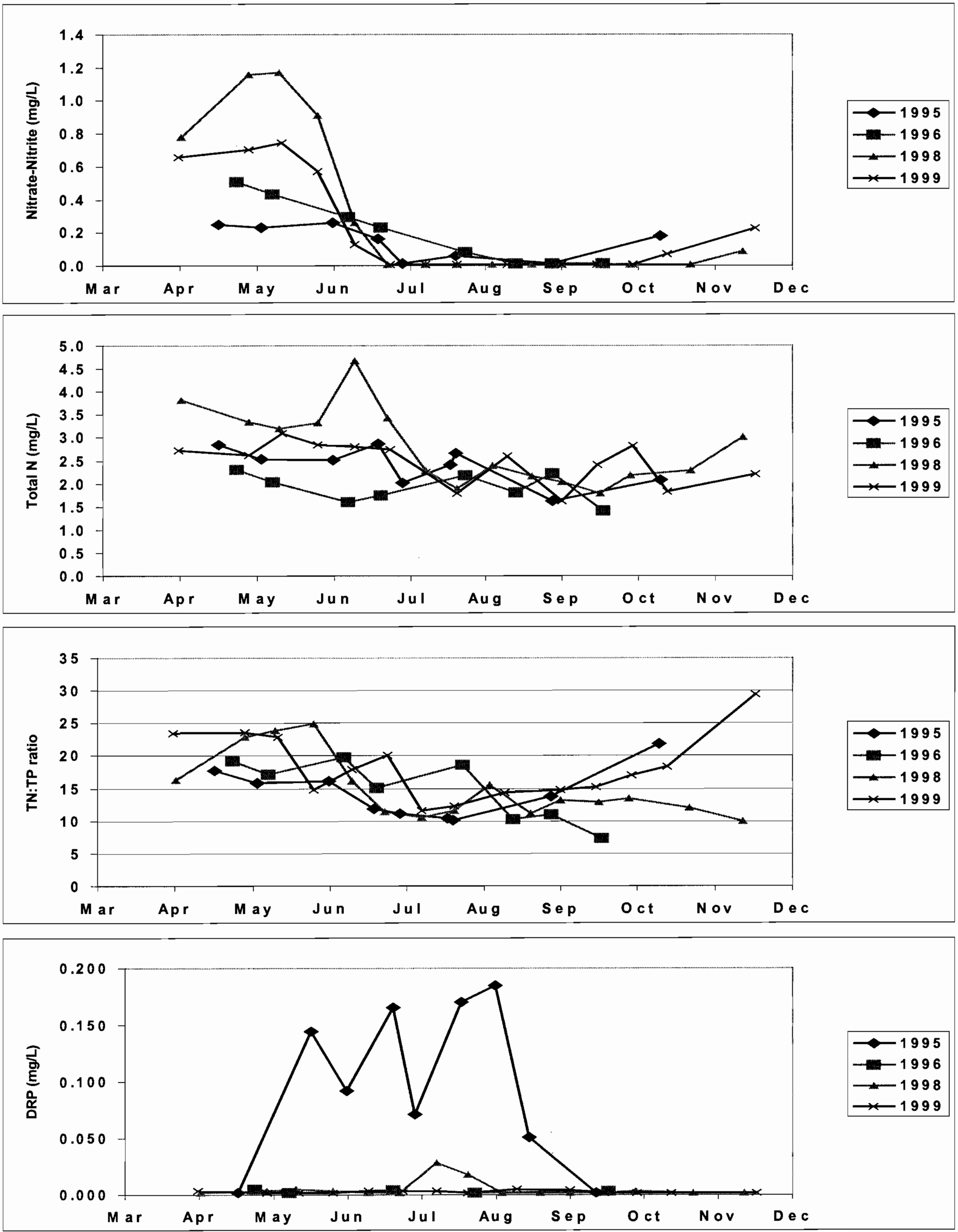


Figure 5 (cont). Seasonal trends in a) NO_3-N, b) total N, c) N:P, and d) DRP in the Deep Hole in Fox Lake. Samples were not collected during the drawdown in 1997.

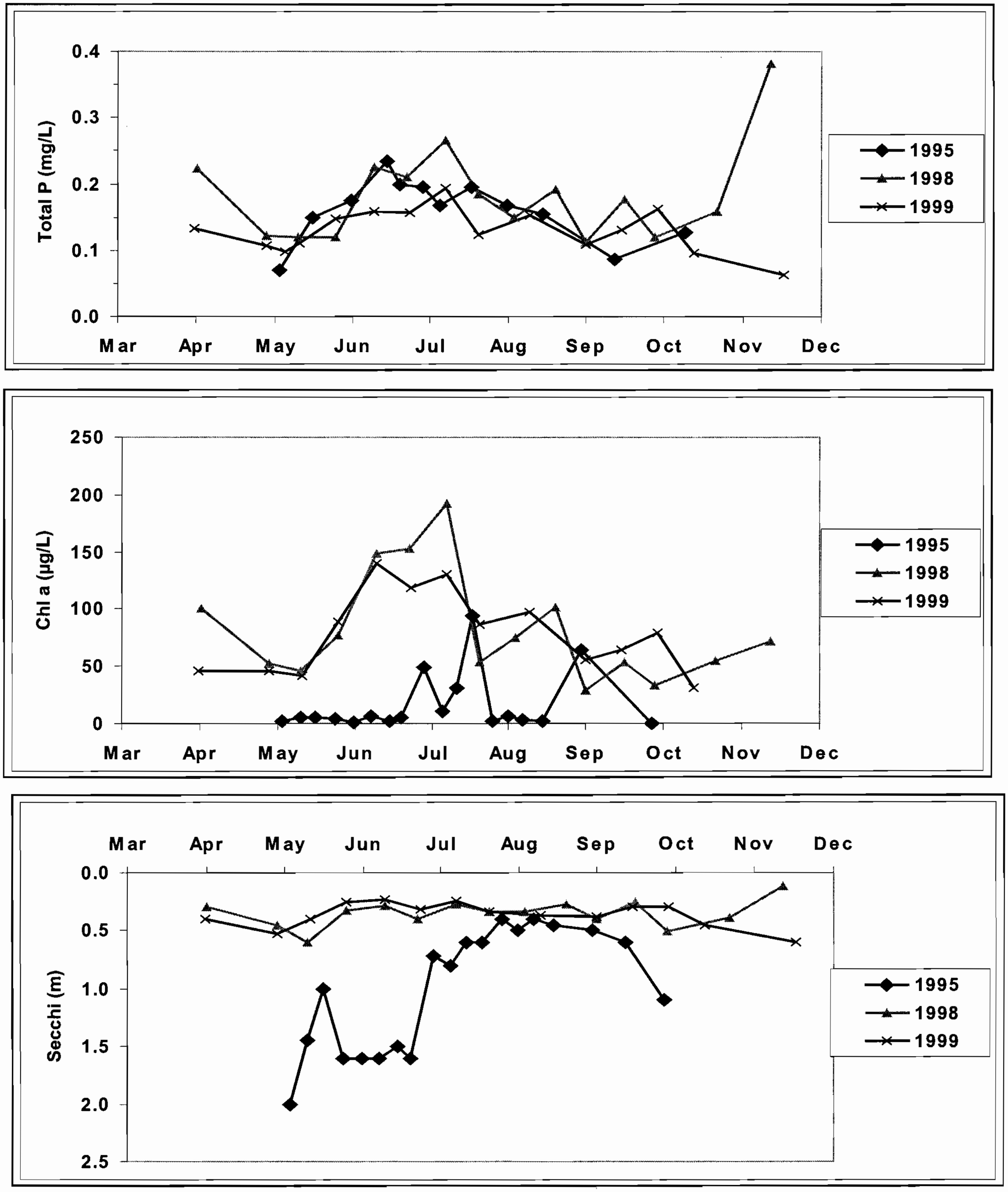


Figure 6. Seasonal trends in a) total P, b) chlorophyll a, and c) Secchi depth in the East Basin of Fox Lake.

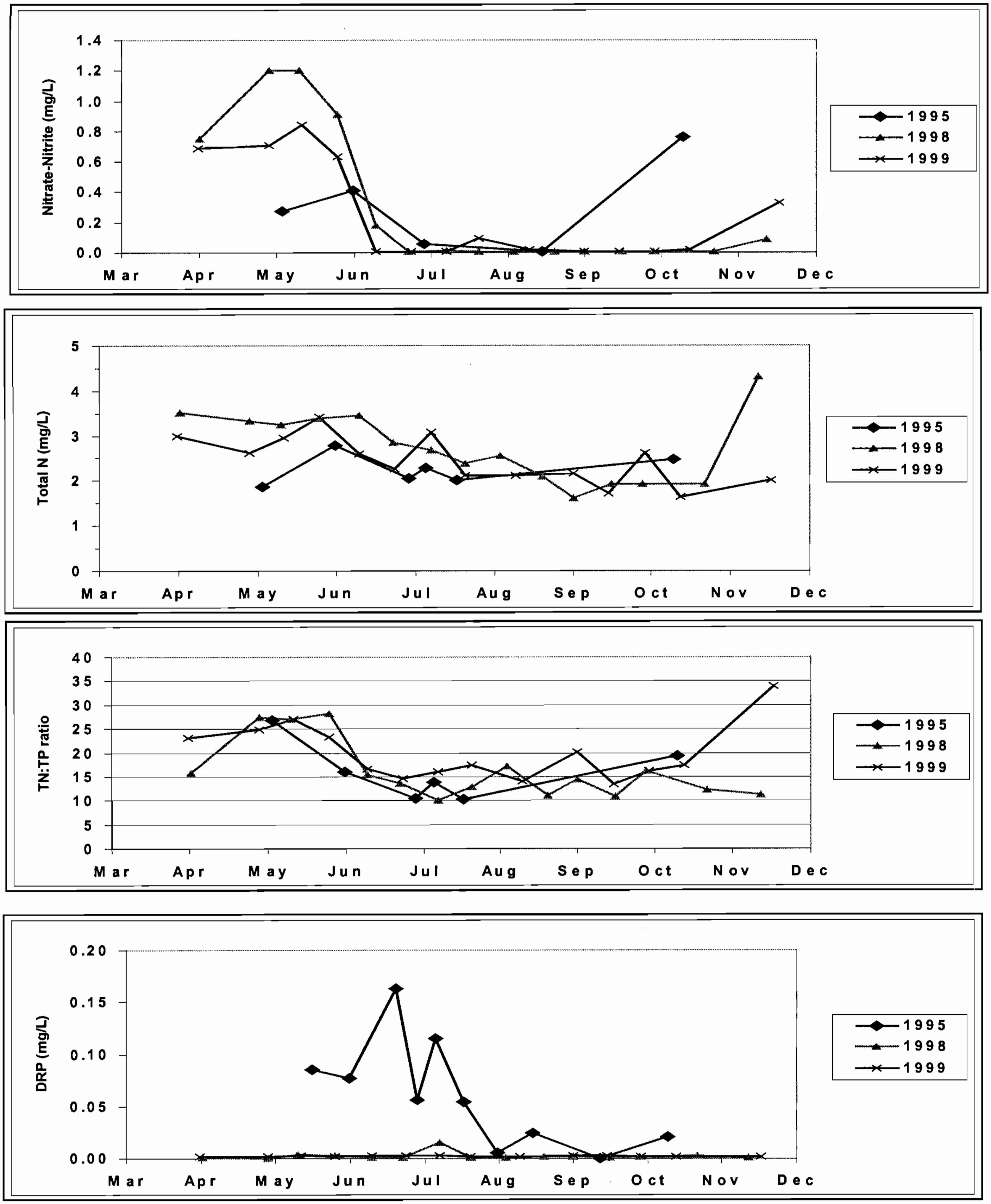


Figure 6 (cont). Seasonal trends of a) NO_3-N, b) total N, c) N:P, and d) DRP in the East Basin of Fox Lake.

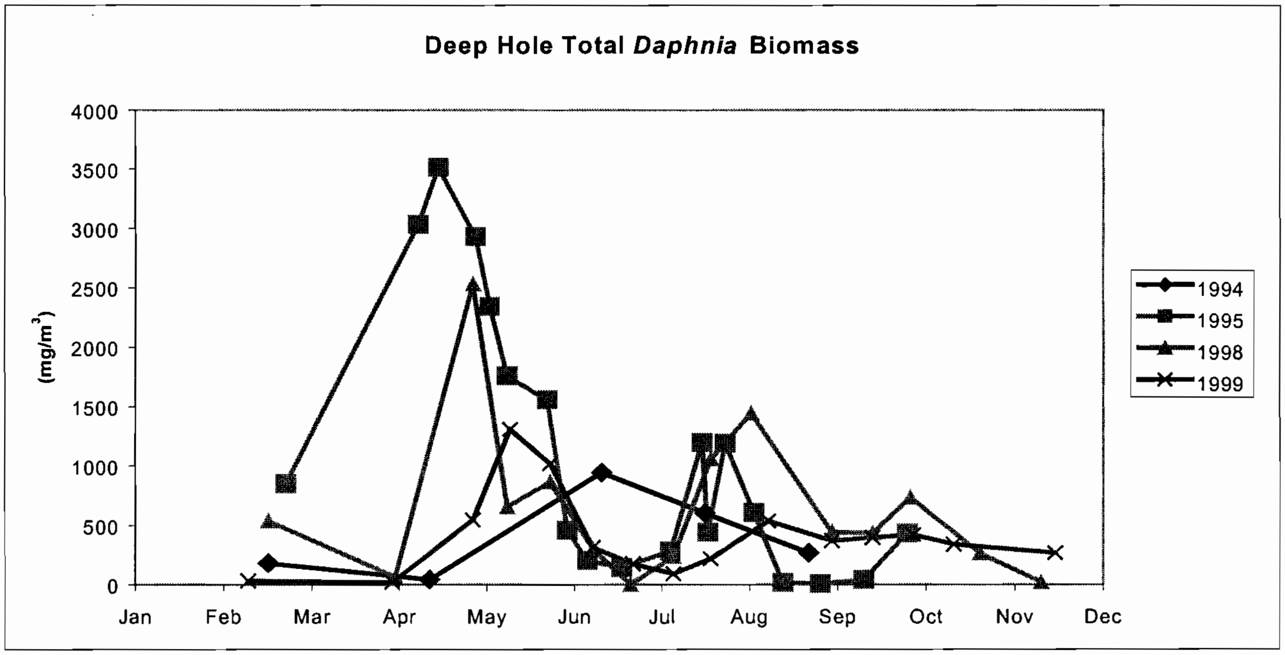


Figure 7. ***Daphnia*** **biomass in the Deep Hole of Fox Lake.**

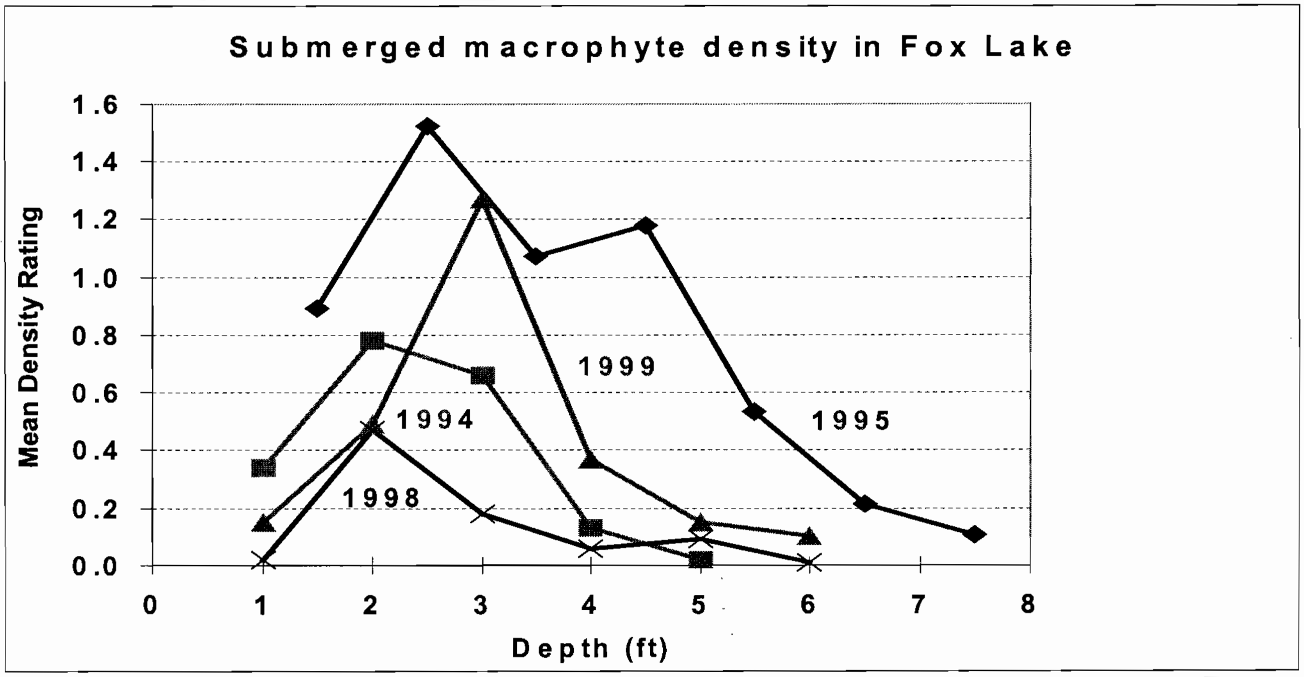
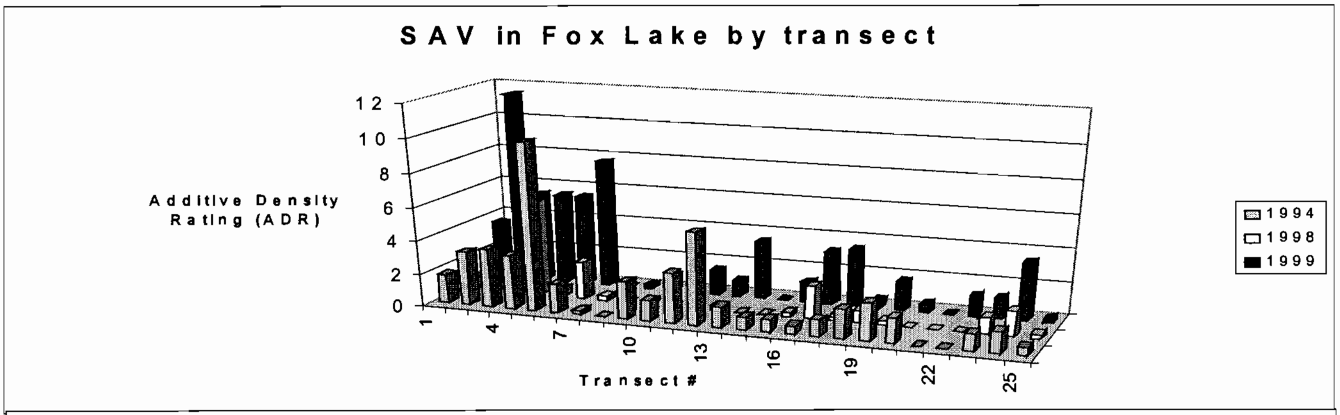
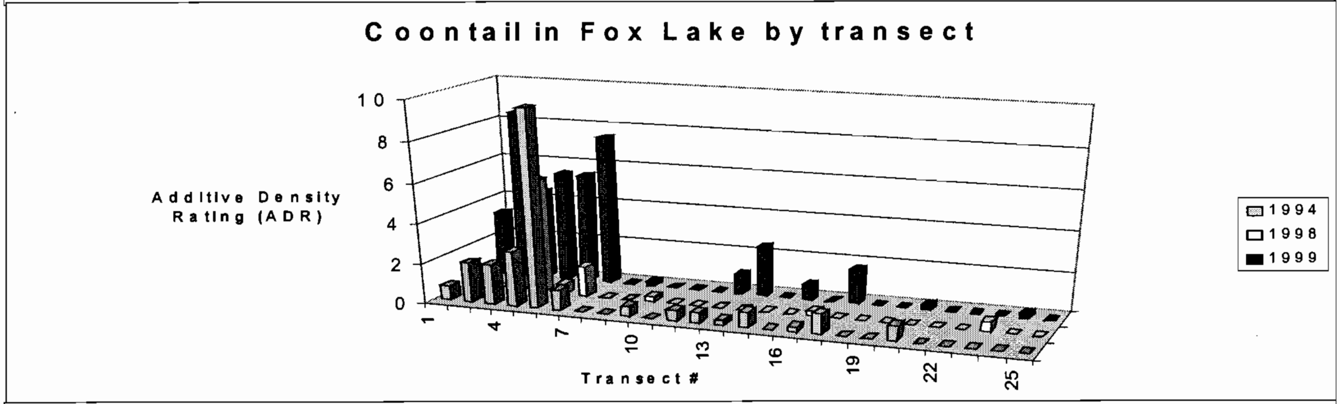
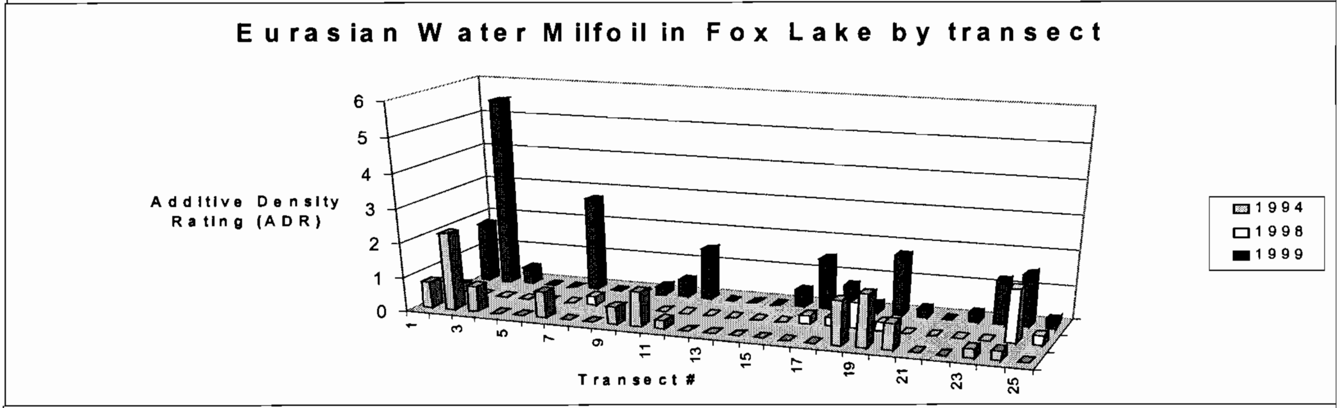


Figure 8. Seasonal densities of submerged vegetation for 2 years prior to drawdown and 2 years following the drawdown.


SAV in Fox Lake by transect


Coontail in Fox Lake by transect


Eurasian Water Milfoil in Fox Lake by transect

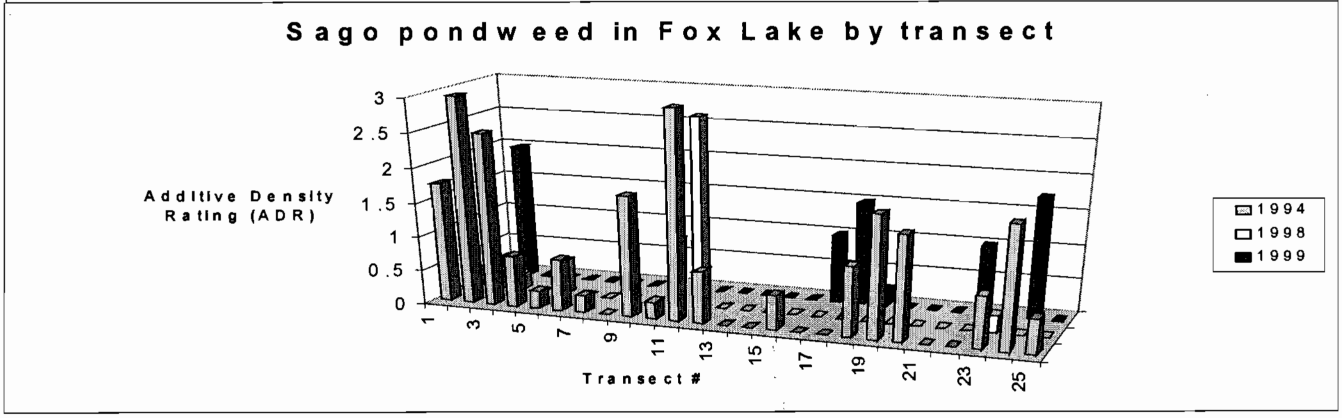

Sago pondweed in Fox Lake by transect

Figure 9. Additive density ratings of common macrophytes in 1994,1998, and 1999.

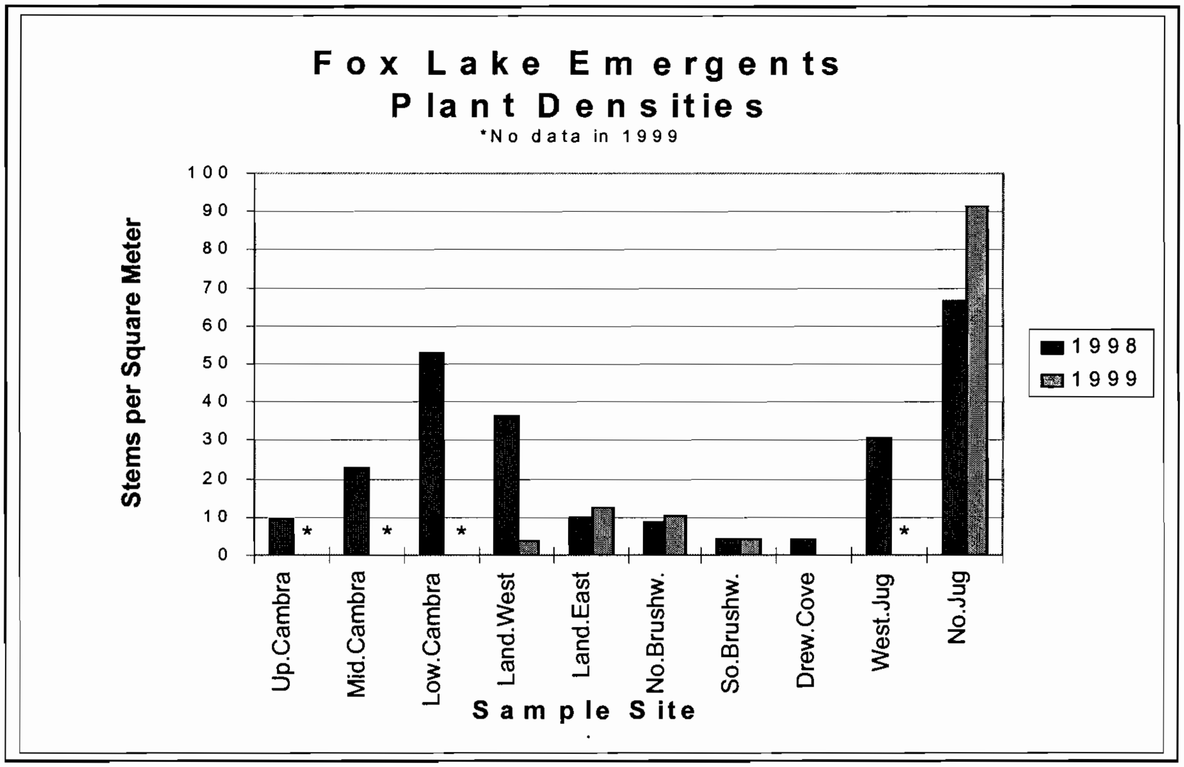


Figure 10. Density if emergent vegetation during for the 2 years following the drawdown.

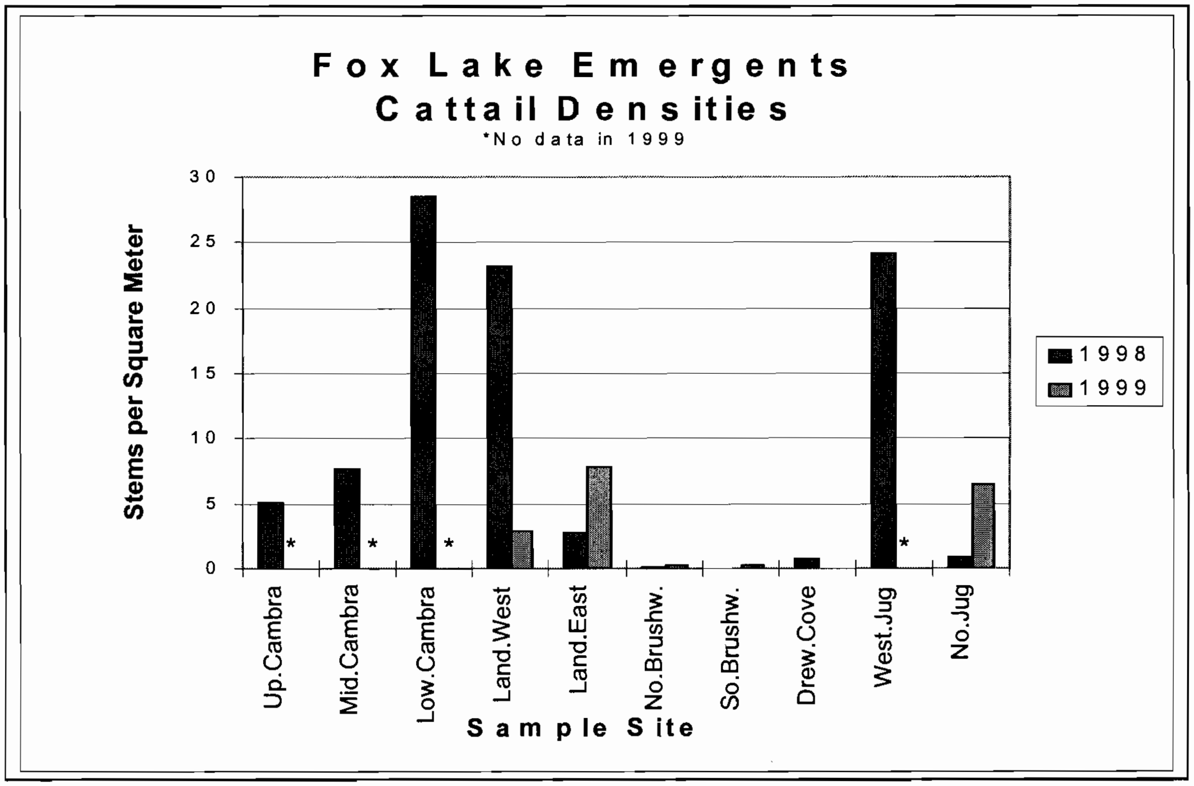


Figure 11. Densities of cattails for the 2 years following the drawdown.

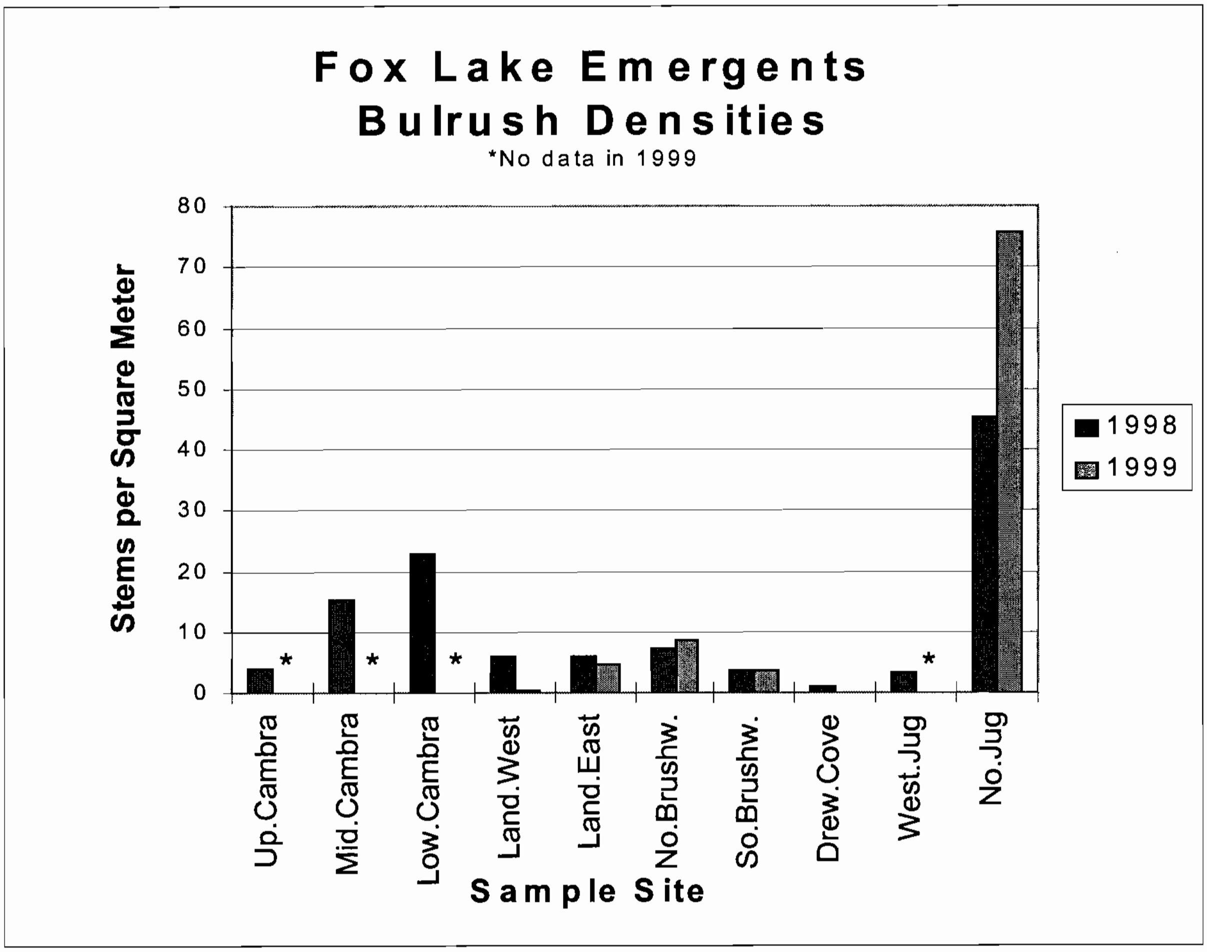


Figure 12. Densities of bulrush for the 2 years following the drawdown.

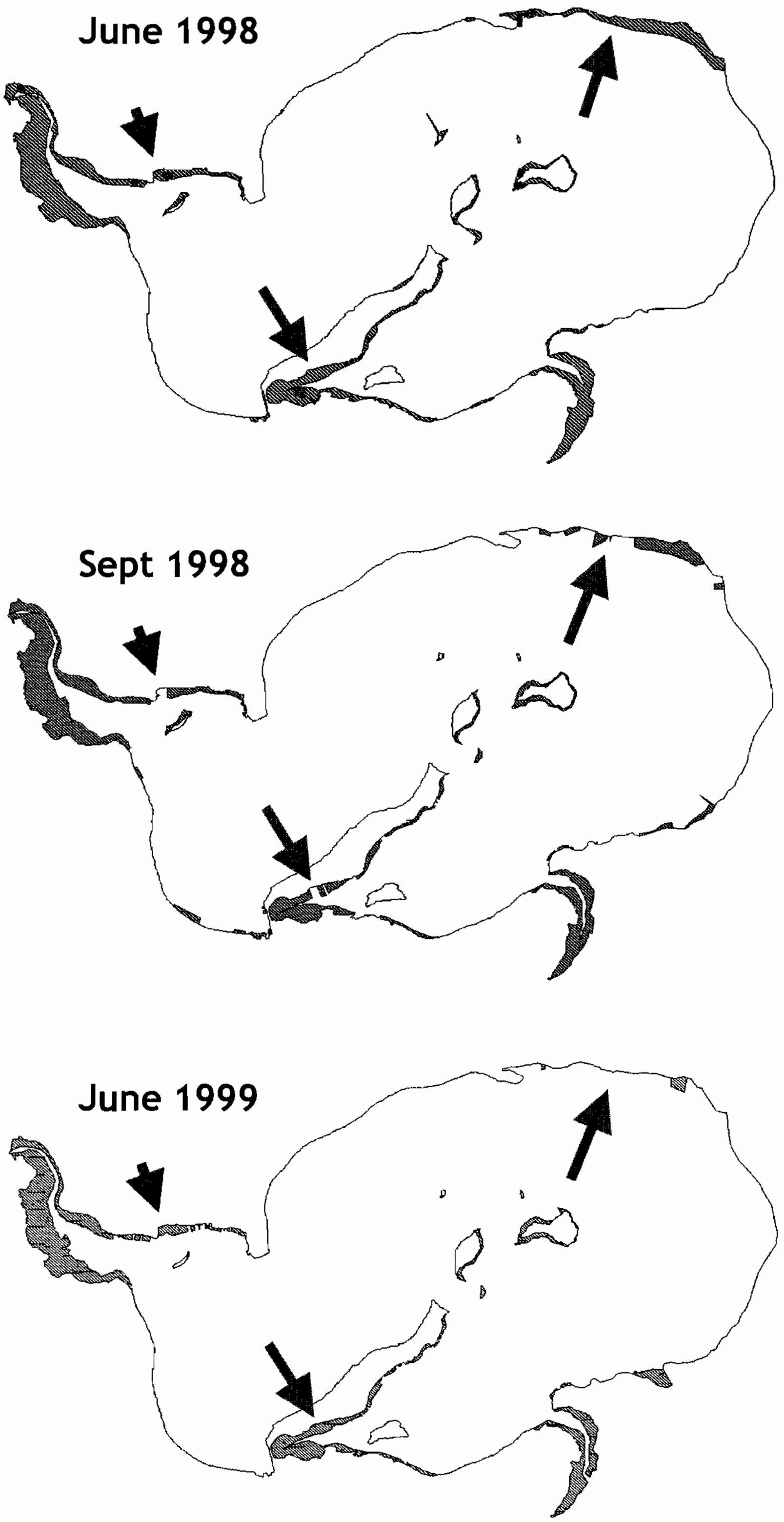


Figure 13. Maps showing changes in emergent vegetation following the drawdown in 1997. Arrows indicate areas where changes occurred in the emergent vegetation.

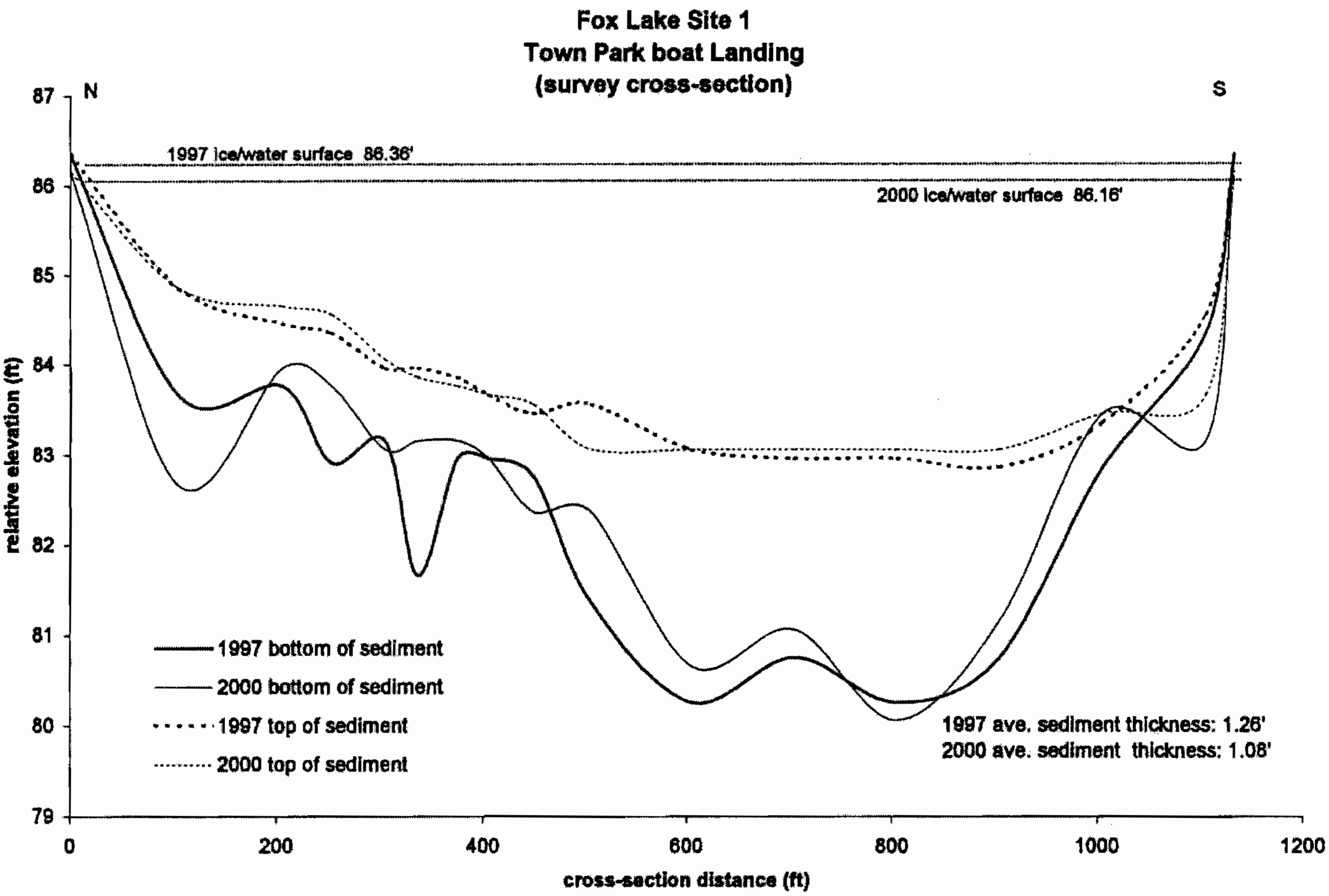


Figure 14. Comparison of sediment thickness before and after the drawdown at Site 1 - Town Boat Landing.

THE JUG

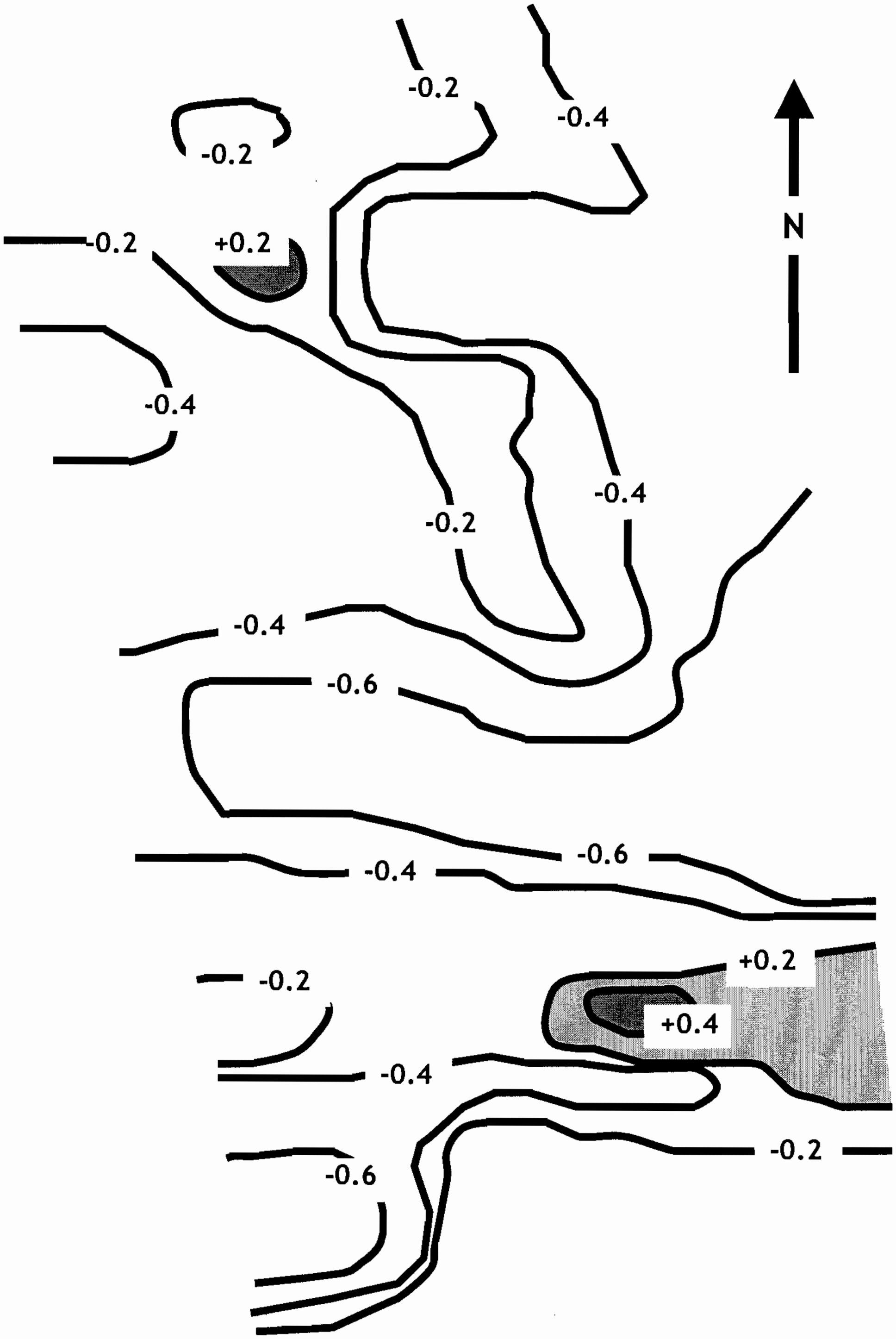


Figure 15. Differences in sediment surface at the Site 3 - The Jug, before and after the drawdown. The shaded areas represent decreased water depth after the drawdown.

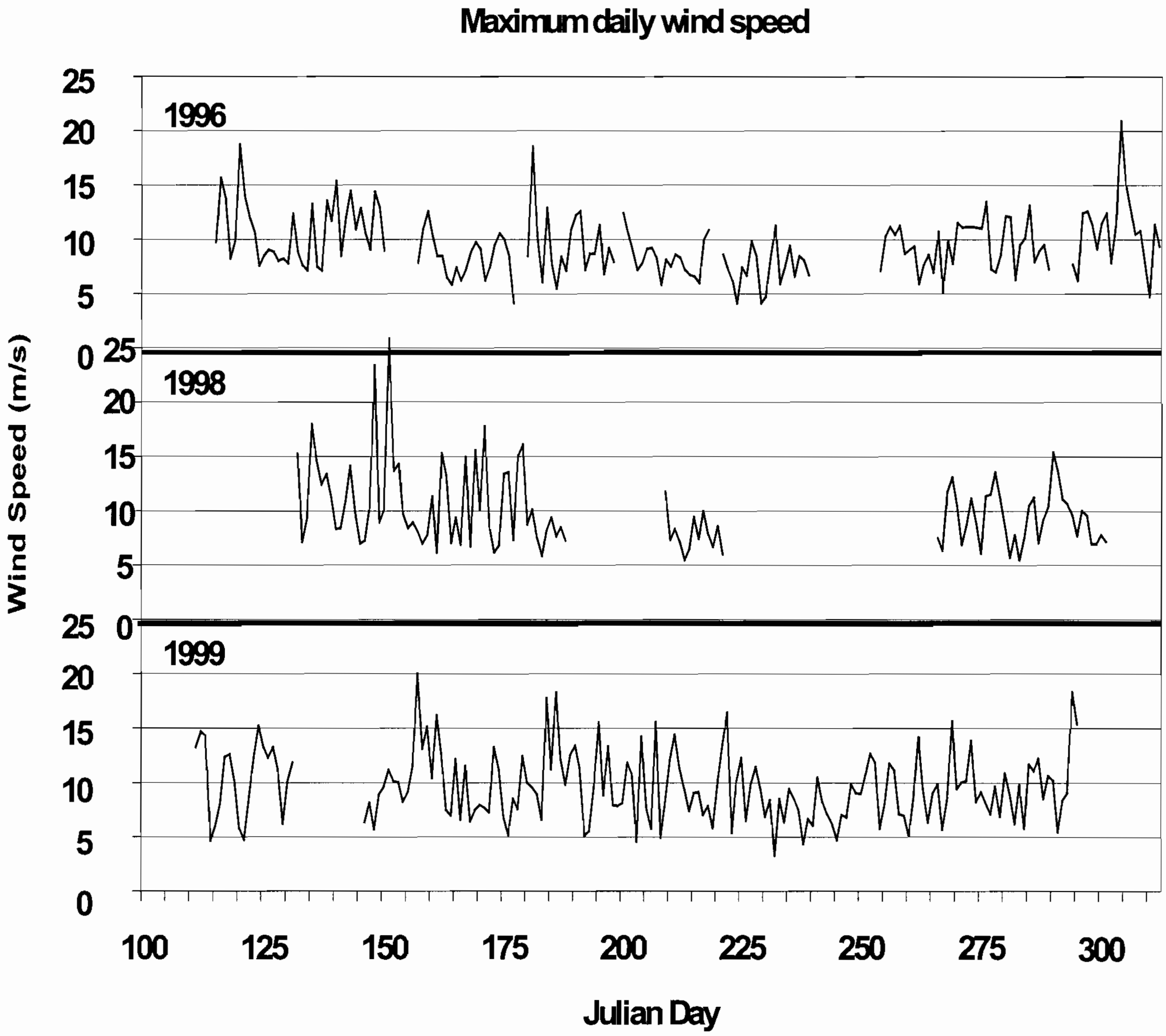


Figure 16. Maximum daily wind speed measured at the Deep Hole of Fox Lake in 1996 and 1998 and the East Basin in 1999, in meters per second. No data was collected during the gaps between the points.

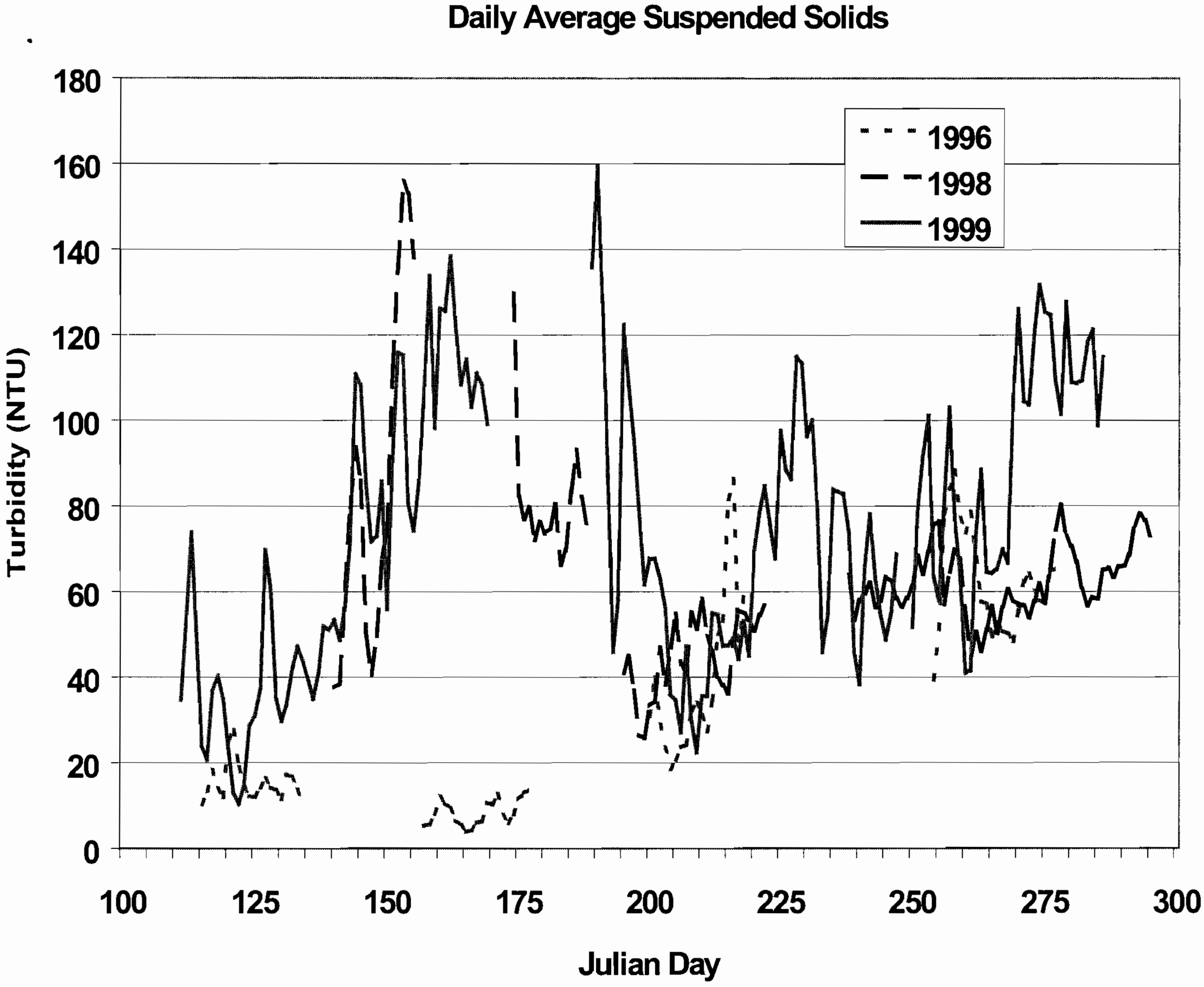


Figure 17. Daily average suspended solids measured in the deep hole during 1996 and 1998, and the East Basin in 1999. Suspended solids was inferred from the turbidity data.

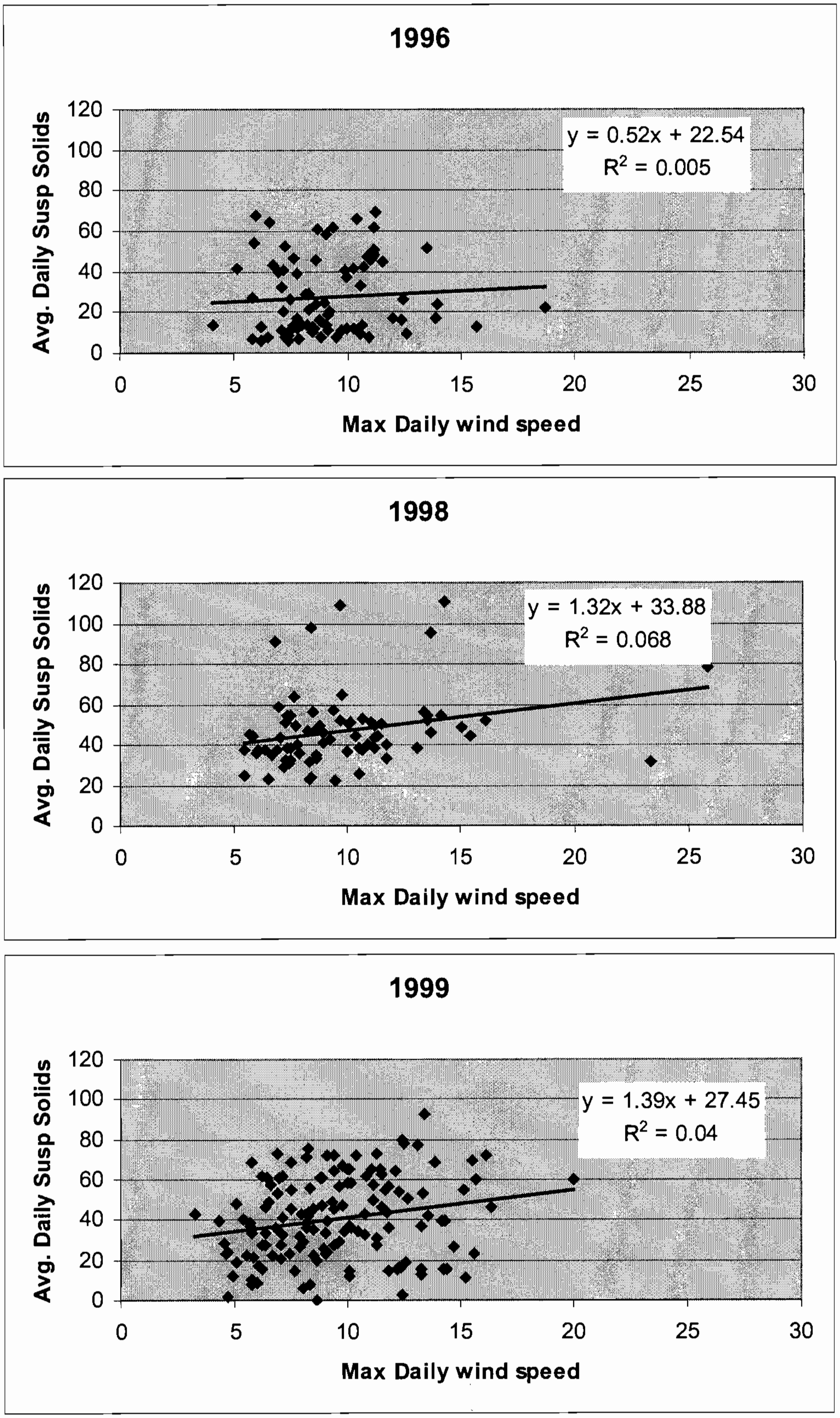


Figure 18. Influence of wind speed on suspended solids in the deep hole in 1996 and 1998, and the East Basin in 1999.