second most important factor to consider is water temperature. Barriers should be placed during cooler months of the year when microbial decomposition rates are at a low point, thus decreasing the rate of release of barrier-buoying gases. When large areas are to be covered with benthic barriers and substantial gas evolution cannot be avoided, benthic barriers should be mechanically affixed to the sediment surface.

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Establishment and Impact of Redbelly Tilapia in a Vegetated Cooling Reservoir

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ABSTRACT

Redbelly tilapia (*Tilapia zilli* Gervais) rapidly established a reproducing population in a North Carolina power plant cooling reservoir after inadvertent introduction in 1984. It eliminated the submersed macrophyte community, including a 57-ha infestation of *Egeria densa* (Planch.) by late 1985. In August 1985, just prior to macrophyte disappearance from the reservoir, the mean estimates of redbelly tilapia density and standing crop were 1,080 fish/ha and 16.6 kg/ha, respectively. When macrophytes were scarce or absent, redbelly tilapia shifted to a diet dominated by detritus. The ability of redbelly tilapia to switch to alternate food sources permitted its population to continue expanding in the absence of macrophytes, the preferred food. Changes in water quality were minimal after macrophyte removal with no increased nutrient enrichment. Factors leading to the establishment of redbelly tilapia were an overwintering refuge provided by continuous thermal discharge > 10 C from the power plant, a paucity of predators largemouth bass (*Micropterus salmoides* Lacepéde) and bluegill (*Lepomis macrochirus* Rafinesque), and the species' ability to utilize alternate food sources following macrophyte removal.

Key words: Egeria densa, macrophyte control, biological control, herbivorous fish, *Tilapia zilli*

INTRODUCTION

Redbelly tilapia (*Tilapia zilli* Gervais), a cichlid native to Africa and the Middle East, has been introduced in the United States for aquatic macrophyte control (Shireman 1984). Because of its inability to survive at water temperatures < 10 C, redbelly tilapia must usually be restocked

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annually in temperate regions to produce effective long-term control of macrophytes. This species has established self-sustaining populations where temperatures are suitable for overwintering such as in Arizona and California or in thermal springs and heated power plant discharges (Legner et al. 1975, Fitzpatrick et al. 1981, Courtenay et al. 1984).

The use of redbelly tilapia to control aquatic macrophytes has produced mixed results depending upon the initial stocking density, the target macrophyte species, and the presence of native fish (Legner et al. 1975, Hauser 1976,[3] Shireman 1984). Sexually mature adults are usually stocked with macrophyte control achieved through the high survival and growth of offspring. Some field and laboratory studies have suggested that redbelly tilapia prefer soft-bodied macrophytes over coarse-textured plants which may influence the effectiveness of the species to control a wide variety of macrophytes found in most reservoirs (Rickel 1975, Fitzpatrick et al. 1981, Saeed and Ziebell 1986).

The objectives of this paper are to (1) document the establishment and expansion of a redbelly tilapia population in a North Carolina power plant cooling impoundment, Hyco Reservoir, over a 6-year period; (2) discuss the impact of this species on the aquatic macrophyte community and water quality; (3) evaluate the feeding behavior of redbelly tilapia in the absence of macrophytes; and (4) provide insight into the factors leading to the successful establishment of this species.

MATERIALS AND METHODS

This study was conducted at Hyco Reservoir, a 1,760-ha impoundment located in north-central North Carolina, approximately 16 km northwest of Roxboro (Figure 1). Hyco Reservoir was constructed by Carolina Power & Light Company (CP&L) during 1964 to provide condenser cooling water and receiving waters for ash pond effluent for the four-unit, coal-fired Roxboro Steam Electric Plant. The power plant has 2,462 megawatts of generating capacity that provides year-round warmwater discharge into Hyco Reservoir. Winter discharge area water temperatures were 14.0 to 24.8 C from December 1984 through March 1990 (CP&L unpublished data).

Hyco Reservoir is a mesotrophic impoundment with a retention time of approximately 180 days (Mallin 1986). The reservoir is dendritic with four major tributaries: Cane Creek Complex, Cobb's Creek, North Hyco River, and South Hyco River. Heated effluent enters the reservoir at the confluence of the North and South Hyco Rivers (Figure 1). Six transects were sampled for fish, macrophytes, and water during the 1982 through 1989 study period: Transect 1 (Cobb's Creek), Transect 2 (North Hyco), Transect 3 (South Hyco), Transect 4 (discharge area), Transect 5 (midreservoir area below the discharge), and Transect 9 (Cane Creek Complex) (Figure 1). Transects 1, 2, and 3 supported locally abundant stands of naiad *Najas minor* (All.) and *Nitella* sp. in shallow coves; Transects 4 and 5 supported few or no macrophytes; and Transect 9 was heavily infested with egeria (*Egeria densa* Planch.) (Figure 1).

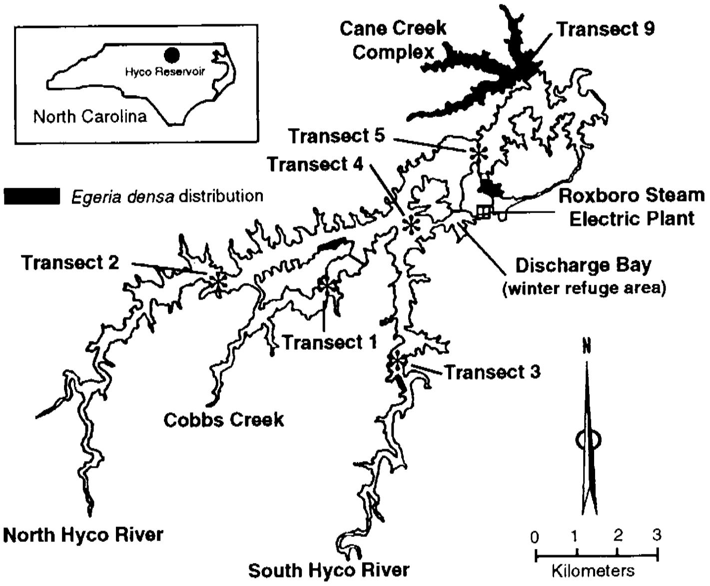

Figure 1. Map of Hyco Reservoir, North Carolina, showing location of sample transects and areas (shaded) of *Egeria densa* (Planch.) infestation prior to introduction of redbelly tilapia.

The relative abundance of redbelly tilapia and other species of fish was determined from annual cove rotenone sampling conducted each August. The sampled coves were located adjacent to established sampling transects. Excluding 1988, samples were collected from the coves at Transects 3, 4, and 9 during the 1983 to 1989 period. The Transect 1 cove was sampled on alternate years from 1983 to 1987, while the Transect 2 cove was sampled on the same alternate year schedule and again in 1989. Cove rotenone procedures followed those outlined by Grinstead et al. (1978). All fish were identified, measured to the nearest mm (total length), and weighed to the nearest gram. The most abundant fish taxa were subsampled for length and weight measurements.

Qualitative survey sampling for aquatic macrophytes was conducted biannually (i.e., spring and fall) at selected sites at Transects 1, 2, 3, 4, and 9 from 1982 to 1986. The surveys consisted of slowly traversing littoral areas < 2 m in depth with an airboat to visually identify macrophyte species and estimate their relative abundance. Quantitative sampling of egeria biomass was conducted monthly from June 1982 through May 1983 in three 1-ha coves at Transect 9. In each cove, 12 samples were collected with a Grontved sampler (Grontved 1957) along stations established at the 1- and 2-m depth. Each sample was washed to remove debris and weighed to the nearest gram after removing excess water. Subsamples of approximately 50 g were taken from each sample for percentage dry weight determination. The subsamples were weighed to the nearest 0.01 g, dried in a forced draft oven for 72 hours at 80 C, and reweighed for determination of percentage dry weight.

Surface water chemistry samples were collected monthly at Transects 3, 4, and 5 from 1982 to 1986 and

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[3] Hauser, W. J. 1976. *Tilapia* can replace herbicides. Seventh Ann. Conf. Calif.-Nev. Chap. Amer. Fish. Soc. Mimeographed paper.

bimonthly during 1988 and analyzed using standard methods (USEPA 1979, APHA 1986). Total nitrogen (TN), total phosphorus (TP), dissolved molybdate reactive phosphorus (DMRP), nitrate-nitrite nitrogen (NO_3-NO_2-N), and alkalinity concentrations were measured. Secchi disk transparency was also measured. The 1982 to 1983 and 1984 to 1988 periods represent "pre-tilapia" and "post-tilapia" conditions, respectively. Water chemistry variables were analyzed with one-way analysis of variance (ANOVA) for each transect. Fisher's protected least significant difference test was utilized to separate means for a variable if there was a significant F-test with ANOVA. The statistical tests were performed using the General Linear Models Procedure of the Statistical Analysis System (SAS®). A Type I errror rate of 5% ($\alpha = 0.05$) was used to judge the significance of the tests.

Dietary habits of redbelly tilapia were determined from fish collected during August 1985 rotenone sampling at Transects 1, 2, 4, and 9 and at Transect 4 with electrofishing during February 1986. Although rotenone sampling is not a desirable collection technique for stomach analysis due to possible regurgitation or incidental predation (Bowen 1983), collecting tilapia by electrofishing or seining was extremely difficult during the warm months (water temperatures > 20 C). These difficulties necessitated the use of rotenone to obtain a sufficient sample size for analysis. Only fish that immediately surfaced after rotenone application on the first day were retained for analysis. Fish were netted and immediately placed on ice to stun them and minimize regurgitation. Ten percent buffered formalin was injected into each stomach to preserve the contents.

In the laboratory, stomachs were excised, blotted dry, and weighed to the nearest 0.1 g. The stomachs were opened and the volume of contents determined to the nearest 0.1 ml. The contents were scanned under a dissecting microscope for macrophyte material, benthic invertebrates, zooplankton, and an other material; quantified; and identified to the lowest recognizable taxa. Stomach contents were subsampled with a 5-ml pipette, placed in a Sedgewick-Rafter cell, and examined under a compound microscope for phytoplankton identification and enumeration. Estimation of the percent composition of the content was made for each stomach. Frequency of occurrence and volumetric percent composition of stomach contents for each transect were computed from the individual stomachs.

RESULTS

Redbelly tilapia were inadvertently introduced into Hyco Reservoir from an on-site aquacultural study during early 1984. The exact number of redbelly tilapia released was not known, but we estimated that no more than 100 fish escaped from a holding cage located in the discharge area (Dr. William W. Hassler, personal communication). In August 1984 the mean density and standing crop estimates of redbelly tilapia were 203/hectare and 2.5 kg/hectare, respectively, and increased approximately tenfold by 1989. By 1989, redbelly tilapia comprised 6.7% of the total mean density and was the fourth most abundant species of fish behind green sunfish, gizzard shad, and satinfin shiner. By weight, redbelly tilapia ranked fifth in relative abundance or 9.5% of the total mean standing crop estimate during 1989 (Table 1). Blue tilapia (*Tilapia aurea* Steindachner) were also released into the reservoir during the same period that redbelly tilapia escaped, although the blue tilapia was not detected until August 1985 (Table 1). The blue tilapia population consistently increased during the 1985 to 1989 period; however, unlike redbelly tilapia, this species remained a minor component of the fish community.

TABLE 1. MEAN DENSITY (NO./HA) AND STANDING CROP (KG/HA) OF MAJOR TAXA OF FISHES COLLECTED DURING COVE ROTENONE SAMPLING AT HYCO RESERVOIR, 1983-1989.

	Year											
	1983		1984		1985		1986		1987		1989	
Taxa	No./ha	Kg/ha	No./ha	Kg/ha	No./ha	Kg/ha	No./ha	Kg/ha	No./ha	Kg/ha	No./ha	Kg/ha
Gizzard shad	6,069	44.2	8,691	97.6	3,975	64.8	872	29.4	5,946	62.6	10,695	81.0
Satinfin shiner	3,812	1.5	3,516	1.8	2,163	2.5	4,563	3.4	5,973	3.0	4,385	2.5
Common carp	13	30.8	11	32.3	5	4.4	6	9.6	3	6.7	20	38.9
Moxostoma sp.	54	5.3	11	1.1	61	51.1	2	0.6	6	0.7	9	5.8
Channel catfish	71	31.2	77	4.4	151	27.3	58	28.4	41	16.9	30	14.4
Ictalurus sp.	592	11.7	367	15.1	371	16.3	62	3.5	224	6.7	598	35.1
Green sunfish	27,444	56.1	23,802	52.9	10,997	56.4	3,793	24.3	10,578	23.9	10,514	54.3
Bluegill	6,373	32.2	1,154	13.3	3,184	29.3	389	10.7	481	4.1	565	5.8
Largemouth bass	6	0.6	6	<0.1	25	1.0	13	0.3	3	<0.1	3	0.2
Redbelly tilapia	0	0	203	2.5	1,080	16.6	783	15.9	1,694	11.9	1,996	25.8
Blue tilapia	0	0	0	0	17	0.5	29	1.4	45	1.2	121	3.4
Crappie[1]	18	0.3	1	<0.1	17	0.5	0	0	1	<0.1	12	1.0
Other taxa[2]	4,905	12.9	1,896	9.1	2,196	13.7	801	6.9	1,574	4.2	971	4.2
Total	49,357	226.8	39,735	230.2	24,242	284.4	11,371	134.4	26,569	141.9	29,919	272.4
Sample size (n)	5		3		5		3		5		4	

[1] Black and white crappie.

[2] Other taxa included golden shiner, spottail shiner, bluehead chub, creek chubsucker, margined madtom, mosquitofish, hybrid sunfish, redbreast sunfish, pumpkinseed, warmouth, and yellow perch.

As a result of selenium bioaccumulation through the food web from continuous ash pond discharge into Hyco Reservoir during recent years, the composition of the fish community had been altered with the major native predator fish, largemouth bass (*Micropterus salmoides* Lacepède), rendered almost nonexistent throughout the reservoir (Table 1). Declines in largemouth bass and bluegill (*Lepomis macrochirus* Rafinesque) populations resulting from reproductive failure were observed during the late 1970s and attributed through bioassay studies to elevated selenium levels within the reservoir (Gillespie and Baumann 1986). Because of the confounding effects of elevated selenium levels in Hyco Reservoir, changes in the fish community caused by the introduction of redbelly tilapia cannot be fully assessed. However, general trends in the dominance of fish species can be described for the study period. Prior to and after the tilapia introduction, the fish community was numerically dominated by green sunfish (*L. cyanellus* Rafinesque), satinfin shiner (*Notropis analostanus* Girard), and gizzard shad (*Dorosoma cepedianum* Günther) (Table 1). The relative abundance of largemouth bass was less than 1% of the total fish density, while bluegill abundance ranged from 1.8% to 13.1% during the study period. Largemouth bass usually comprise at least 5 to 6% of the total standing crop in southeastern United States impoundments (Davies et al. 1982). More detailed information on the fish community of Hyco Reservoir is given in CP&L (1986[4]).

Prior to the 1984 introduction of redbelly tilapia, eight taxa comprised the submersed aquatic macrophyte community (Table 2). Qualitative observations indicated *Nitella* sp. and naiad were locally abundant in many coves (< 4 m deep) throughout the reservoir. Pondweed (*Potomageton diversifolius* Raf.) and spikerush (*Eleocharis baldwinii* Torr.) were widely distributed and occurred in isolated patches. *Hydrilla verticillata* (L.f) Royle also occurred in several small patches (usually < 2-m diameter) near a public boat ramp at Transect 2. The dominant macrophyte in Hyco Reservoir prior to the redbelly tilapia introduction was egeria, particularly in the Cane Creek Complex (Transect 9). Initially discovered in Hyco Reservoir during 1974, egeria spread rapidly throughout the Cane Creek Complex and infested a cumulative surface area of approximately 57 hectares by 1983 (Schiller 1983). Surveys with a recording depth finder showed all depths ≤ 3 m in the Cane Creek Complex were infested with egeria. Several smaller stands of egeria (< 10 hectares) also occurred throughout the reservoir.

From June 1982 through May 1983, egeria biomass ranged from 142 to 318 g/m^2 dry weight with a mean biomass of 221 g/m^2 ± 16.5 SD (data not shown). No quantitative biomass samples of egeria were collected after May 1983; however, regular qualitative observations continued through 1989. During 1984, the total areal coverage of egeria appeared similar to the coverage observed during 1983; but there was a noticeable decline in the amount reaching the surface. By 1985, nearly all macrophytes, excluding small, isolated occurrences of naiad and egeria, had disappeared from Hyco Reservoir (Table 2). By early September 1985, littoral areas within the Cane Creek Complex that had previously supported dense stands of egeria during the 1982 through 1983 period were almost devoid of vegetation. The egeria that remained grew in scattered patches approximately 1 m in diameter. Many of the lateral and apical meristems of the remaining egeria were tattered or missing which suggested grazing activity by redbelly tilapia. After 1985 no submersed macrophytes were observed in Hyco Reservoir (Table 2).

TABLE 2. RELATIVE ABUNDANCE[1] OF SUBMERSED AQUATIC MACROPHYTES FROM QUALITATIVE VISUAL SURVEYS OF HYCO RESERVOIR, 1982-1986.[2]

	Year				
Taxa	1982	1983	1984	1985	1986
Nitella sp.	+ + +	+ + +	+ + +	0	0
Potamogeton crispus	+	+	0	0	0
P. diversifolius	+ +	+ +	+ +	0	0
Najas guadalupensis	0	+ +	+ +	0	0
N. minor	+ + +	+ + +	+ +	+	0
Eleocharis baldwinii	+ +	+ +	0	0	0
Egeria densa	+ + +	+ + +	+ + +	+	0
Hydrilla verticillata	0	+	+	0	0

[1] 0 = absent, + = isolated occurrences, + + = scattered throughout reservoir, + + + = locally abundant throughout reservoir.

[2] Visual surveys conducted after 1986 (1987-1990 period) indicated no submersed aquatic macrophytes throughout the reservoir.

No consistent, increasing trend was observed in TN, TP, and DMRP concentrations at Transects 3, 4, and 5 during or after macrophyte removal by redbelly tilapia (Figure 2). Total nitrogen, TP, and DMRP concentrations were generally lower during the macrophyte eradication period than concentrations observed in 1982 through 1983 prior to the tilapia introduction. A significant increase in NO_3-NO_2-N ($P \leq 0.05$, $F = 3.40$) was detected at Transect 5 after macrophyte removal; but no significant differences were found at Transects 3 and 4, although there appeared to be an increasing trend at those areas during the eradication period. Alkalinity was significantly higher during 1986 at Transects 3 ($P \leq 0.001$, $F = 11.16$), 4 ($P \leq 0.05$, $F = 2.52$), and 5 ($P \leq 0.001$, $F = 6.86$) when macrophytes completely disappeared. However, alkalinity at Transects 4 and 5 declined during 1988 with the values similar to those observed prior to macrophyte elimination. Secchi disk transparency did not decrease following macrophyte removal as would be expected if there was a shift towards increased phytoplankton production.

Examination of 121 stomachs from juvenile and adult redbelly tilapia during August 1985 (Table 3) indicated a diverse diet consisting primarily of organic detritus and filamentous algae (predominantly *Spirogyra* sp., *Oscillatoria* sp., and *Phormidium* sp.). Six categories of food items were consumed by redbelly tilapia throughout the reservoir: detritus (organic and inorganic); filamentous algae and phytoplankton; benthic invertebrates (chironomids, oligochaetes, and water mites); zooplankton (*Diaptomus* sp., *Sida crystallina, Bosmina longirostris, Keratella* sp., and Os-

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[4] CP&L. 1986. Roxboro Steam Electric Plant 1985 Environmental Monitoring Report. Carolina Power & Light Company. New Hill, NC.

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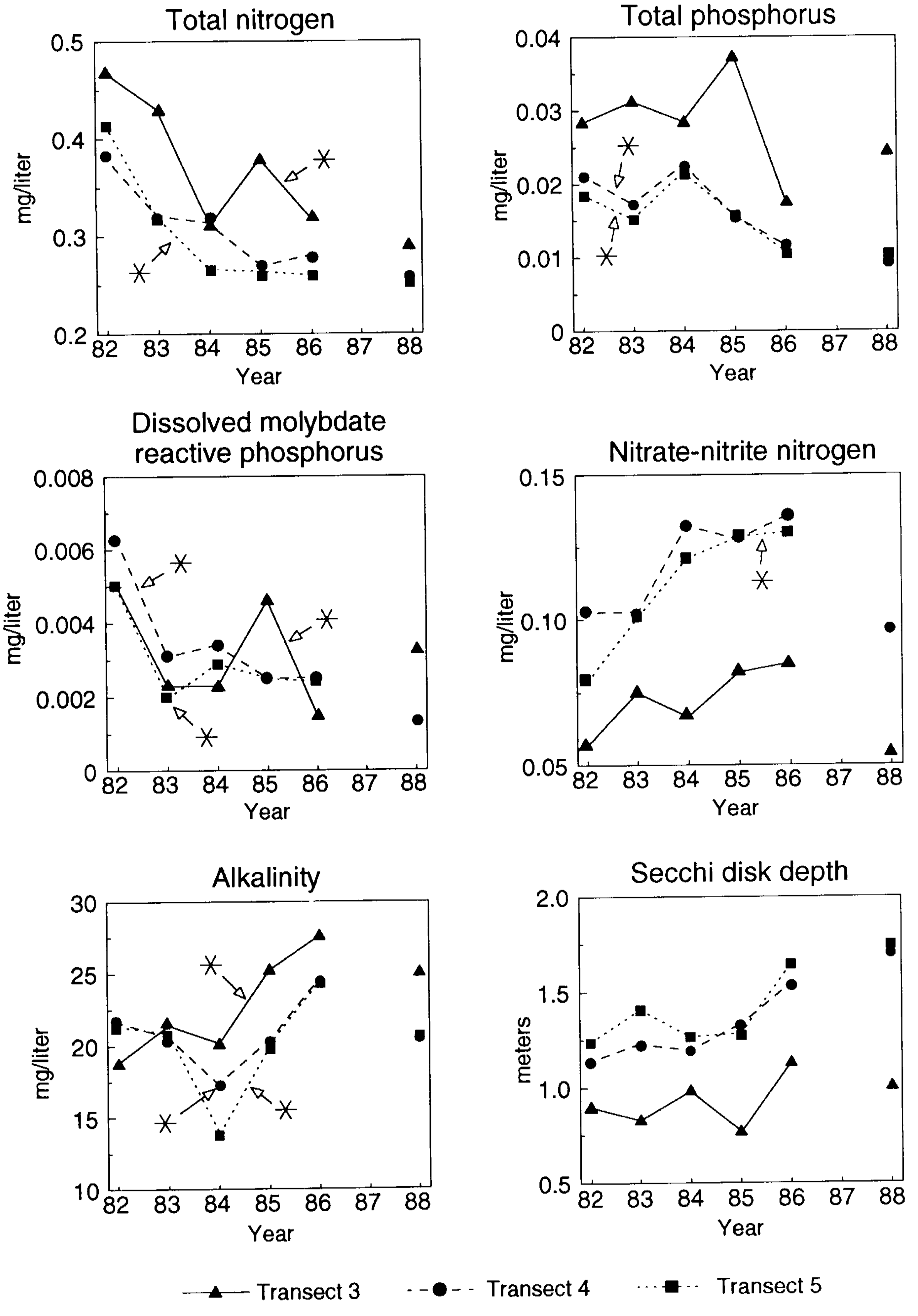

Figure 2. Temporal trends of selected water chemistry variables at Transects 3, 4, and 5 of Hyco Reservoir, 1982 to 1988. The symbol * denotes a significant difference at the P ≤ 0.05 level (Note: No samples were collected during 1987 and dissolved molybdate reactive phosphorus and nitrate-nitrite nitrogen were not measured at Transect 5 during 1988).

TABLE 3. PERCENT FREQUENCY OF OCCURRENCE (O) AND VOLUMETRIC COMPOSITION (V) OF FOOD ITEMS CONSUMED BY REDBELLY TILAPIA FROM VARIOUS AREAS OF HYCO RESERVOIR, AUGUST 1985. VALUES OF MISCELLANEOUS FOOD ITEMS (<10%) ARE OMITTED FROM THE TABLE.[1]

	Area									
	Transect 1		Transect 2		Transect 4		Transect 9		Whole Reservoir	
Food item	O	V	O	V	O	V	O	V	O	V
Organic detritus	92	38	91	50	100	64	55	13	85	41
Inorganic detritus	0	0	13	4	21	3	13	1	13	2
Filamentous algae	64	13	78	16	90	26	58	5	74	15
Benthic invertebrates	60	3	21	1	22	1	39	<1	36	1
Zooplankton	52	3	26	3	10	1	19	<1	24	2
Egeria densa	0	0	0	0	0	0	61	76	12	19
Fish scales	48	21	9	1	14	1	6	<1	18	6
Fish remains	32	16	9	21	12	3	19	4	17	11
Sample size	25		23		42		31		121	
Size range (mm) of fish	39-98		39-102		40-184		48-203		39-203	
Mean length (mm)	57		68		96		95		82	

[1] Miscellaneous items included other algae, ostracods, water mites, *Najas* sp., and unidentified macrophytes.

tracoda); macrophytes (egeria and *Najas* sp.); and fish remains.

Sixty-one percent of the redbelly tilapia stomachs from the vegetated Transect 9 contained egeria (Table 3). Organic detritus and filamentous algae were the most frequently occurring food items in redbelly tilapia stomachs from Transects 1, 2, and 4 which were sparsely vegetated at the time of sampling (August 1985). Volumetrically, stomach contents of fish from Transect 9 consisted of 76% egeria; 13% organic detritus; and 5% filamentous algae with the remaining material (6%) consisting of inorganic detritus, other algae, benthic invertebrates, zooplankton, and fish remains. Organic detritus and filamentous algae (> 50% of the stomach contents) comprised the bulk of the redbelly tilapia diet at Transects 1, 2, and 4. Benthic invertebrates and zooplankton were frequently consumed by redbelly tilapia; however, these two items comprised 6% or less of the total volume of the diet and appeared to have been ingested incidentally during consumption of detritus. In only a few stomachs were these items sufficient enough to indicate deliberate predation. Fish remains and scales were present in some stomachs suggesting some incidental predation.

Dietary analysis of redbelly tilapia overwintering in the nonvegetated discharge area (Transect 4) during February 1986 also indicated organic detritus as the major food item (Figure 3). Inorganic detritus comprised a minor component of the diet. Of the 68 stomachs examined, 32% were empty suggesting reduced feeding activity during the overwintering period. The length distribution of redbelly tilapia collected that had food items present in stomachs ranged from 66 to 158 mm (mean length = 103 mm; SD = 20.3).

DISCUSSION

Based on stomach analysis and visual observations, establishment of the redbelly tilapia population was responsible for elimination of the submersed macrophyte community within a 2-year period in Hyco Reservoir. No known published studies to date have documented complete elimination of macrophytes, including infestations of egeria, by redbelly tilapia in a large reservoir for the length of time (i.e., 6 years) documented in our study. The species has effectively controlled vegetation in smaller water bodies such as irrigation canals or ponds (Hauser 1975 and 1976[3], Legner et al. 1975, Rickel 1975, Fitzpatrick et al. 1981). In a laboratory experimental study of nonpreferred plant foods, Fitzpatrick et al. (1981) showed redbelly tilapia consumed smaller amounts of Eurasian watermilfoil (*Myriophyllum spicatum* var. *exalbescens* Fern) and egeria than *Chara* sp. and *Najas marina* (L.). Saeed and Ziebell (1986) also observed that redbelly tilapia consumed very little egeria during feeding experiments and concluded that lakes infested with egeria would probably need alternative control methods due to this nonpreference. Our field observations contradict these macrophyte preference results obtained under laboratory conditions and indicate redbelly tilapia will consume large quantities of "nonpreferred" food items such as egeria. Rickel (1975) also noted that redbelly tilapia shifted to *Najas* sp. after *Chara* sp., a preferred food item, was eliminated from experimental ponds in Arizona.

In August 1985 just prior to the total elimination of macrophytes from Hyco Reservoir, the mean density and

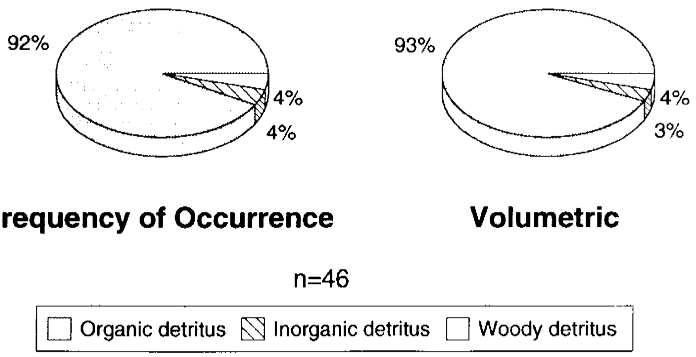

Figure 3. Frequency of occurrence and volumetric composition percentage of food items consumed by overwintering redbelly tilapia in the discharge area (Transect 4) of Hyco Reservoir during February 1986.

standing crop of redbelly tilapia reservoirwide were 1,080 fish/hectare and 16.6 kg/hectare, respectively. Hauser (1975) indicated that redbelly tilapia stocked at a density of 4,740 fish/hectare in Flax Canal, California, reduced aquatic macrophyte cover (primarily Eurasian watermilfoil) by 86% within a 5-month period. Hauser (1976[3]) also reported that 405 redbelly tilapia/hectare would effectively control but not eradicate aquatic macrophytes in California irrigation canals. Rickel (1975) stocked 61 pairs of redbelly tilapia broodstock per hectare and the subsequent F_1 generation achieved complete control of *Chara* sp. in ponds, but no final areal density or standing crop estimates of redbelly tilapia were given at the time of macrophyte control. The mean densities of redbelly tilapia in Hyco Reservoir during the 1984-1985 period when aquatic macrophytes were eliminated ranged from 203 fish to 1,080 fish/hectare which were lower than densities reported by Hauser for immediate eradication of macrophytes.

Although all macrophytes disappeared from the reservoir within the 2-year period, there was no consistent trend in increased nutrient enrichment or a concomitant decrease in Secchi disk transparency. However, NO_3-NO_2-N concentrations suggested an increasing trend as did alkalinity levels. Leslie et al. (1983) detected a significant increase in NO_3NO_2-N in two of four Florida lakes following macrophyte removal by grass carp (*Ctenopharygodon idella* Valenciennes). Increased alkalinity may have been related to decreased photosynthetic activity and the resulting release of carbonate ions following elimination of macrophytes during the 1984 through 1985 period. Noble et al. (1986) found significantly higher alkalinity concentrations in Lewis Creek Reservoir, Texas, following macrophyte removal by grass carp and suggested there was a release of $CaCO_3$ and $MgCO_3$ formerly bound in the macrophytes into the water column. Mitzner (1978) reported a significant increase in alkalinity following a 91% reduction of aquatic macrophytes by grass carp in the 29-ha Red Haw Lake, Iowa. Increases in alkalinity have not always been consistently observed following macrophyte removal. Lembi et al. (1978) found no change or a slight decrease in alkalinity in experimental ponds stocked with grass carp over a 2-year period. A significant increase in alkalinity was observed in only one of four Florida lakes in the Leslie et al. (1983) study.

Our inability to detect any consistent large-scale changes in nutrient concentrations in Hyco Reservoir following macrophyte removal was probably related to the relatively free-flowing nature of a mainstem impoundment with a retention time of 180 days, the varying effects of watershed nutrient inputs particularly at Transect 3 during the study period, and the relative amount of macrophyte biomass removed compared to the total surface area and volume of the reservoir.

Three major factors appeared to be responsible for the successful establishment and expansion of redbelly tilapia present at Hyco Reservoir. First, the thermal discharge of the Roxboro Steam Electric Plant provided sufficient overwintering conditions since the species introduction. The power plant supplies 26% of CP&L's generating capacity and has not shut down for extended periods during the winter months which would induce large-scale mortality of redbelly tilapia from cold shock. Water temperatures in the overwintering discharge area remained above 10 C throughout the study period which has been reported as the lower lethal temperature for redbelly tilapia (Chervinski 1982).

A second factor was the lack of largemouth bass and, to a lesser extent, adult bluegill in Hyco Reservoir resulting from selenium bioaccumulation and subsequent reproductive failure. Hauser (1976[3]) documented heavy predation on redbelly tilapia by adult largemouth bass and channel catfish in Rositas Canal, California, and suggested predation lowered the redbelly tilapia population and subsequently reduced its grazing impact on macrophytes. Fitzpatrick et al. (1981) observed largemouth bass attacking schools of young-of-year redbelly tilapia in an experimental pond; however, no data were presented to show relative predation effects on the tilapia population. The authors concluded that stocking redbelly tilapia in ponds without other species of fish could provide an effective means of control of some macrophyte species and that additional research was needed to fully understand interactions with native species of fish. Bickerstaff et al. (1984) reported increased predation on redbelly tilapia fry by adult bluegill when the amount of protective vegetative cover was reduced in experimental enclosures. The investigators speculated that introductions of redbelly tilapia would likely fail under conditions of high predator densities, especially adult bluegill and largemouth bass, and there would be little or no aquatic macrophyte control exerted by redbelly tilapia in such situations.

Finally, the ability of redbelly tilapia to readily shift to alternate food sources, such as detritus, allowed the population to continue expansion in Hyco Reservoir after macrophytes were eliminated. Studies by Hauser (1975), Spataru (1978), and Fitzpatrick et al. (1981) determined redbelly tilapia is an opportunistic feeder with the ability to consume a wide variety of food items (e.g., algae, detritus, benthic invertebrates, macrophytes, and zooplankton).

Our experience at Hyco Reservoir indicates redbelly tilapia can effectively eliminate a variety of macrophytes in a large reservoir within a relatively short time period. Even with large-scale removal of macrophytes, we found no consistent trend of nutrient enrichment in the reservoir. Maintaining a sizable overwintering population and low predation from piscivorous native fish are probably key factors in the long-term control of macrophytes with redbelly tilapia. A possible disadvantage of using this species for biological control of macrophytes in other situations is its ability to switch to alternate food sources after macrophytes disappear and still maintain a viable reproducing population. Although adult redbelly tilapia are opportunistic and can switch their feeding habits, the predominance of detritus in their stomachs indicated minimal diet overlap with native fishes in Hyco Reservoir.

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Response of Two Alligatorweed Biotypes to Quinclorac

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ABSTRACT

Greenhouse studies evaluated the influence of foliar applications of quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) on two morphologically distinct alligatorweed biotypes. Quinclorac was applied at 0.3 and 0.6 kg/ha to well-rooted plants that had been cut back and allowed to regrow for two, four, or six weeks to simulate treatment at different stages of regrowth. Herbicide damage and overall effects on growth were significantly greater in the slenderstem than in the broadstem biotype, probably reflecting greater leaf surface are per unit of shoot biomass in the slenderstem biotype. Regrowth from roots and rhizomes was similar for both biotypes, and no herbicide symptoms were observed on the new growth, suggesting poor basipetal translocation. The relative growth rates of slenderstem alligatorweed were reduced sigificantly more than those of the broadstem biotype following either root or leaf treatment. The results of this study suggest that certain alligatorweed biotypes may be more tolerant to herbicides than others and may provide a partial explanation for the variability observed in the response of alligatorweed to herbicides.

Key words: Alternanthera philoxeroides, herbicide resistance, morphology, growth.

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