EVAPOTRANSPIRATION/EVAPORATION (E/E_o) RATIOS FOR AQUATIC PLANTS

CLAUDE E. BOYD[1]

ABSTRACT

Ratios of evapotranspiration/open-water evaporation (E/E_o) were determined for population of five species of aquatic plants grown for 6 months (May-October) in 5.77-m^2 tanks at Auburn, Alabama (32.5° N latitude). E/E_o ratios were as follows: *Panicum regidulum,* 1.58; *Juncus effusus,* 1.52; *Carex lurida* 1.33; *Alternanthera philoxeroides,* 1.26; *Justicia americana,* 1.17. Regression analyses did not reveal strong, simple correlations among daily or monthly values for meteorologic variables and evapotranspiration by aquatic plants.

Key Words: Aquatic weeds, transpiration, water loss, wetlands, marsh plants, water budgets.

INTRODUCTION

A number of workers (6, 8, 15, 16, 17) have shown that most aquatic plants enhance water loss from lake surfaces. Ratios of evapotranspiration to open-water evaporation (E/E_o) are often above 1.4, and some are above 2.0. Although evapotranspiration rates by aquatic plants are correlated with solar radiation, daily mean air temperature, and plant canopy characteristics (6, 8, 15), equations for estimating evapotranspiration by aquatic plants from plant canopy characteristics and meteorologic data are too complex to be of much practical value (15). However, estimates of E/E_o ratios are useful to aquatic resource managers interested in estimating the possible impact of aquatic plant communities on water budgets.

In research described herein, E/E_o ratios were determined over a 6-month period for five species of aquatic plants, alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb.), soft rush (*Juncus effusus* L.), water willow (*Justicia americana* (L.) Vahl.), sedge (*Carex lurida* Wahlenb.), and panic grass (*Panicum regidulum* Nees), for which no E/E_o ratios were found in the literature. Ratios of E/E_o for these species were compared with literature values of E/E_o for other species.

MATERIALS AND METHODS

Plant stands were established in rectangular tanks with inside dimensions of 284 cm x 203 cm x 41 cm deep. The tanks were constructed of concrete blocks laid around the edges of 15-cm thick, steel-reinforced concrete slabs. A thick layer of earth was banked around the outside of the tanks for insulation. Tanks were built in a level, open, grassed area beside 12.5 ha of small, earthen research ponds on the Auburn University Fisheries Research Unit near Auburn, Alabama (32.5° N. latitude). Tanks were in three rows; the distance between tanks in a row and between rows was 5 m. A stilling well was placed in each tank to facilitate water-level measurements with a hook gauge. In late March and early April 1985, *A. philoxeroides, J. effusus, J. americana, C. lurida,* and *P. regidulum* stock for tanks was obtained from ponds and streams in the vicinity of Auburn, Alabama. Each species was established in three tanks. Shoots and attached roots and rhizomes of rooted plants were transplanted to tanks at densities observed in the natural stands which served as plant sources. Stand densities in shoots/m^2 were as follows: *A. philoxeroides,* 200; *J. effusus,* 1,500; *J. americana,* 150; *C. lurida.* 800; and *P. regidulum,* 650. Three tanks without plants served as controls for measurement of evaporation from a free water surface. Algal growth was prevented in control tanks by periodic applications of copper sulfate at 1 mg/liter. Except for control tanks which were not fertilized, each tank received monthly applications of 250 g of commercial inorganic fertilizer (10% N; 10% P_2O_5; 10% K_2O).

Water-level measurements were made to the nearest 0.001 cm with a hook gauge between 0700 and 0800 daily from May through October 1985. Adjustments for rainfall were made using the catch of an adjacent rain gauge. Water levels were maintained so that they were always 5 to 10 cm below the tops of tank walls. The following meteorological data were collected daily at the site: maximum-minimum air temperature, Class A pan evaporation, rainfall, and solar radiation (with pyranograph). Maximum and minimum temperatures were averaged to estimate the mean daily temperature.

Every two weeks, standing crop and leaf area index estimates were obtained for *A. philoxeroides, J. americana,* and *J. effusus.* However, because of difficulty in obtaining leaf area index values for *C. lurida* and *P. regidulum,* standing crop and leaf area index estimates were made only once at the time when stands appeared to be at peak standing crop. Three random quadrats (0.25 m^2) were selected in each tank. The number of plants per quadrat was counted, and the shoots were cut at the mud surface and harvested for determination of oven dry weight. Dry matter standing crop was calculated as the number of plants per meter square multiplied by the average dry weight per plant. The area of leaves from five plants in each tank was determined with a Licor leaf area meter. Both sides of leaves were included in area measurements. Leaf area per square meter was the product of the number of plants per square meter, average number of leaves per plant, and average area per leaf. Leaf area index (LAI) refers to the ratio of leaf area to water surface area.

[1]Department of Fisheries and Allied Aquacultures, Alabama Agricultural Experiment Station, Auburn University, Alabama 36849

RESULTS AND DISCUSSION

Plants grew well in the tanks. Average values for dry matter standing crop and LAI on different sampling dates are presented for *A. philoxeroides, J. americana,* and *J. effusus* in Fig. 1. Peak standing crops occurred in May for *J. effusus,* in July for *A. philoxeroides,* and in August for *J. americana.* Standing crop values for *J. americana* declined rapidly soon after peak standing crop was attained; a much slower decline was noted for *A. philoxeroides* and *J. effusus.* Changes in LAI were related closely to changes in standing crop. Peak standing crop for *C. lurida* (800 g/m^2) and *P. regidulum* (1,120 g/m^2) were attained in mid June. At this time, LAI values were 8.1 for *C. lurida* and 12.1 for *P. regidulum.* Once these two species attained peak standing crop, little change was noted in shoot height and density. Variation in standing crop and LAI among replicates of treatments was not great: coefficients of variation ranged from 5 to 16%. Standing crop and LAI values were within the ranges of standing crop and LAI values reported in the literature for these and similar species (2, 3, 7, 8, 9, 11, 14).

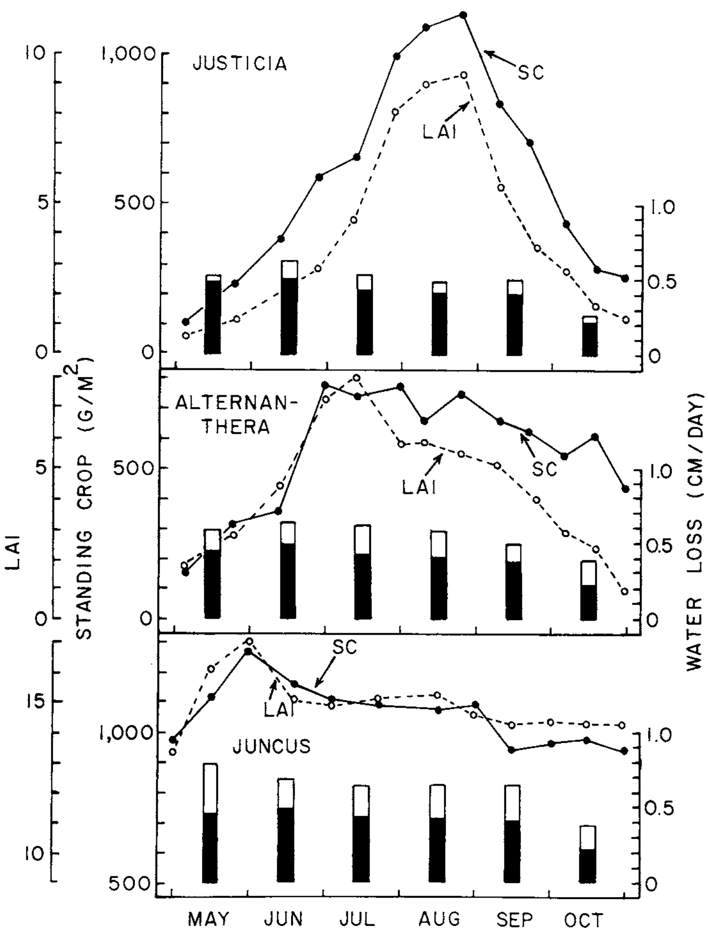

Figure 1. Dry matter standing crops (SC), leaf area index (LAI) values, and monthly averages of daily water loss by *Justicia americana, Alternanthera philoxeroides,* and *Juncus effusus* at Auburn, Alabama. Water loss rates are shown as bars. The entire bars represent water losses from vegetated tanks; the dark portions of the bars represent water loss from the control (unvegetated) tanks. Each treatment was replicated three times.

Monthly averages of daily water loss rates for *A. philoxeroides, J. americana,* and *J. effusus* were always greater than rates for controls (Fig. 1). Tanks stocked with *J. effusus* lost more water than tanks containing *A. philoxeroides* and *J. americana.* Average daily water losses for *A. philoxeroides* and *J. americana* were similar. Water loss rates were fairly constant for each species for the period May through September. Standing crop and LAI increased to a peak and then began to decline during this period; water loss was not related closely to standing crop and LAI. Water loss declined in October when air temperatures dropped and condition of plants deteriorated. Monthly averages of daily water loss rates for *P. regidulum* were higher than those for *C. lurida* (Fig. 2), but tanks for both species had greater water losses than control tanks. Water losses for both species were high in May and June; there was a decrease in water loss during July and August. Water losses for both species increased in September but decreased in October (Fig. 2).

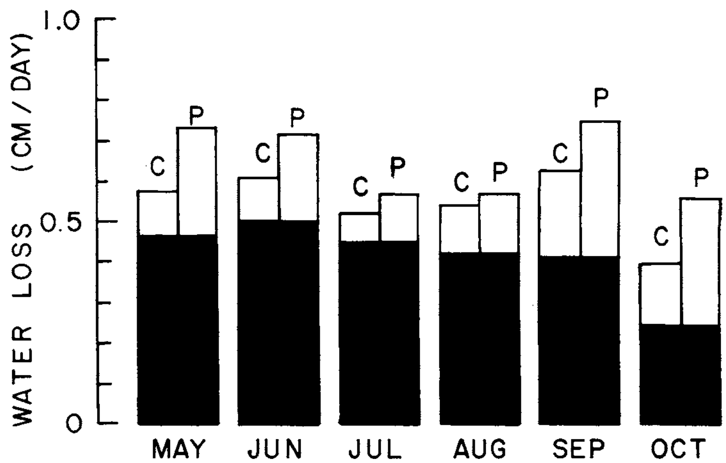

Figure 2. Monthly averages of daily water loss by *Carex lurida* (C) and *Panicum regidulum* (P). The entire bars represent water losses from vegetated tanks; the dark portions of the bars represent water loss from the control (unvegetated) tanks. Each treatment was replicated three times.

Meteorological data were within normal ranges for Auburn, Alabama, during the period May-October 1985 (Table 1). Regression analyses did not reveal strong, simple correlations among daily or monthly meteorologic variables (X) and evapotranspiration rates by aquatic plants (Y). Snyder and Boyd (15) developed complex multiple regression equations which provide fairly accurate estimates of evapotranspiration by *Eichhornia crassipes* (Mart.) Solms and *Typha latifolia* L. Unfortunately, such equations are of little value to water resource managers, because sufficient data for solving equations seldom are available. Therefore, no attempt was made in this study to develop complex equations for estimating evapotranspiration.

Average E/E_0 ratios for the five species and total water loss values for the 6-month period are summarized in Table 2. Total water losses and E/E_0 ratios increased as follows: *J. americana* < *A. philoxeroides* < *C. lurida* < *J. effusus* < *P. regidulum.* E/E_0 ratios ranged from 1.17 to 1.58.

TABLE 1. MONTHLY SUMMARY OF METEOROLOGICAL DATA FOR MAY-OCTOBER 1985 AT AUBURN, ALABAMA.

Variable	May	June	July	Aug.	Sept.	Oct.
Mean daily air temperature (°C)	20.9	25.3	25.6	26.1	23.2	20.6
Precipitation (cm)	4.4	9.5	28.2	5.6	3.0	8.0
Class A pan evaporation (cm)	19.3	18.7	14.7	15.5	16.7	10.1
Solar radiation (g cal cm^{-2} day^{-1}	507	475	440	449	409	267

TABLE 2. AVERAGES AND STANDARD DEVIATIONS FOR WATER LOSSES AND EVAPOTRANSPIRATION/EVAPORATION (E/E_o) RATIOS FOR THE PERIOD MAY-OCTOBER 1985 FOR AQUATIC PLANTS GROWN IN TANKS AT AUBURN, ALABAMA. EACH TREATMENT WAS REPLICATED THREE TIMES.

Treatment	Water loss (cm)	E/E_o
Control (no plants)	76.4 ± 3.8	—
Panicum regidulum	121.4 ± 12.1	1.58 ± 0.15
Juncus effusus	116.1 ± 10.4	1.52 ± 0.12
Carex lurida	101.3 ± 8.6	1.33 ± 0.09
Alternanthera philoxeroides	96.3 ± 10.6	1.26 ± 0.13
Justicia americana	89.3 ± 8.0	1.17 ± 0.11

Ratios for E/E_o for other species are reported below:

Species	E/E_o	Source
E. crassipes	1.26	(6)
	1.62	(15)
	1.70	(8)
T. latifolia	1.75	(15)
	1.8	(1)
	2.5	(13)
Acorus calanus L.	2.0	(13)
Pontederia cordata L.	1.2	(13)
Scirpus validus Vohl.	1.9	(13)
Nymphaea odorata	1.0	(13)
Lemna minor L.	0.9	(8)
Wolffia columbiana Karst	0.89	(4)
Spirodela polyrhiza (L.) Schleid	0.85	(4)

Data for *E. crassipes* and *T. latifolia* illustrate that different E/E_o ratios have been reported for the same species. These discrepancies may be related to differences in methodology, but climatic conditions and plant stand characteristics also affect E/E_o ratios (8, 15). Plants which covered the water surface with a single layer of leaves (*N. odorata, L. minor, W. columbiana,* and *S. polyrhiza*) had E/E_o ratios of 1.0 or less. All species which develop a leaf canopy above the water surface had E/E_o ratios above 1.0. Values of E/E_o for species considered in the present study (Table 2) fall within the range of E/E_o ratios found in the literature and listed above.

Evaporation from a Class A evaporation pan often is multiplied by a pan coefficient of 0.7 to estimate evaporation from open-water areas of lakes (5). A pan coefficient was determined for estimating evapotranspiration by the five species of aquatic plants from Class A pan evaporation data. The pan coefficients based on water loss over the 6-month period from the Class A evaporation pan (Table 1) and vegetated tanks were as follows: *P. regidulum,* 1.28; *J. effusus,* 1.22; *C. lurida.* 1.07; *A. philoxeroides,* 1.01; *J. americana.* 0.94. Pan coefficients for *E. crassipes* and *T. latifolia* were 1.55 and 1.72, respectively (15).

LITERATURE CITED

1. Bernatowiez, S., S. Leuzczynski, and S. Tycznksa. 1976. The influence of transpiration by emergent plants on water balance in lakes. Aquatic Bot. 2:275-288.
2. Boyd, C. E. 1969. Production, mineral nutrient absorption, and biochemical assimilation by *Justicia americana* and *Alternanthera philoxeroides*. Archiv. Hydrobiol. 66:139-160.
3. Boyd, C. E. 1971. Further studies on productivity, nutrient, and pigment relationships in *Typha latifolia* populations. Bull. Torrey Bot. Club. 98:144-150.
4. Boyd, C. E. 1975. Competition for light by aquatic plants in fish ponds. Ala. Agr. Exp. Sta., Auburn University, Ala., Circular 215. 19 p.
5. Boyd, C. E. 1985. Pond evaporation. Trans. Amer. Fish. Soc. 114:299-303.
6. Brenzy, O., I. Mehta, and R. K. Sharma. 1973. Studies on evapotranspiration of some aquatic weeds. Weed Sci. 21:197-204.
7. Center, T. D., and N. R. Spencer. 1981. The phenology and growth of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) in a eutrophic northcentral Florida lake. Aquatic Bot. 10:1-32.
8. DeBusk, T. A., J. H. Ryther, and L. D. Williams. 1983. Evapotranspiration of *Eichhornia crassipes* (Mart.) Solms and *Lemna minor* L. in central Florida: Relation to canopy structure and season. Aquatic Bot. 16:31-39.
9. Gorham, E. 1974. The relationship between standing crop in sedge meadows and summer temperature. J. Ecol. 62:487-491.
10. Jervis, R. A. 1969. Primary production in the freshwater marsh ecosystem of Troy Meadows, New Jersey. Bull. Torrey Bot. Club 96:209-231.
11. Knipling, E. B., S. H. West, and W. T. Haller. 1970. Growth characteristics, yield potential, and nutritive value of water hyacinths. Soil Crop Sci. Soc. Florida. 30:51-63.
12. Nicholson, S. A., and D. G. Best. 1974. Root: shoot and leaf area relationships of macrophyte communities in Chautauqua Lake, New York. Bull. Torrey Bot. Club. 101:96-100.
13. Otis, C. H. 1914. The transpiration of emerged water plants: its measurement and relationships. Bot. Gaz. 58:457-494.
14. Polisini, J. M., and C. E. Boyd. 1972. Relationships between cell-wall fractions, nitrogen, and standing crop in aquatic macrophytes. Ecology 51:484-488.
15. Snyder, R. L., and C. E. Boyd. 1986. Evapotranspiration by *Eichhornia crassipes* (Mart.) Solms and *Typha latifolia* L. Aquatic Bot. 19:In press.
16. Timmer, L. E., and L. W. Weldon. 1967. Evapotranspiration and pollution by water hyacinth. Hyacinth Control J. 6:34-37.
17. Van der Weert, R., and G. E. Kamerling. 1974. Evapotranspiration of water hyacinth (*Eichhornia crassipes*). J. Hydrology. 22:201-212.