SUITABILITY OF ALEWIFE AS A PELAGIC FORAGE FISH FOR SOUTHEASTERN RESERVOIRS

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Abstract: Alewife *(Alosa pseudoharengus)* were evaluated as a pelagic forage fish for southeastern reservoirs based on results of trophic and population ecology studies conducted in Claytor Lake, Virginia. Positive attributes of the alewife forage based included: a) establishment of a prolific and self-sustaining population, b) high desirability and availability to pelagic predators, and c) a positive impact on growth of pelagic sportfish. Negative attributes included: a) predation on larval fish, b) low desirability and/or availability to littoral sportfishes, c) rapid growth beyond a size vulnerable to most predators, d) fluctuating population levels, e) alteration of zooplankton size composition by selective predation on largest forms, and f) emigration to a downstream reservoir. Alewife are most suitable for introduction to waters managed primarily for pelagic piscivores on a put-grow-take basis. Because of the potential for emigration, management decisions regarding alewife should be developed on a regional rather than local basis.

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Introductions of planktivorous forage fishes into reservoir systems are frequently considered to augment production of piscivorous sportfishes. In the southeastern United States, the principal reservoir forage species are the gizzard shad *(Dorosoma cepedianum)* and the threadfin shad *(D. petenense)*. These clupeids feed primarily upon plankton, detritus and benthos (Kutkuhn 1957, Miller 1967, Baker and Schmitz 1971). The trophic status of shad would appear to make them ideal forage fish since they convert underutilized food material into biomass that can be consumed by piscivores. Unfortunately, both shad species have often proved inadequate. Gizzard shad rapidly grow beyond a size vulnerable to most predators (Dendy 1946, Rathum 1969, Jester and Jensen 1972) whereas the threadfin shad is limited in its range due to an inability to withstand temperatures below 9°C for prolonged periods (Strawn 1963). The search for the ideal forage fish has led to the consideration of exotic species such as the anadromous alewife. The impetus for establishing landlocked populations of this clupeid results from the highly successful Great Lakes' salmonid fishery which is sustained by an abundant alewife forage base.

An early establishment of alewife in a southeastern reservoir occurred in Claytor Lake, Virginia. Alewife from Lake Hopatcong, New Jersey, were introduced to Claytor Lake in 1968 specifically to serve as a pelagic forage fish. No other clupeid species occur in Claytor Lake. From 1977 through 1979, we studied the trophic interactions of alewife with other species resident in Claytor Lake. The investigation was undertaken to assess the overall impact of alewife on the recreational fishery of Claytor Lake and, more generally, to evaluate the desirability of introducing alewife to other reservoirs in the southeast. Results from our research are synthesized with data from the literature in this evaluation. The evaluation is based on criteria we feel are indicative of an ideal pelagic forage fish. Such a fish would be: 1) prolific and self-sustaining, 2) trophically efficient, 3) desirable

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and available to predators, 4) a positive influence on sportfish growth, 5) vulnerable to predation throughout its life cycle, 6) non-emigrating, and 7) devoid of adverse interspecific impact (independent of the littoral zone, stable in abundance, non-piscivorous, and trophically non-competitive). These criteria are a revised and expanded version of those listed by Kimsey (1957). The rationale for each of these criteria is provided in the subsequent evaluation.

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STUDY AREA

Claytor Lake is a mainstream hydroelectric impoundment of the New River located in southwestern Virginia, filled in 1939. It has a surface area of 1,820 ha at a normal pool elevation of 663 m above mean sea level and drains approximately 3,862 km^2. The reservoir includes approximately 161 km of shoreline, contains approximately 2.74×10^8 m^3 of water and has a maximum depth of 37.5 m (Roseberry 1950). Claytor Lake contains several shallow coves but with little rooted aquatic vegetation. The littoral ($<$ 5m depth) regions are not otherwise extensive. The marginally eutrophic lake is dimictic, containing a distinct thermocline throughout the summer with spring and fall overturns. Anoxic conditions occur in summer in the hypolimnion (Boaze 1972). Ice cover commonly occurs from approximately mid-January through mid-March.

The fishery of Claytor Lake is similar to other impoundments in the region. The primary angler-exploited species are black basses *(Micropterus salmoides, M. dolomieui, M. punctulatus)*, striped bass *(Morone saxatilis)* maintained on a put-grow-take basis, white bass *(Morone chrysops)*, walleye *(Stizostedion vitreum vitreum)* maintained by natural spawning and supplemented by stocking, channel catfish *(Ictalurus punctatus)*, crappie *(Pomoxis nigromaculatus* and *P. annularis)* bluegill *(Lepomis macrochirus)* and yellow perch *(Perca flavescens)*. Although alewife were introduced to provide forage for all angler exploited species, they were particularly intended to serve as food for the large, pelagic predators (striped bass, white bass, and walleye).

METHODS

Sampling was conducted on 2 to 4 dates per month, April through December 1978 and April through August 1979. Alewife and adult sportfish were collected from the surface to 20-m depth in pelagic areas using a vertical gillnet system (Kohler et al. 1979). As has been noted elsewhere (Lindenberg 1976), alewife were not highly vulnerable to daytime gillnet capture. All sampling was conducted in 8-hour periods between dusk and dawn. Nets were inspected at 4-hour intervals. In littoral depths, alewife and sportfish were captured by a 91.5 m experimental horizontal gillnet. The horizontal gillnet was set concomitantly with the vertical gillnets and alone on several other dates. These collections were supplemented by several electroshocking samples. Weights, lengths, and scales were taken from adult sportfish collected by all methods prior to preservation of their stomachs in 10 percent formalin for later laboratory analysis. Alewife were preserved in formalin; weights, lengths, and scales were taken from preserved specimens. Young-of-the-year sportfish were obtained from cove-rotenone samples conducted by the Virginia Commission of Game and Inland Fisheries.

Stomach contents of alewife and young-of-the-year sportfish were analyzed using volumetric methodology (Lagler 1956, Windell and Bowen 1978). Items were identified with reference to keys for insects (Pennak 1978), zooplankton (Edmondson 1959, Pennak 1978) and fish (Pflieger 1975, Eddy and Underhill 1978). Identifications were made to the lowest taxonomic category permitted by the state of digestion.

Contents of each stomach were placed in separate petri dishes and viewed under a dissecting microscope. Large items such as insects were identified and enumerated at 10X. The remaining contents were washed into a 50 ml graduate cylinder, diluted to 25 to 40 ml with 40 percent isopropyl alcohol, and thoroughly mixed using a stirring magnet. A 1-ml subsample was removed with a Hensen-Stempel pipet and transferred to a plexiglass counting wheel. All organisms in the subsample were identified and enumerated using a dissecting microscope at 10X. Permanent slides were made of organisms which were difficult to identify at low magnification. A duplicate subsample, as described, was examined from each individual stomach. The median number of zooplankters in paired subsamples were not significantly different ($P > 0.05$, Wilcoxon's signed-rank analysis). The mean of the 2 subsamples was multiplied by the dilution factor to estimate the actual count. Lengths of 25 to 50 randomly chosen individuals of each zooplankton species found in alewife stomachs were measured (body length exclusive of external spines or setae) using an ocular micrometer. These lengths were compared (Wilcoxon's rank-sum analysis) to the plankton length distributions sampled from the water column on the same dates. Volumes of each zooplankton species found in stomachs were determined indirectly using methods as described by Kutkuhn (1958) and McComish (1967).

Analytical techniques as described for alewife and young sportfish were employed to determine the importance of alewife and alternative forage species in the diet of adult piscivorous fish. Sportfish analyzed for stomach contents included walleye, striped bass, white bass, largemouth bass, smallmouth bass, spotted bass, black crappie, and white crappie. All volume measurements were determined by water displacement. The total length of consumed but undigested fish was measured to the nearest millimeter to assess the size distribution of utilized forage species.

Scale samples were used for age and growth determinations of alewife, walleye, white bass, striped bass, black basses, crappies and yellow perch. Scales from adult sportfish were collected from the body near the tip of the right pectoral fin (Lagler 1956). Scales from alewife were taken from the midline just above the insert of the anal fish (Rothschild 1963). Length of fish at formation of each annulus was calculated using the corrected Lee method (Lagler 1956).

Crustacean zooplankton samples were collected with a 5.8-liter Kemmerer bottle concomitant with alewife netting. Zooplankton were sampled near midnight in a location central to the vertical gillnets at 2-m depth intervals from the surface to 20 m. Virtually all alewife were collected in the upper 10 m of the water column. Zooplankton samples from 0 to 10 m were pooled for comparison with alewife stomach contents. These samples were concentrated by filtering them through a Wisconsin net (0.076 mm mean aperture diameter). Zooplankton samples were placed in labelled bottles and preserved in 70 percent ethyl alcohol, 3 percent formalin, and Congo Red stain. In the laboratory, each zooplankton sample was concentrated on coarse filter paper using a suction pump. Nauplii were then enumerated and all zooplankton, excluding nauplii and rotifers, were mounted on slides using a commercially available mounting medium (CMCP 9 & 10, MacMillan Co.). Organisms in each sample were identified and enumerated. On each sampling date in which alewife were collected, lengths of 25 to 50 randomly chosen members of each species of zooplankton relatively abundant in the water-column were measured.

CRITERIA EVALUATION OF ALEWIFE

Prolific and Self-sustaining Population

An ideal forage fish should be prolific so as to accommodate intensive predator pressure. As with other clupeids, fecundity of alewife is high with a median of 18,000 eggs/adult female in Claytor Lake (Nigro and Ney 1980). The alewife population in Claytor Lake has been self-sustaining since initial introduction in 1968-1969, and the alewife has subsequently become the most abundant fish in the reservoir. Not all forage fish can survive and propagate in various systems and/or regions. For example, threadfin shad were stocked in Claytor Lake in 1964 and 1965 but proved unable to survive the winter temperature regime (Boaze 1972).

Trophically Efficient

An ideal forage fish should feed exclusively on underutilized food material such as plankton, converting it into biomass that can be consumed by piscivores. Alewife in Claytor Lake did not fully meet this criterion. Although zooplankton and aquatic insects comprised the largest components of alewife annual diet (Fig. 1), alewife in both limnetic and littoral regions consumed numerous larval fish during summer. Excluding the high incidence of piscivory, however, alewife food habits in Claytor Lake were similar to those examined in other inland waters, where they are essentially planktivorous (Odell 1934, Gross 1959, Morsell and Norden 1968, Lackey 1968, Hutchinson 1971, Wells 1980).

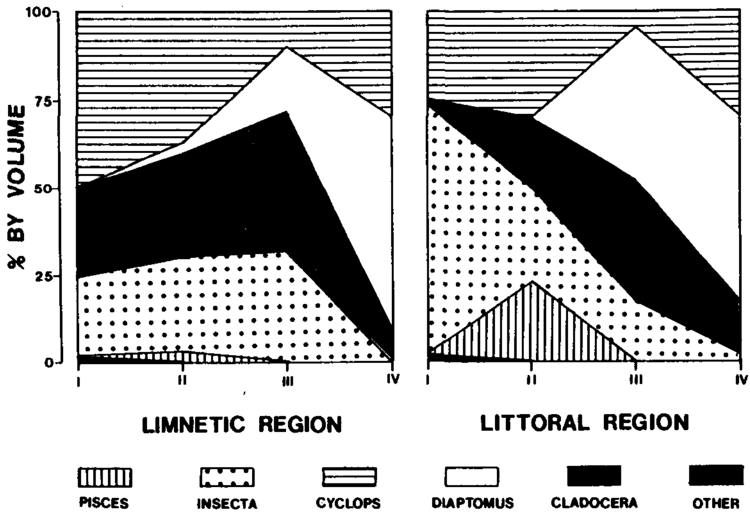

Fig. 1. Seasonal food habits (percent total volume) of alewife collected in the limnetic and littoral region, Claytor Lake, Virginia, 1977-1979. Seasons are represented as: I, spring (March-May); II, summer (June-August); III, fall (September-November); and IV, winter (December).

Desirable and Available to Predators

An ideal forage fish should be highly desired as prey by predators. Alewife were an apparent preferred prey of pelagic predators (striped bass, white bass, walleye) but were of minor importance in diets of littoral-inhabiting black basses and were not found in stomach contents of black and white crappie (Table 1). Alternative forage included crayfish, golden shiner *(Notemigonus chrysoleucas)*, sunfishes, crappies, and yellow perch. Alewife may not have been readily available to black basses and crappie due to spatial segregation.

Positive Influence on Sportfish Growth

An ideal forage fish should have a positive impact on the growth of sportfish. Growth rates of white bass and walleye increased following establishment of the alewife forage base whereas black basses, crappie generally decreased (Table 2). Although no striped bass were stocked prior to alewife establishment, food habit analyses (Table 1) indicate that this large, pelagic predator preys extensively upon alewife, and its growth should there-

Table 1. Percent total volume by season of food items found in stomachs of adult sportfish, 1977-1979, Claytor Lake, Virginia.

Predator	Percent Total Volume															
	Alewife				Other Fish[1]				Crayfish				Insects			
	W	S	S	F[2]	W	S	S	F	W	S	S	F	W	S	S	F
Walleye	100.0	93.1	66.6	29.8	0.0	6.9	32.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
	(24)[3]	(40)	(33)	(31)												
White bass	-	97.3	-	0.0	-	0.0	-	29.8	-	2.1	-	66.7	-	0.4	-	3.5
	(0)	(35)	(0)	(31)												
Striped bass	100	100	94.6	100	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(5)	(8)	(9)	(13)												
Black basses[4]	0.0	45.7	-	0.0	88.5	16.4	-	92.2	11.5	31.3	-	7.8	0.0	0.0	-	0.0
	(3)	(47)	(0)	(25)												
Crappie[5]	0.0	0.0	0.0	0.0	100	0.0	69.9	100	0.0	0.0	0.0	0.0	0.0	99.8	30.1	0.0
	(6)	(18)	(40)	(16)												

[1]Includes sunfishes, minnows and yellow perch

[2]Denotes winter, spring, summer and fall, respectively

[3]Total number of fish examined

[4]Includes largemouth, smallmouth, and spotted bass

[5]Includes black and white crappie

Table 2. Comparison (Wilcoxon's signed rank analysis) of sportfish median total length (mm) at terminal annuli before and after alewife establishment in Claytor Lake, Virginia.

Species & Age	Median Total Length	
	Before[1]	After[2]
Walleye		
I	227	248 c
II	380	401 c
III	489	458
IV	568	573
White Bass		
I	153 a	146
II	245	284 c
III	297	335 c
IV	343	382 c
Largemouth Bass		
I	142	141
II	274 c	253
III	356 b	319
IV	404	390
Smallmouth Bass		
I	134 a	95
II	264 c	188
III	337 c	302
IV	396	401
Spotted Bass		
I	146b	104
II	236 c	185
III	278	268
IV	332 a	288
V	366	349
White Crappie		
I	101 c	94
II	157 a	109
III	217	228

[1]Data from Roseberry 1950 and, for white bass, from Boaze (1972)
[2]Data from this study, 1976-1978 as years of growth
a,b,c Denotes significantly larger ($P < 0.05$, 0.01 and 0.001 respectively) values.

fore be highly associated with the alewife forage base. A large clupeid forage base is thought to be essential for establishment of landlocked striped bass (Bailey 1974).

Vulnerable to Predation Throughout Life-Cycle

An ideal forage fish should never grow out of the forage class, possibly becoming a competitor with sportfish for available food while no longer representing a source of prey itself. Alewife growth in Claytor Lake exceeds all documented growth rates (Table 3) for landlocked populations. The large size attained may limit the value of older alewife as forage for sportfishes. In order to consume age 2 alewife (ca. 200 mm TL), largemouth bass must be at least 426 mm TL, walleye 724 mm TL, and striped and white bass 554 mm TL (Jenkins and Morais 1978). Sportfishes of these sizes are not abundant in Claytor Lake whereas alewife > 200 mm TL were commonly collected. As a consequence, sportfish predation was limited to age 0+ and 1+ alewife in Claytor Lake. Maximum total length of alewife in stomach contents was 165 mm. Nigro and Ney (1980) established that alewife spawn in Claytor Lake from May through July, similar to observations reported in other inland waters (Odell 1934, Rothschild 1966, Norden 1967). Consequently, young-of-the-year alewife should be morphologically available to most piscivorous sportfish through much of the summer and early fall. The extended spawning season appears to mitigate the effect of rapid alewife growth on their availability to predators.

Table 3. Growth rates of alewife from Claytor Lake, Virginia, 1976-1978, compared with growth rates from other inland water bodies.

	Total lengths (mm) for successive ages				
Water and Source	I	II	III	IV	V
Claytor Lake—1976-1978 present study[1]	162	194	207	213	-
Lake Michigan Norden (1967)[1]	94	140	159	173	-
Lake Ontario Graham (1956)[1]	77	134	156	161	184
Lake Hopatcong, N.J. Gross (1959)[2]	76	108	150	-	-
Seneca Lake, N.Y. Odell (1934)[1]	68	144	151	168	172
Cayuga Lake, N.Y. Rothschild (1965)[2]	102	121	130	138	144
Echo Lake, ME. Lackey (1970)[1]	114	175	-	-	-

[1]back calculations

[2]length frequency

Non-Emigrating

An ideal forage fish should not emigrate from the system for which it was intended and become established in other areas. The potential for inadvertent establishment of alewife populations is evidenced by their unforeseen spread throughout the Great Lakes (Miller 1957). It should be anticipated that alewife will readily spread to other systems after introduction into a mainstream impoundment such as Claytor Lake. In fact, alewife are now established in Bluestone Lake, West Virginia, an impoundment over 100 km downriver from Claytor Lake (Fred Leckie, personal communication, West Virginia Department of Natural Resources). Because alewife were not intentionally stocked in Bluestone Lake, it is presumed that this population originated from Claytor Lake stock. From Bluestone Lake, it may be possible for alewife to emigrate to the Ohio River and then into much of the Mississsippi drainage.

Devoid of Adverse Interspecific Impact

An ideal forage fish should have no detrimental impacts on resident fish populations. Specific attributes which minimize adverse interspecific impact include:

a) Independence from the littoral zone—An ideal forage fish should not be tied to the littoral zone during any part of its life cycle to minimize competition with young shore-oriented sportfish for habitat and/or trophic resources. In the Great Lakes, alewife have been documented to occupy all lacustrine regions during various seasons (Smith 1968). In the course of this study, alewife were frequently collected in littoral nearshore regions of Claytor Lake during spring and summer. On a seasonal basis, alewife inhabit and potentially impact all regions of Claytor Lake with the possible exception of shallow coves where adult and young-of-the-year alewife were rarely collected, despite the use of various sampling gears.

b) Population stability—An ideal forage fish population should remain stable so as not to upset the predator: prey balance. Seasonal die-offs of alewife are a common occurrence, and a major die-off occurred in Claytor Lake during the exceptionally cold winter of 1977-78. Extreme fluctuations in alewife abundance may adversely impact adult piscivores if sufficient alternative prey is unavailable. Conversely, piscivore populations, inflated by a previously abundant alewife forage base, may then prey intensively on alternative forage fishes, including sport species.

c) Non-piscivorous—An ideal forage fish should not incorporate fish into its diet. Alewife in Claytor Lake consumed the young (maximum 26 mm TL) of at least 5 fish species (largemouth bass, white bass, *Lepomis* sp., yellow perch, golden shiner) as well as their own young (Kohler and Ney 1980). Alewife predation on larval fish has been suspected as a causative factor for the collapse of several resident fish populations of the Great Lakes (Smith 1970, Wells and McLain 1972). Observations from Claytor Lake support that hypothesis.

d) Trophically non-competitive—An ideal forage fish should not compete with sportfishes for available food. Alewife and young-of-the-year sportfishes preyed on similar food items but dietary overlaps (Levins 1968) were only significant between alewife and young yellow perch (Fig. 2). Although direct interspecific competition for food was not conclusively established, alewife may have an indirect adverse impact on other species in life stages of corresponding trophic level by altering the zooplankton food complex. Alewife in Claytor Lake were found to be highly size-selective planktivores (Table 4) as has been demonstrated in northern lakes (Brooks 1968, Hutchinson 1971, Janssen 1976, Janssen and Brandt 1980). On all collection dates, lengths of *Daphnia retrocurva* as well as cyclopoid and calanoid copepods (adults and copepodites) in alewife stomach contents were significantly ($P < 0.05$) greater than respective lengths in limnetic plankton samples. No consistent difference was evident in length comparisons with *Diaphanosoma leuchtenbergianum*. The analysis was limited to the above zooplankters which for periods of comparison

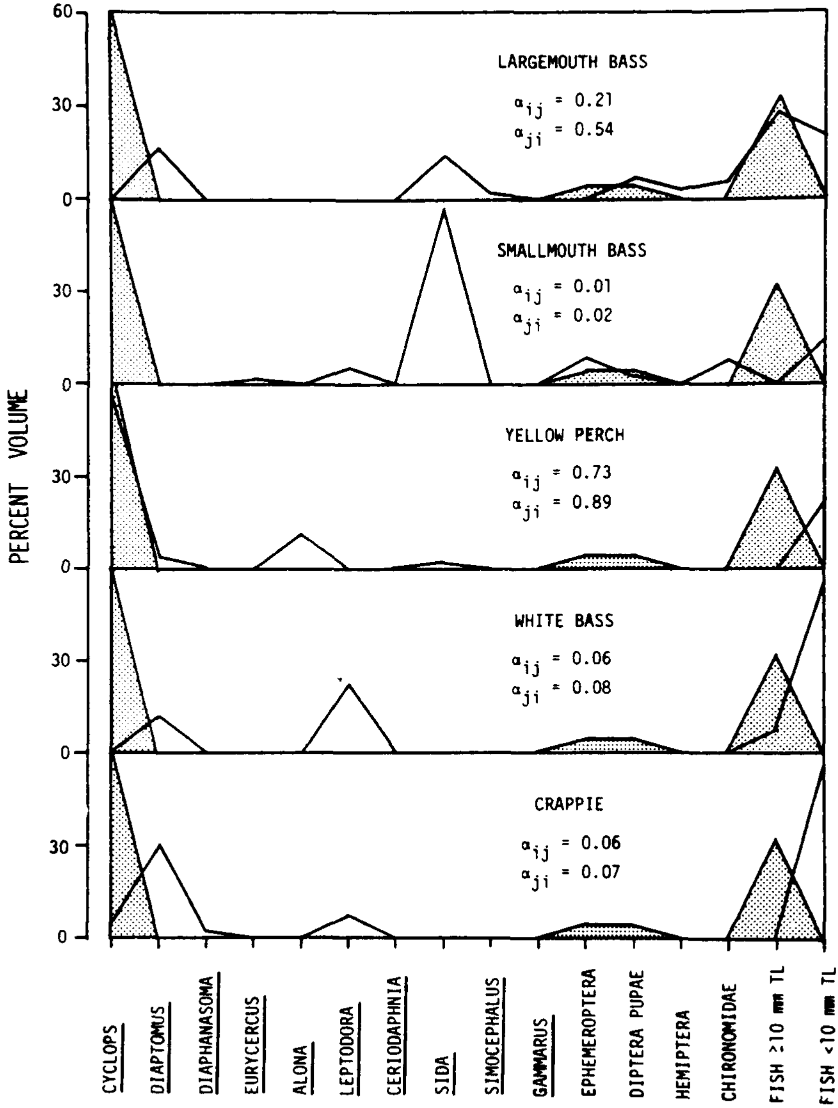

Fig. 2. Representation of dietary overlaps among alewife (i, shaded area) and young-of-the-year sportfishes (j), Claytor Lake, Virginia. All fish collected in littoral zone in late June and early July, 1978. Dietary overlap of alewife on sportfish (α ij) and of sportfish on alewife (α ji) computed by Levins (1968) method.

Table 4. Median lengths (mm) of major zooplankters (N= 25-50 specimens) collected from water column on various dates compared by Wilcoxon's rank-sum analysis to respective lengths observed in stomach contents of alewife collected on same dates, Claytor Lake, Virginia.

	Daphnia		Diaphanosoma		Cyclopoid Copepoda[1]		Calanoid Copepoda[1]	
Date	Water	Stomach	Water	Stomach	Water	Stomach	Water	Stomach
7/11/78	0.78	1.40 c	0.63	0.76 c	1.13	1.30 c	1.01	1.12
7/13/78	1.03	1.31 b	0.08	0.76	0.86	1.30 c	-	-
7/18/78	0.89	1.23 c	0.82	0.84	0.82	1.26 c	-	-
7/27/78	0.97	1.22 c	0.88 c	0.79	0.92	1.28 c	0.97	1.32 c
8/01/78	1.12	1.32 a	0.84 c	0.74	1.11	1.26 a	1.08	1.26 c
8/15/78	-	-	0.76 b	0.66	0.84	1.16 b	1.04	1.19 b
9/14/78	-	-	-	-	0.68	1.28 c	-	-
9/20/78	-	-	0.71	0.74	0.86	1.17 c	1.03	1.10 b
10/05/78	0.69	1.09 b	-	-	0.78	1.09 c	0.99	1.11 c
11/01/78	0.08	1.26 c	-	-	0.61	1.26 c	-	-
5/28/79	0.79	1.24 c	0.74	0.84 a	0.87	1.37 c	-	-
6/05/79	1.04	1.21 b	0.77	0.84	1.14	1.38 c	-	-
6/11/79	1.21	1.47 c	-	-	1.06	1.30 c	-	-
7/16/79	-	-	-	-	0.80	1.13 c	-	-

[1]Adults and copepodites

a,b,c Denotes significantly larger (P 0.05, 0.01, 0.001) values.

represented greater than 95 percent (by number) of the limnetic species complex. Alewife have shifted zooplankton size distributions toward small forms in other lacustrine systems (Brooks and Dodson 1965, Wells 1970, Warshaw 1972) by their intensive size-selective predation. The disparity in alewife abundance between 1978 (following die-off) and 1979 (population recovered) provided the opportunity to assess the response of the zooplankton community to alewife size-selection predation in Claytor Lake. In agreement with the results of other studies (Wells 1970, Warshaw 1972), major limnetic zooplankters *(Daphnia, Diaphanosoma, Cyclops, Diaptomus)* were significantly ($P < 0.05$, Wilcoxon's rank-sum analysis) smaller in August 1979 compared to respective median lengths sampled the previous August following the alewife population collapse. Such alewife-induced changes in zooplankton composition may adversely impact young sportfish which may be size-dependent as well as size-selective planktivores (Gailbraith 1967, Siefert 1972, Wong and Ward 1972, McCaig 1980).

MANAGEMENT IMPLICATIONS

Although alewife in Claytor Lake possessed several undesirable traits for a forage fish, no forage species has proven to be universally ideal for southeastern reservoirs. Shifts in zooplankton composition toward small forms have also been attributed to selective plankivory of threadfin shad (Applegate and Mullan 1969) and Mississippi silversides *(Menidia audens)* (Li et al. 1976). Large sizes attained by older gizzard shad prevent their utilization by piscivores (Jester and Jensen 1972, Carver et al. 1978) and severe competition with young sportfish for available food has been reported (Kutkuhn 1957, Miller 1960, Baker and Schmitz 1971). Rainbow smelt *(Osmerus mordax)* are highly piscivorous (Selgeby et al. 1978). Conceivably, adverse impacts may occur with any introduction of a forage fish. Consequently, the alewife should not be abandoned as a potential introduction but rather should cautiously be considered as one alternative.

Introduction of alewife into systems managed primarily for black basses should be avoided. Alewife were rarely utilized by black basses in Claytor Lake, and bass recruitment and growth may be hindered by alewife interspecific trophic interactions. Alewife piscivory was potentially the most significant area of trophic interaction that would affect sportfish recruitment. Growth, as well as recruitment, may also have been impeded by trophic competition with alewife. Trophic competitive interactions may be of a direct (i.e. competition for available food) and/or indirect (i.e. alewife-induced changes of food supply) nature.

Alewife introductions should be limited to waters too cold for threadfin shad and where such waters are managed primarily for pelagic predators on a put-grow-take basis. In systems containing self-sustaining populations of pelagic predators, all alternatives should be considered before introducing alewife. Being highly migratory, alewife will likely spread throughout much of a watershed, wide-scale stocking programs could result in inadvertent alewife establishment in much of the Southeast. Therefore, the use of alewife as a pelagic forage fish should involve regional rather than site-specific planning.

The success of a pelagic predator such as a striped bass depends to a large extent upon availability of a suitable forage fish. Consequently, a decision to introduce a pelagic predator into a system lacking pelagic forage fish must often be accompanied by a decision to introduce a fish such as the alewife. Benefit-risk analysis should include both species. Management efforts have generally focused on the top carnivores with little regard to the potential adverse ecological impact of the introduced forage species.

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