North American Journal of Fisheries Management 15:766–772, 1995
American Fisheries Society

An Evaluation of the Value of Harvest Restrictions in Managing Crappie Fisheries

M. S. ALLEN AND L. E. MIRANDA

National Biological Service, Mississippi Cooperative Fish and Wildlife Research Unit[1]
Post Office Drawer BX, Mississippi State, Mississippi 39762, USA

Abstract.—We used an equilibrium yield model to simulate the effect of reducing exploitation on yield and average weight of white crappies *Pomoxis annularis,* based on empirical growth data and various levels of conditional natural mortality. Modeling indicated that reducing exploitation would likely increase yield as fish growth increased and natural mortality decreased; however, reducing exploitation would not substantially affect yield when conditional natural mortality exceeded 30–40%, regardless of growth. For instance, a 250-mm minimum length limit provided higher yield than a 200-mm minimum length limit only if growth was above average and conditional natural mortality was less than 30–40%. Average weight of crappies harvested increased with growth and length at recruitment to the fishery but decreased with exploitation and conditional natural mortality. Our results suggest that a length limit could improve both yield and average weight for crappie fisheries only if growth is rapid and natural mortality is low. If natural mortality is not low, a length limit could improve average weight of fish harvested without substantially reducing yield.

Most management of crappies *Pomoxis* spp. before the late 1980s consisted of liberal harvest regulations to prevent stunting (Mitzner 1984). The use of harvest restrictions to reduce exploitation in crappie populations has increased in recent years, but the observed or predicted success of regulations has differed across crappie populations. For example, Colvin (1991a, 1991b) and Webb and Ott (1991) found that if growth was adequate, the average size of white crappies *P. annularis* could be improved through size restrictions. Conversely, Reed and Davies (1991) documented rapid growth in a lake containing both white crappies and black crappies *P. nigromaculatus* but recommended against size restrictions because high natural mortality would negate the benefits of delaying harvest. Larson et al. (1991) also documented high natural mortality and recommended liberal harvest restrictions (length and bag limits) in several black crappie populations. Eder (1990) found that annual exploitation averaged 84% over 4 years, yet satisfactory black crappie fishing persisted because recruitment was consistent.

The success of a regulation hinges on the growth and mortality of each crappie population, as well as on angler satisfaction and compliance. Rapid growth and low natural mortality increase the potential for successful harvest restrictions, whereas slow growth or high natural mortality reduces benefits of restrictive regulations. To examine these relations, we used empirical growth and mortality data for white crappies compiled from the literature to model yield and average fish weight for populations with various growth and natural and fishing mortalities.

Methods

We compiled estimates of total annual mortality (A) and total annual exploitation (u) from studies documented in agency reports, theses, and journal articles. Authors had estimated A from the descending portion of a catch curve assembled by forming an age-frequency distribution as described by Ricker (1975). Estimates of u were made from returns of tagged fish captured by anglers. From A and u, we estimated conditional natural mortality (n), the total mortality in the absence of fishing mortality (Ricker 1975), as

$$n = -[(A - m)/(m - 1)],$$

where

$$m = 1 - \exp\{u[\log_e(1 - A)]/A\}.$$

Estimates of growth were also compiled from agency reports, theses, and journal articles. Growth estimates were derived through back-calculation of length at age from scales or otoliths. We used the average length at age computed from all the studies compiled to portray medium growth, and we used 1 SD below or above the mean to model slow and fast growth, respectively. Brody–Bertalanffy models were fit to the length-at-age data for slow, medium, and fast growth to estimate

[1] The Unit is jointly sponsored by the Mississippi Department of Wildlife, Fisheries and Parks, Mississippi State University, and the National Biological Service.

TABLE 1.—Yearly mortality (A), exploitation (u), and conditional natural mortality (n) estimates for white crappies. Estimates are expressed as percentages; those over successive years are means. Blanks indicate missing data.

Lake and state	Age interval	Year(s)	A	u	n	Source
Weiss, Alabama[a]	2–4	1988	64	34	61	Reed and Davies (1991)
Hayes Center, Nebraska	2–4	1979–1981	74	"Low"		Ellison (1984)
Chase, Kansas	3–8	1976–1985	64			Mosher (1985)
Lyon, Kansas	2–5	1977–1983	76			Mosher (1985)
Sooner Lake, Oklahoma	2–4	1977–1980	94	8	92	Angyal et al. (1987)
Stockton, Missouri	2–7	1981	86	48	45	Colvin (1991a)
Pomme de Terre, Missouri	2–6	1981–1982	81	49	35	Colvin (1991a)
Columbus, Mississippi	1–5	1988	77			Hammers and Miranda (1991)
	1–7	1993	79	45	59	Brock (1994)
Delaware, Ohio	2–6	1988–1990	72			Miller (1991)
Deer Creek, Ohio	2–8	1990	67	62	8	Miller (1991)
Buckeye, Ohio	3–8	1990	56			Miller (1991)
Piedmont, Ohio	3–8	1990	71			Miller (1991)
Cowan, Ohio	2–5	1989–1990	48	35	16	Miller (1991)
Skiatook, Oklahoma	1–4	1987	88	49	61	Zale and Stubbs (1991)
	1–3	1988	80	41	54	Zale and Stubbs (1991)
	1–4	1989	91	53	63	Zale and Stubbs (1991)

[a] Estimates of A, u, and n are for black crappies and white crappies for this lake.

the model parameters t_0 and k (defined below) and L_∞ (average asymptotic total length).

We used Jones' modification of the Beverton and Holt equilibrium yield model (Ricker 1975) for estimating yield (Y) and average weight ($\bar{w}$):

$$Y = [(FN_0e^{Fr}W_\infty)/k]\beta(X,P,Q);$$
$$\bar{w} = (Y/F)/(R/Z);$$

F = instantaneous fishing mortality;
N_0 = the hypothetical number of individuals that reach hypothetical age t_0;
t_0 = the hypothetical age at which the fish length would have been zero if growth was always according to the Brody–Bertalanffy relation;
t_r = the age of recruitment to the fishery;
$r = t_r - t_0$;
W_∞ = the average asymptotic weight of a fish;
k = the Brody growth coefficient;
β = the incomplete beta function;
$X = e^{-kr}$;
$P = Z/k$;
Z = instantaneous total mortality;
$Q = b + 1$;
b = the exponent in the population weight–length relation;
$R = N_0e^{-Mr}$;
M = instantaneous natural mortality.

We arbitrarily set N_0 = 1,000. The value of W_∞ was estimated from L_∞ with Neumann and Murphy's (1991) weight–length equation. We modeled two lengths at recruitment to the fishery (i.e., minimum length limits): 200 and 250 mm total length. Varying growth and length at recruitment directly affected t_r and thus the number and size of fish recruiting to the fishery. We estimated the value of t_r by solving the Brody–Bertalanffy equation for the age at which fish reached the minimum length limit.

Values of $\beta(X,P,Q)$ were obtained from the tables published by Wilimovsky and Wicklund (1963). The exponent b was set at 3.375, the closest value to the average for white crappie populations (3.332, Neumann and Murphy 1991) available in Wilimovsky and Wicklund (1963). The larger slope used in our simulations led to slight underestimates of Y and $\bar{w}$, but equal trends.

Results

Total annual mortality averaged 75% (N = 17) and ranged from 48 to 94% (Table 1). Exploitation averaged 42% (N = 10) and ranged from 8 to 62%. Conditional natural mortality averaged 49% (N = 10) and ranged from 8 to 92%. Several of the mortality estimates in Table 1 represent an average of several years; thus, the means we have estimated represent larger sample sizes than those identified.

Average total length at ages 1 through 8 were 92, 168, 221, 257, 285, 298, 339, and 362 mm (Table 2). Several of the estimates we identified represented means of several years; thus, the 23 estimates represent a total 65 lake-years. For the Brody–Bertalanffy model, L_∞ derived from the mean lengths was 353 mm and k was 0.374 (Figure 1). The model predicted that under a 200-mm minimum length limit restriction, slow-growing fish would recruit to the fishery at age 3.2, medium-

TABLE 2.—Length-at-age (total length) data for white crappies reported for various reservoirs. Values across years are means. Blanks indicate missing data.

Lake and state	Year	Age 1	2	3	4	5	6	7	8	Source
Kentucky Lake, Kentucky		117	201	264	302	325				Carter (1953)
Lake Wappapello, Missouri		76	178	259	297	320				Patriarche (1953)
Cumberland Lake, Tennessee		79	157	231						Carter (1967)
Dale Hollow, Tennessee		75	172	235						Range (1973)
Sooner Lake, Oklahoma	1981	118	177	221	270					Glass and Maughan (1982)
Findeis Pond, Nebraska	1981	86	147	185	218					Gabelhouse (1984)
Hatcher Lake, Kansas	1980	61	175	259	305					Gabelhouse (1984)
McCord Lake, Iowa	1981	83	175	208	231					Gabelhouse (1984)
Poots Lake, Iowa	1981	81	147	183	221	264	279			Gabelhouse (1984)
Starks Pond, Kansas	1980	74	157	218	246	264	284			Gabelhouse (1984)
Smith Lake, Nebraska	1981	91	135	157	175	191				Gabelhouse (1984)
Smith Pond, Nebraska	1981	84	127	165	191	206	249			Gabelhouse (1984)
Kentucky Lake, Kentucky	1982	75	163	234	296	343				Parrish et al. (1986)
Lake Barkely, Kentucky	1982	78	164	230	280	322				Parrish et al. (1986)
Lake of the Ozarks, Missouri	1973–1983	94	178	231	259	290	315	309		Colvin (1991a)
Stockton, Missouri	1975–1983	89	191	257	285	297	310	345		Colvin (1991a)
Pomme de Terre, Missouri	1974–1983	97	185	241	272	305	312			Colvin (1991a)
Wappapello, Missouri	1976–1987	91	165	218	254	287	318	343	358	Colvin (1991a)
Moon Lake, Mississippi	1987	103	165	200	233	291	267			Hammers and Miranda (1991)
Columbus Lake, Mississippi	1988	123	179	220	260	281	332	332	365	Hammers and Miranda (1991)
	1993	86	145	207	254	292	309	365		Brock (1994)
Weiss Lake, Alabama	1988	137	200	242	273					Reed and Davies (1991)
Skiatook Lake, Oklahoma	1986–1990	112	177	218	278					Zale and Stubbs (1991)

growing fish at age 2.7, and fast-growing fish at age 1.9. With a 250-mm restriction, slow-growing fish would recruit at age 4.8, medium-growing fish at age 3.7, and fast-growing fish at age 2.9.

Yield and average weight of crappies harvested were affected by mortality and growth. Yield of crappies increased directly with growth and inversely with conditional natural mortality, n (Figure 2). At low n, yield increased with u, peaked, and decreased. At high n, yield increased asymptotically with u. Yield benefits resulting from increasing length at recruitment occurred when growth was fast and natural mortality was low; however, at high n, yield remained relatively unaffected by length at recruitment (i.e., length limit). Average weight increased with growth and length at recruitment but decreased with increases in u and n (Figure 3). The rate of increase in average weight with decreases in u (slopes of lines in Figure 3) increased with growth but decreased with n and length at recruitment.

Implications for Managing with Harvest Restrictions

Our model and review of mortality suggest that reducing exploitation through harvest restrictions may often not improve yield in crappie fisheries. The model indicated that yield is likely to be improved through harvest restrictions only when growth is fast and natural mortality is low (parabolic lines in Figure 2). However, our review of mortality suggested that conditional natural mortality in crappie populations was usually high, averaging near 50%. Our inferences are supported by observations made by Larson et al. (1991) and Reed and Davies (1991), who recommended against restrictive regulations because of relatively high natural mortality in reservoirs containing black crappies and white crappies.

Our model suggested that harvest restrictions can improve the average weight of fish harvested. Reductions in u improved average weight substantially when growth was fast and natural mortality was low, but improvements dwindled as growth decreased and natural mortality increased (note the change in slopes of lines in Figure 3). Increasing size at recruitment to the fishery with length limits improved average weight of fish harvested (note vertical distance between solid lines and corresponding dashed lines in Figure 3). Additionally, although length limits increased yield only when natural mortality was less than about 30–40%, length limits did not substantially reduce yield when natural mortality was higher than about 30–40% (note the vertical differences between solid lines and corresponding dashed lines in Figure 2). Because natural mortality in crappie populations is normally higher than 30–40%, length limit regulations are unlikely to increase yield, but they can

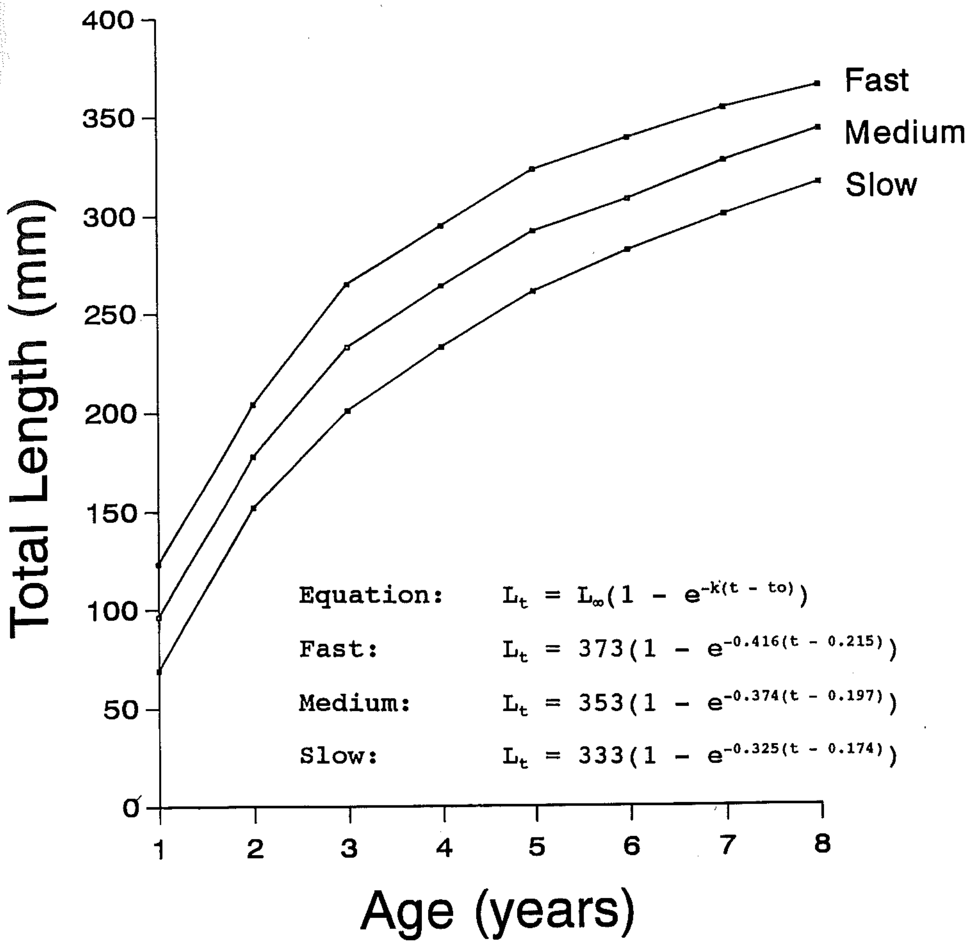

FIGURE 1.—Relation between total length and age for slow, medium, and fast growth of white crappies in lake populations. Medium growth represents the mean of 65 lake-years of age data compiled from agency reports, theses, and journal articles. Slow and fast growth represent 1 SD below and above the mean, respectively. Values for the Brody–Bertalanffy growth equations are shown for each growth rate (L_∞ is asymptotic length, L_t is length at age t, k is the growth coefficient, and t_0 is age at zero length).

potentially increase size of fish creeled by anglers while sustaining their harvest biomass, although reducing the number of fish they creel. We caution that length limits higher than those modeled in this study may reduce yield more substantially.

Crappie populations having low natural mortality, individuals that exhibit rapid growth, or both are better candidates for improved yield and average weight through reduced exploitation. Colvin (1991a, 1991b) documented below-average natural mortality and rapid growth in two reservoirs and suggested that minimum length limits might improve the average size of crappies by limiting harvest to fish ages 3 and older, allowing younger fish to remain in the fishery. Webb and Ott (1991) documented improved average weight in two white crappie populations after implementing 254-mm length restrictions, and they suggested that growth overfishing (harvest that reduces the size of fish below the maximum yield per recruit) occurred before the regulations; thus, protecting small crappies increased the average fish weight.

Another characteristic of many crappie populations is highly variable recruitment (Goodson 1966; Swingle and Swingle 1967; Miller et al. 1990; Hooe 1991), which may result in years with low numbers of harvestable-sized fish. Webb and Ott (1991) suggested that length restrictions might lessen effects of variable recruitment by protecting the smaller fish of each year-class to supplement

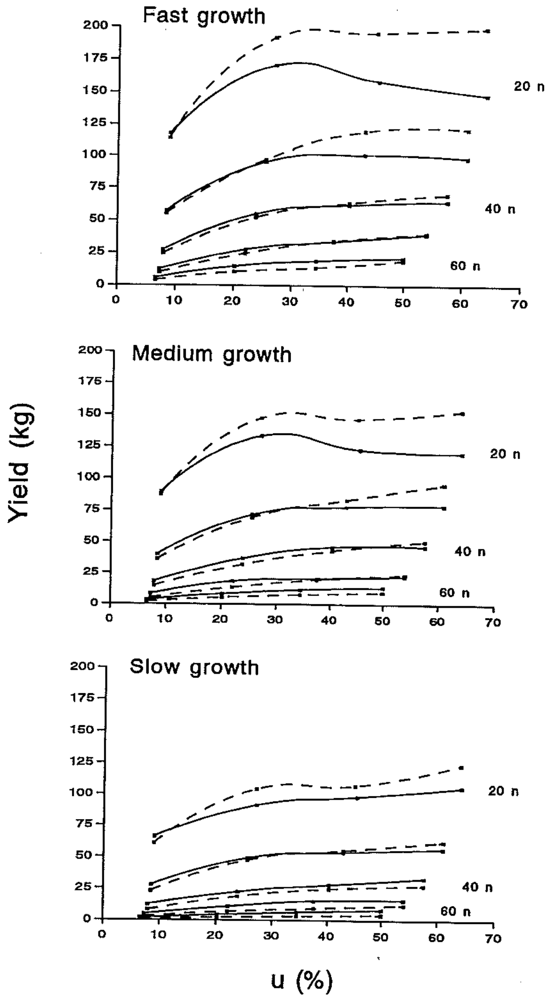

FIGURE 2.—Yield simulations based on 1,000 (N_0) white crappies recruited to the fishery at 200 mm (solid lines) or 250 mm (dashed lines). Percent conditional natural mortalities (n, $1 - e^{-M}$) and percent exploitation rates (u) for fast, medium, and slow growth are shown. Conditional natural mortality is defined as mortality in the absence of fishing and is shown in 10% increments on each plot.

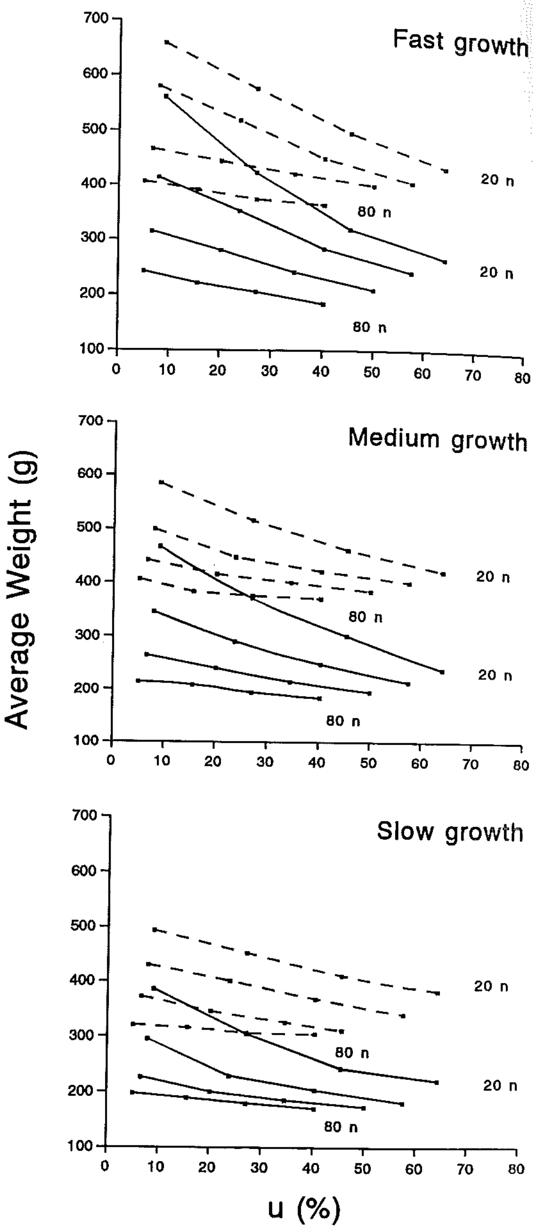

FIGURE 3.—Average weight (g) simulations for white crappies recruited to the fishery at 200 mm (solid lines) or 250 mm (dashed lines) and various percent conditional natural mortalities (n) and exploitation rates (u). Conditional natural mortality is shown in 20% increments on each plot.

the fishery in years when year-classes are weak. Thus, slower-growing fish of each year-class would be protected from harvest to dampen the severity of a subsequent weak or failed year-class. This management strategy has the most promise for crappie populations in which natural mortality is relatively low and slower-growing fish of each year-class can be preserved for harvest in the following year(s). Conversely, after years of high recruitment, crappie growth may decrease, likely because of intraspecific competition (Heidinger et al. 1985). After periods of high recruitment, improved yield and average weight induced through harvest restrictions may be diminished by slower growth.

Our results suggest that improving both yield and average weight of crappies by reducing exploitation may be the exception and not the rule, with harvest restrictions improving yield and average weight only in populations with rapid growth and below-average natural mortality. Average weight, however, can be improved with length limits. This improvement will usually come at the price of fewer fish in the creel but may not necessarily reduce yield appreciably unless limits are set too high. We suggest that statewide bag and length limits may not be the optimal management strategy for crappie populations. Managers may optimize fishery benefits derived from crappie populations by regulating harvest according to existing mortality and growth conditions and to angler preference for composition of their creel, which may range from many small fish to a few large ones.

Our model, however, assumed additive mortality (i.e., a linear relation between u and A but with slope not necessarily equal to one). Thus, any decrease in u with the additive model would result in some decrease in A. Alternatively, mortality could be compensatory (Anderson and Burnham 1976). In this case, at some low to intermediate level of u, A would remain unchanged because natural mortality would decrease to compensate for reduced fish density. Likewise, reduced exploitation might be accompanied by increased natural mortality so that A would remain unchanged. We note that if compensatory mortality occurs, the additive model we used might overestimate yield at low u because fewer fish would be available for harvest than would be predicted with an additive model. Although compensatory mortality has not been documented for adult fishes, further evaluation of the compensatory and additive mortality hypotheses may prove useful for managing crappie fisheries.

Acknowledgments

This research was funded by the Mississippi Department of Wildlife, Fisheries and Parks through Federal Aid in Sport Fish Restoration, project F-105, and by the Mississippi Agriculture and Forestry Experiment Station. We thank R. Brock for assistance with the literature review. J. Boxrucker, M. Colvin, D. Jackson, M. Maceina, H. Schramm, and M. Webb provided helpful comments on a previous draft of this manuscript.

References

Anderson, D. R., and K. P. Burnham. 1976. Population ecology of the mallard: VI. The effect of exploitation on survival. U.S. Fish and Wildlife Service Resource Publication 128.

Angyal, R., R. Glass, and O. E. Maughan. 1987. The characteristics of the white crappie population of Sooner Lake, Oklahoma. Proceedings of the Oklahoma Academy of Science 67:1–10.

Brock, R. E. 1994. Growth, fishing and natural mortalities of crappies in two Mississippi Lakes. Master's thesis. Mississippi State University, Starkville.

Carter, B. T. 1967. Growth of three centrarchids in Lake Cumberland, Kentucky. Kentucky Department of Fish and Wildlife Resources Fishery Bulletin 44.

Carter, E. R. 1953. Growth rates of the white crappie, *Pomoxis annularis,* in Kentucky lakes. Kentucky Department of Fish and Wildlife Resources Fishery Bulletin 12.

Colvin, M. A. 1991a. Population characteristics and angler harvest of white crappies in four large Missouri reservoirs. North American Journal of Fisheries Management 11:572–584.

Colvin, M. A. 1991b. Evaluation of minimum-size limits and reduced daily limits on the crappie populations and fisheries in five large Missouri reservoirs. North American Journal of Fisheries Management 11:585–597.

Eder, S. 1990. Angler use of black crappie and the effects of a reward-tag program at Jamesport Community Lake, Missouri. American Fisheries Society Symposium 7:647–654.

Ellison, D. G. 1984. Trophic dynamics of a Nebraska black crappie and white crappie population. North American Journal of Fisheries Management 4:355–364.

Gabelhouse, D. W., Jr. 1984. An assessment of largemouth bass slot length limits in five Kansas lakes. Kansas Fish and Game Commission, Federal Aid in Sport Fish Restoration, Project F-9-P-3, Final Report, Emporia.

Glass, R., and E. O. Maughan. 1982. Factors influencing fish populations in Oklahoma Lakes and Ponds. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration, Project F-41-R, Job 7, Final Report, Oklahoma City.

Goodson, L. F. 1966. Crappie. Pages 312–322 *in* A. Calhoun, editor. Inland fisheries management. California Department of Fish and Game, Sacramento.

Hammers, B. E., and L. E. Miranda. 1991. Comparisons of methods for estimating age, growth, and related population characteristics of white crappies. North American Journal of Fisheries Management 11:492–498.

Heidinger, R. C., B. Tetzlaff, and J. Stoeckel. 1985. Evidence of two feeding subpopulations of white crappie (*Pomoxis annularis*) in Rend Lake, Illinois. Journal of Freshwater Ecology 3:133–143.

Hooe, M. L. 1991. Crappie biology and management. North American Journal of Fisheries Management 11:483–484.

Larson, S. C., B. Saul, and S. Schleiger. 1991. Exploitation and survival of black crappies in three Georgia reservoirs. North American Journal of Fisheries Management 11:604–613.

Miller, R. L. 1991. Crappie management investigations. Ohio Department of Natural Resources, Division of Wildlife, Federal Aid in Sport Fish Restoration, Project F-29-R-29 to R-30, Final Report, Columbus.

Miller, S. J., D. D. Fox, L. A. Bull, and T. D. McCall. 1990. Population dynamics of black crappie in Lake Okeechobee, Florida, following the suspension of commercial harvest. North American Journal of Fisheries Management 10:98–105.

Mitzner, L. 1984. Crappie management: problems and solutions. North American Journal of Fisheries Management 4:339–340.

Mosher, T. D. 1985. Assessment of white crappie growth and survival at two Kansas state fishing lakes. Kansas Game and Fish Commission, Dingell–Johnson/Pittman–Robertson Comprehensive Option, Project FW-9-P-(1-4), Emporia.

Neumann, R. M., and B. R. Murphy. 1991. Evaluation of the relative weight (W_r) index for assessment of white crappie and black crappie populations. North American Journal of Fisheries Management 11: 543–555.

Parrish, D. L., T. D. Forsythe, and T. J. Timmons. 1986. Growth and condition comparisons of white crappie in two similar large reservoirs. Journal of the Tennessee Academy of Science 61(4):92–95.

Patriarche, M. H. 1953. The fishery in Lake Wappapello, a flood-control reservoir on the St. Francis River, Missouri. Transactions of the American Fisheries Society 82:242–254.

Range, J. D. 1973. Growth of five species of game fishes before and after introduction of threadfin shad in Dale Hollow Reservoir. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners 26(1972):510–518.

Reed, J. R., and W. D. Davies. 1991. Population dynamics of black crappies and white crappies in Weiss Reservoir, Alabama: implications for the implementation of harvest restrictions. North American Journal of Fisheries Management 11:598–603.

Ricker, W. E. 1975. Computation and interpretation of biological statistics in fish populations. Fisheries Research Board of Canada Bulletin 191.

Swingle, H. S., and W. E. Swingle. 1967. Problems in dynamics of fish populations in reservoirs. Pages 229–243 *in* Reservoir fishery resources symposium. American Fisheries Society, Southern Division, Reservoir Committee, Bethesda, Maryland.

Webb, M. A., and R. A. Ott, Jr. 1991. Effects of length and bag limits on population structure and harvest of white crappies in three Texas reservoirs. North American Journal of Fisheries Management 11: 614–622.

Wilimovsky, N. J., and E. C. Wicklund. 1963. Tables of the incomplete beta function for the calculation of fish population yield. University of British Columbia, Vancouver.

Zale, A. V., and K. C. Stubbs. 1991. Development of a white crappie fishery in a stage-fill impoundment in Oklahoma. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration, Project F-41-R-13, Final Report Oklahoma City.