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Effects of thermal effluent on body condition of largemouth bass

PAR POND, an 1,100-hectare reservoir in South Carolina, has received heated effluent from a nuclear production reactor since 1957. A notable feature of the reservoir[1] is the abundance and abnormally high catchability of largemouth bass (*Micropterus salmoides*[2]). Most reported responses of bass to the thermal situation in Par Pond are interpreted as inconsequential[3–7]; increases in the densities of certain intestinal parasites[8] and the incidence of red-sore disease[9] in thermal areas are considered detrimental. Fishery scientists use body condition[10] as an index for estimating a fish's well-being or fitness[11] as well as the relative suitability of the habitat[12]. Body condition (K) of an individual is established by the relationship $K = 10^5 W \times L^{-3}$, where W = body weight (g) and L = standard length (mm). However, caution must be exercised to ensure that ontogenetic changes in body shape, seasonal and sex differences, and small sample sizes do not preclude the effective use of the index for comparative purposes among individuals[10]. This report takes these reservations into account and compares body condition of largemouth bass collected from heated and unheated waters in Par Pond. The unique feature of this study is that data from 10 years are available on a large sample ($n > 10{,}000$) of largemouth bass, an important species of warmwater sport fish. Lower body condition is associated with moderate thermal conditions comparable to many industrial settings and is correlated with lower levels of stored fat and with the incidence of red-sore disease.

Bass were collected primarily by angling or electrofishing, and the following data were obtained: capture date, location within the reservoir, standard and or total length, and body weight. Body condition (K) was determined using the standard length of each fish. The regression of standard and total length indicated a highly predictable relationship ($r = 0.999$; n = 3,000) between these two measurements. So, if only total length had been taken on a particular fish, standard length was estimated for calculating K values. To eliminate the juvenile component from the comparisons and to preclude problems emanating from ontogenetic changes in shape and symmetry[10], only individuals ≥ 20.0 cm standard length are included in this study.

Par Pond receives moderate thermal loading equivalent to power reactor levels creating surface temperatures with ΔT values of up to 10 °C in the heated areas[13]. Mean maximum surface temperatures during reactor operations in summer months were 35 °C in thermally-altered areas and 31 °C in unaffected locations; in winter mean temperatures were 20 °C in heated areas and 16 °C at natural sites[14]. Complete descriptions of the physical, chemical and biological characteristics of Par Pond are given in other reports[1,15]. Bass taken within 200 m of the effluent (the area of maximum elevated temperatures) were classed as being from the heated area; those from other locations in Par Pond were grouped for analysis as being from unheated habitats. The unheated sampling areas were 2–7 km from the heated area. Substantial evidence exists to indicate that some Par Pond bass occasionally move long distances in the reservoir[16], although movement between distant regions is minimal[17,18]. Hence, a particular section of lake has a relatively discrete subpopulation that maintains its integrity relative to other sections.

There is a strong correlation between body condition of largemouth bass and the location of capture relative to the heated effluent (Table 1). Adult fish from unheated areas exhibited significantly higher mean condition factors than those from the heated area. Condition factors were usually higher in both heated and unheated areas during winter than during any other season. Lowest condition factors occurred in unheated areas in spring or autumn of most years, whereas summer was always the period of poorest body condition for bass in the

Table 1 Mean body condition coefficients (K) of largemouth bass (*Micropterus salmoides*) from a South Carolina reservoir receiving heated effluent

Season*	Winter		Spring		Summer		Autumn	
	H	U	H	U	H	U	H	U
1967	—	—	—	—	1.99 (17)	2.17 (27)	—	—
1968	—	—	—	—	—	—	—	—
1969	2.32 (187)	2.41 (174)	2.12 (281)	2.27 (195)	1.97 (44)	2.31 (419)	2.00 (335)	2.21 (59)
1970	2.28 (62)	2.35 (211)	2.12 (148)	2.17 (201)	2.12 (33)	2.32 (296)	2.19 (18)	2.14 (13)
1971	2.22 (273)	2.14 (61)	— —	— —	1.85 (87)	1.94 (79)	2.01 (18)	— —
1972	2.54 (23)	2.46 (19)	— —	— —	2.10 (52)	2.32 (274)	2.09 (46)	2.20 (276)
1973	2.30 (65)	2.38 (331)	2.08 (55)	2.14 (200)	1.91 (210)	2.19 (181)	1.97 (43)	2.32 (131)
1974	— —	— —	— —	— —	— —	— —	2.14 (115)	2.28 (57)
1975	2.26 (366)	2.50 (228)	2.25 (457	2.38 (447)	1.87 (432)	2.12 (562)	2.41 (153)	2.41 (112)
1976	2.37 (164)	2.44 (98)	2.30 (200)	2.33 (272)	2.02 (201)	2.20 (207)	2.05 (246)	2.16 (160)
Total	2.29 (1140)	2.39 (1122)	2.20 (1141)	2.28 (1315)	1.93 (1059)	2.25 (2018)	2.10 (974)	2.25 (808)

Sample sizes are indicated in parentheses. H, fish collected from waters heated by thermal effluent; U, fish collected in unheated, normal temperature portions of lake, 2–7 km from H. Standard errors for season and location of individual years ranged from 0.01 to 0.05. Body conditions of all bass from thermal areas in a particular season are significantly lower ($P < 0.05$) than those during the same season from natural areas.

* Winter = December, January, February; summer = June, July, August; spring = March, April, May; autumn = September, October, November.

Table 2 Standard lengths ($\bar{x}$ cm) of bass from Par Pond reservoir in different seasons

Season	Males		Females	
	H	U	H	U
Winter	32.1 ± 0.19 (270)	33.4 ± 0.13 (356)	35.6 ± 0.19 (354)	35.8 ± 0.17 (425)
Spring	32.3 ± 0.24 (112)	32.8 ± 0.16 (271)	35.7 ± 0.16 (365)	35.4 ± 0.18 (355)
Summer	32.3 ± 0.15 (199)	32.8 ± 0.11 (524)	35.4 ± 0.17 (225)	35.6 ± 0.13 (597)
Autumn	32.2 ± 0.36 (82)	32.4 ± 0.20 (257)	36.6 ± 0.38 (102)	34.6 ± 0.33 (203)

The data show that adult female bass from this reservoir are significantly larger than adult males; however, no length differences are apparent between different seasons or thermally different locations. Comparisons are based on samples taken between 1969 and 1973 in which sex was determined by dissection. H, heated habitats; U, natural temperature habitats. Values are means ± s.e.m. with the number of determinations shown in parentheses.

heated area. Females ($\bar{x} = 35.5$; s.e. = 0.067, $n = 2{,}626$) from all locations and during all seasons were significantly longer (standard length in mm) than males ($\bar{x} = 32.6$; s.e. = 0.059; $n = 2{,}071$). However, no consistent difference in condition factors was observed between the sexes. Average fish length within each sex was relatively constant between seasons and locations; (Table 2). Thus seasonal and locational differences in condition factors are attributable to differences in individual weights in otherwise similarly-sized fish. No consistent trend in body condition was apparent from one year to the next over the 10-yr sampling period (Table 1).

The amount of body fat that can be removed by dissection is minimal in individuals having low body conditions (Fig. 1). Although the relationship is not readily definable to a linear or curvilinear model, bass with body conditions less than 1.8 have no intracoelomic fat reserves. Thus, fish with low body condition are low in stored energy reserves.

The simplest explanation for the differences in body condition and body fat levels among adult Par Pond bass is as follows. (1) Although some transient fish are attracted to the effluent, most bass inhabiting the heated area of the reservoir are permanent residents[16–18]. (2) Although bass in the heated area may frequent cooler, stratified waters, a sufficient proportion of time is spent in the heated layer to elevate body temperatures[3]. (3) An elevation in temperature of largemouth bass results in an increase in metabolism[19]. (4) Fat reserves are called upon when food intake is insufficient to meet energy requirements of some vertebrates, including fish[20]. (5) Metabolic demands would be elevated during the warmer months when body temperatures are highest (D. H. B., unpublished). (6) Frequent observations indicate that population levels of forage fish, primarily *Lepomis* spp., the mainstay in the diet of adult bass from Par Pond[4], are dramatically reduced during these warmer months. Also, associated with the advent of warmer weather is the greater expenditure of energy and loss of weight as a consequence of spawning. thus, the combination of increased metabolism, reduced food intake, reproductive activity and depletion of intracoelomic fat reserves results in a loss of weight and reduced body condition. These findings draw attention to subtle biological effects of thermal pollution that may go unnoticed without critical, systematic examination on a long-term basis.

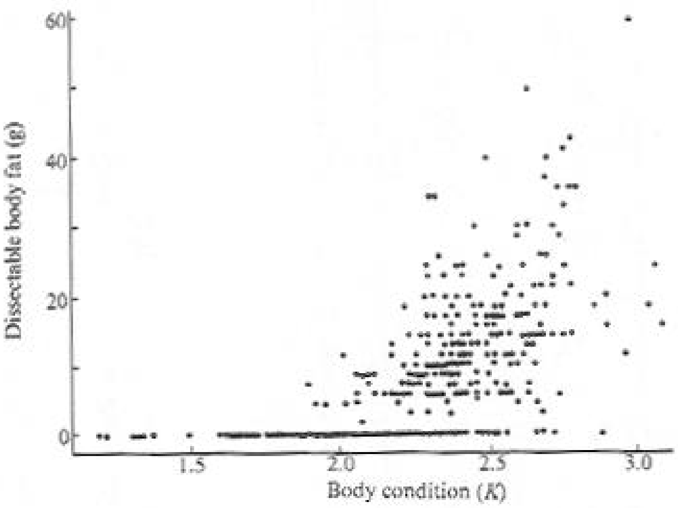

Fig. 1 Relationship between body condition and intracoelomic fat reserves of largemouth bass (*Micropterus salmoides*: $n = 275$) taken during the summer and autumn of 1973 from a thermally influenced reservoir in South Carolina.

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1. Gibbons, J. W. & Sharitz, R. R. *Amer. Sci.* **62,** 660–671 (1974).
2. Gibbons, J. W., Hook, J. T. & Forney, D. L. *Prog. Fish Cult.* **34,** 88–90 (1972).
3. Bennett, D. H. *Archs Hydrobiol.* **68,** 376–381 (1971).
4. Bennett, D. H. & Gibbons, J. W. *Trans. Am. Fish. Soc.* **101,** 650–654 (1972).
5. Bennett, D. H. & Gibbons, J. W. *Trans. Am. Fish. Soc.* **104,** 77–82 (1975).
6. Yardley, D., Avise, J. C., Smith, M. H. & Gibbons, J. W. *AEC Symp. Ser.* (CONF-730505) 255–263 (1974).
7. Smith, M. H. & Scott, S. L. *Bull. Georgia Acad. Sci.* **95,** 215–219 (1976).
8. Eure, H. E. & Esch, G. W. *AEC Symp. Ser.* (CONF-730505) 207–215 (1974).
9. Esch, G. W., Hazen, T. C., Dimock, F. V. & Gibbons, J. W. *Trans. Am. Microsc. Soc.* **95,** 687, 693 (1976).
10. LeCren, E. D. *J. Anim. Ecol.* **20,** 201–219 (1951).
11. Everhart, W. H., Eipper, A. W. & Youngs, W. D. *Principles of Fishery Science* 288 (Cornell University Press, Ithaca, 1975).
12. Lagler, K. F. *Freshwater Fishery Biology* 421 (William Brown, Dubuque, 1975).
13. Lewis, W. M., Jr *AEC Symp. Ser.* (CONF-730505) 1–27 (1974).
14. Hazen, T. C. thesis, Wake Forest Univ. (1978).
15. Parker, E. D., Hirshfield, M. F. & Gibbons, J. W. *J. Water Pollution Control Fedn* **45,** 726–733 (1973).
16. DuPont, S. P. thesis, Univ. Georgia (1976).
17. Gibbons, J. W. & Bennett, D. H. *Proc. 3rd natn. Symp.* (CONF-7105-p.1) Oak Ridge, 325–327 (1971).
18. Quinn, T., Esch, G. W., Hazen, T. C. & Gibbons, J. W. *Copeia.* (in the press).
19. Hazen, T. C., Esch, G. W., Glassman, A. B. & Gibbons, J. W. *J. Fish. Biol.* (in the press).
20. Hoar, W. S. *General and Comparative Physiology* (Prentice-Hall, Englewood Cliffs, 1966).

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