

Comparative Clinicopathological Responses of Striped Bass and Palmetto Bass to Acute Stress

EDWARD J. NOGA,* CHENGJIE WANG,¹ AND CAROL B. GRINDEM

North Carolina State University, College of Veterinary Medicine,
4700 Hillsborough Street, Raleigh, North Carolina 27606, USA

RAMY AVTALION

Department of Biology, Bar Ilan University, Ramat Gan, Israel

Abstract.—Selected clinicopathological features were compared between resting striped bass *Morone saxatilis* and palmetto bass (striped bass female × white bass *M. chrysops* male) and fish subjected to an acute (2-h-long) confinement stress. The taxa differed significantly in resting plasma lysozyme activities and leukocyte responses to mitogen stimulation. Confined fish of both taxa showed similar elevations in plasma osmolality, potassium, anion gap, creatinine, and glucose, suggesting a shock response. However, striped bass displayed slightly more severe perturbations, including elevated albumin and total protein, that indicated hemoconcentration. At least some of the intertaxon differences may have been associated with the greater ability of palmetto bass to adapt to culture conditions.

The striped bass *Morone saxatilis* is considered to be one of the most sensitive fish species to environmental stress (Kerby 1993). In contrast, palmetto bass, the hybrid of female striped bass with male white bass *M. chrysops*, is considered to be less prone to stress (Noga et al. 1994). These differences in culture adaptability are indicated by the longer time required by striped bass to recover from a stressful event and the greater incidence of opportunistic disease among striped bass after stress (Noga et al. 1994). The acknowledged differences in adaptation to culture between these two taxa provided the opportunity to examine how two genetically similar fish differ physiologically under controlled conditions. In this paper, we compare the taxa with respect to certain clinical chemical and immunological functions measured for resting fish and for fish subjected to an acute stress.

Methods

Test fish.—Striped bass (Roanoke River strain, first generation; spawned at Edenton National Fish Hatchery, Edenton, North Carolina) and palmetto bass (*M. saxatilis* female × *M. chrysops* male, first generation; spawned at Pamlico Aquaculture Center, Aurora, North Carolina) were maintained in a flow-through freshwater system. Fish used for most experiments were about 24 months old and

ranged from 310 to 390 mm in total length. Palmetto bass used for mitogen blastogenesis experiments were about 36 months old. (Age differences in the range of 24–36 months should not have affected stress responses: Strange and Cech 1992). Fish were fed a commercial pelleted feed twice daily and were maintained on a 12-h light:12-h dark photoperiod.

Confinement system.—Test fish were acclimated to a 1,500-L holding tank (about 1 fish/30 L) with flow-through well water for at least 2 months before experiments began. For the clinical chemistry and lysozyme tests, detailed below, 10–12 fish of each taxon were quickly and simultaneously removed from the holding tank and placed into 20-L glass test aquaria having 10 L of water (one fish per aquarium). An anesthetic overdose (200 mg tricaine/L buffered with 400 mg NaHCO₃/L) was immediately added to the water in 11 of the test aquaria (5 hybrid and 6 striped bass) and the anesthetized fish were sampled as described below. These were deemed to be resting (unstressed) fish, and each fish was considered a replicate. The remaining 5–6 fish of each taxon were left in their test aquaria, which were each supplied with a constant flow (2 L/min) of well water. During the confinement, dissolved oxygen was 6.8–7.5 mg/L, temperature was 19 ± 1°C, pH was 6.65–6.87, unionized ammonia was less than 0.001 mg/L, and nitrite was less than 0.10 mg/L. These conditions were the same as those in the holding tank. After 2 h of confinement, an anesthetic overdose was added to all test aquaria and fish were sampled as described below.

* Corresponding author: ed.noga@ncsu.edu

¹ Present address: 6504 Lakes Divide Road, Temple Terrace, Florida 33637, USA.

Received March 27, 1998; accepted October 6, 1998

Fish for the mitogen blastogenesis tests were quickly moved from their separate holding tank to 20-L glass aquaria, one fish per aquarium. They were immediately anesthetized with tricaine, and their blood and spleen were sampled as described below.

Sampling regimen.—For clinical chemistry and lysozyme tests, all fish in the unstressed group were bled via the caudal vessels within 3 min of being removed from the 1,500-L holding tank; blood was taken in a heparinized, 22-gauge, 2.5-cm-long needle attached to a 3-mL syringe. The blood was centrifuged at $13,500 \times$ gravity for 10 min at 4°C and the plasma was stored at -70°C until tested for lysozyme and clinical chemistry. For the mitogen blastogenesis tests, fish were sedated with tricaine and blood was collected from the caudal sinus into heparinized syringes via 22-gauge needles. Whole-blood samples were immediately diluted 1:10 with A-L medium (Luft et al. 1991; GIBCO, Grand Island, New York). The spleen was then harvested from each fish.

Lysozyme assay.—Lysozyme was measured by the turbidimetric assay described by Parry et al. (1965) with modifications described below. To determine the optimal pH for lysozyme activity, lyophilized *Micrococcus luteus* (M-3770, Sigma Chemical Co., St. Louis, Missouri) was suspended in 0.045 M phosphate buffer (PB) at various pH values. The final concentration of *M. luteus* was 300 $\mu\text{g}/\text{mL}$. This bacterial suspension (985 μL) was mixed with 15- μL aliquots of pooled fish plasma in a cuvette (Fisher Scientific, Raleigh, North Carolina). Pooled fish plasma consisted of equal volumes of plasma from either four unstressed striped bass or four unstressed palmetto bass sampled before the stress experiment began. Each cuvette was briefly vortexed and the decrease in absorbance (ΔA) per minute was recorded with a spectrophotometer at 600 nm at 25°C . The optical density (OD) at the 30th second and 90th second were used for calculating enzyme activity.

For tests of lysozyme activity in individual test fish, *M. luteus* was suspended in 0.045 M PB (pH 6.35). Hen egg white lysozyme (Sigma L-6876) in PB was used as a positive control. All tests for lysozyme activity were run in duplicate. For the assay, 1 unit of lysozyme activity was defined as that giving an absorbance change of 0.001/min.

Clinical chemistry.—Sodium, potassium, chloride, total CO_2 , creatinine, phosphate, calcium, aspartate aminotransferase, lactate dehydrogenase, and glucose were measured with an automated chemistry analyzer (Monarch Plus Instrumentation

Laboratory, Lexington, Massachusetts). Anion gap was calculated as $(\text{Na} + \text{K}) - (\text{Cl} + \text{total CO}_2)$. Osmolality was determined by freezing point depression (Precision System, model 5004, Sudbury, Massachusetts).

Mitogen blastogenesis.—After heparinized whole blood had been collected, the fish were exsanguinated by caudal sinus puncture to reduce the number of erythrocytes in the spleen. Each spleen was removed via a ventral incision and placed into 4 mL of A-L medium. Leukocytes were teased free with scissors and forceps and tissue debris was removed by sedimentation. Splenic leukocytes were counted with a hemocytometer and adjusted with A-L medium to 5×10^7 cells/mL. Cell viability exceeded 95% as determined by trypan blue dye exclusion.

One hundred microliters of mitogen dilutions (concanavalin A [ConA]; Sigma Lot 12H9408) were placed into wells of a 96-well microtiter plate (Falcon, Becton Dickinson Labware, Lincoln Park, New Jersey). Then, 100 μL of splenic leukocytes or the 1:10 dilution of whole-blood suspension were added to each well. Duplicate cultures were treated with each mitogen concentration. Cultures were incubated in 95% air : 5% CO_2 in a modular incubation chamber (Billups-Rothenburg, Inc.) for 3 d at 24°C . Lymphocyte proliferation was measured by incorporation of [methyl- ^3H]-thymidine (ICN, Irvine, California, specific activity 6.7 curies (Ci)/ μmol) into DNA. ^3H -thymidine (0.8 μCi) in 20 μL of A-L medium was added to each well 16 h before cells were harvested. These conditions were previously determined to be optimal for *Morone* species (Wang et al. 1997).

Cells were harvested with a multiple, semiautomatic cell harvester (Bellco Glass, Vineland, New Jersey) in a vacuum less than 58.4 cm of mercury and rinsed first with distilled water and then with 95% alcohol. Cell debris and macromolecules incorporating ^3H -thymidine-labeled DNA were collected on fiberglass filter disks (Cambridge Technology, Cambridge, Massachusetts). Filter disks were dried and placed in liquid scintillation vials (7 mL), and 4 mL of scintillation fluid (Ecoscint O, National Diagnostics, Atlanta, Georgia) were added to each vial. The radioactivity was quantitated by liquid scintillation counting in a beta counter (1219 Rackbeta, LKB Instruments, Monmouth, New Jersey). Results were expressed as counts per minute (cpm) or a stimulation index (SI), which was calculated: $\text{SI} = (\text{cpm of stimulated culture})/(\text{cpm of nonstimulated [control] culture})$.

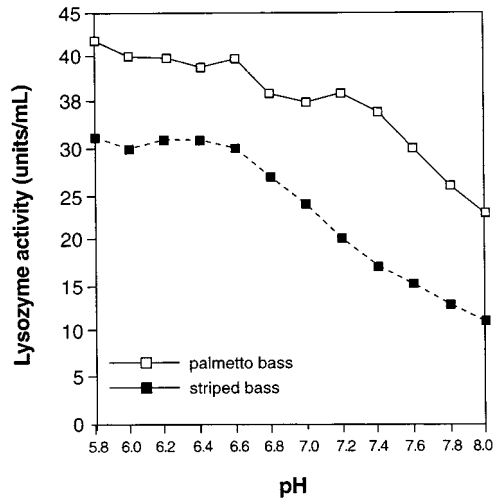


FIGURE 1.—Effect of pH on lysozyme activity of pooled striped bass and palmetto bass plasma from unconfined fish. One unit of lysozyme activity gives an absorbance change of 0.001/min.

Statistical analysis.—The Statistical Analysis System (SAS; SAS Institute, Cary, North Carolina) was used for all statistical calculations. The GLM (general linear models) procedure modeled lysozyme activity as a quadratic function of pH with fish taxon (striped versus palmetto) as a class

variable. Differences in clinical chemistry and lysozyme variables between taxa and between stressed and unstressed groups within taxa were evaluated with *t*-tests. Mitogen-stimulated responses were compared between taxa via analysis of variance (ANOVA) and Tukey's multiple comparisons (Neter et al. 1990). The significance of differences was judged relative to $\alpha = 0.05$.

Results

The highest lysozyme activity measured was between pH 5.8 and 6.6. For both taxa, activity decreased at more alkaline pH (Figure 1). The effect of pH on lysozyme activity was similar to that previously reported for striped bass serum lysozyme (Blazer et al. 1995). Among unstressed fish, lysozyme activity was significantly greater in palmetto bass than in striped bass plasma for both pooled samples (Figure 1) and individual samples (Table 1). Stressed fish of both taxa exhibited significantly higher lysozyme levels than unstressed fish (Table 1).

The lysozyme activity of the pooled plasma samples used to determine optimum pH (Figure 1) was greater than the mean resting plasma lysozyme levels of fish used in the experiment (Table 1). This discrepancy was due to enhanced activity in the pooled samples. The mean values of the four

TABLE 1.—Clinical chemical values for striped and palmetto bass blood before and after confinement stress. Values are means \pm SE for 5–6 fish; U denotes a lysozyme unit representing an absorbance change of 0.001/min; IU denotes international unit.

Variable	Striped bass			Palmetto bass			<i>P</i> : Striped versus palmetto bass ^a	
	Before Confinement	After confinement	<i>P</i> ^b	Before confinement	After confinement	<i>P</i> ^b	Before confinement	After confinement
Lysozyme (U/mL)	19 \pm 2	29 \pm 2	0.01	27 \pm 2	40 \pm 5	0.01	0.01	0.06
Osmolality (mosmols/kg)	348 \pm 2	375 \pm 4	0.00	356 \pm 2	387 \pm 4	0.04	0.01	0.06
Na (meq/L)	181 \pm 4	179 \pm 4	0.78	174 \pm 2	176 \pm 3	0.67	0.18	0.50
K (meq/L)	3.85 \pm 0.08	4.70 \pm 0.28	0.01	3.31 \pm 0.24	5.14 \pm 0.42	0.01	0.08	0.41
Cl (meq/L)	143 \pm 2	137 \pm 1	0.04	144 \pm 2	137 \pm 4	0.17	0.78	0.94
Total CO ₂ (mmol/L)	9.5 \pm 1.0	0.8 \pm 0.3	0.00	10.7 \pm 0.9	2.4 \pm 0.7	0.00	0.39	0.08
Anion gap (meq/L)	28.5 \pm 5.0	46.5 \pm 4.1	0.02	23.7 \pm 1.3	42.3 \pm 3.0	0.00	0.37	0.43
Albumin (g/dL)	1.1 \pm 0.0	1.2 \pm 0.0	0.04	1.3 \pm 0.0	1.3 \pm 0.1	0.69	0.00	0.15
Total protein (g/dL)	3.8 \pm 0.1	4.3 \pm 0.1	0.04	4.6 \pm 0.1	4.6 \pm 0.2	0.90	0.00	0.19
Albumin-globulin ratio	0.4 \pm 0.0	0.4 \pm 0.0	1.00	0.4 \pm 0.0	0.4 \pm 0.0	1.00	1.00	1.00
Glucose (mg/dL)	100 \pm 28	406 \pm 20	0.00	118 \pm 10	333 \pm 28	0.00	0.56	0.07
Aspartate aminotransferase (IU/L)	23 \pm 6	42 \pm 5	0.05	45 \pm 21	74 \pm 12	0.26	0.37	0.05
Lactate dehydrogenase (IU/L)	221 \pm 92	98 \pm 40	0.26	164 \pm 54	258 \pm 77	0.35	0.61	0.11
Creatinine (mg/dL)	0.5 \pm 0.0	0.7 \pm 0.1	0.03	0.3 \pm 0.0	0.5 \pm 0.0	0.01	0.01	0.02
Phosphate (mg/dL)	10.0 \pm 0.3	10.3 \pm 0.5	0.69	9.8 \pm 0.2	14.7 \pm 1.0	0.00	0.62	0.01
Calcium (mg/dL)	10.6 \pm 0.1	12.5 \pm 0.3	0.00	11.1 \pm 0.2	12.9 \pm 0.2	0.00	0.04	0.26

^a Probability of a nonsignificant difference between taxa.

^b Probability of a nonsignificant difference between before- and after-confinement values.

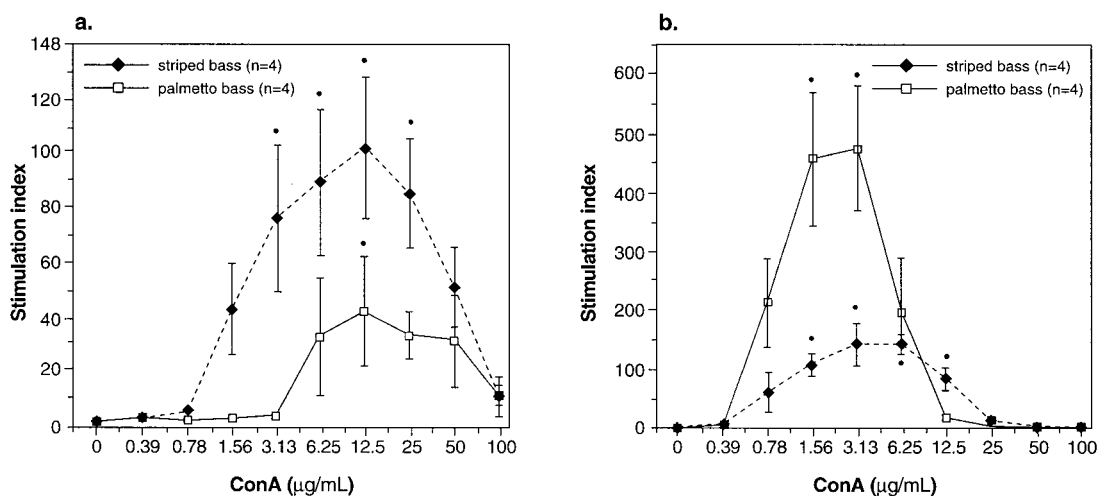


FIGURE 2.—Stimulation indices (SIs) for palmetto bass and striped bass blood cells that were stimulated with serially diluted concanavalin A (ConA) at 24°C for 3 d: (a) whole blood; (b) splenocytes. Error bars are SEs. The SIs labeled with asterisks were significantly different from the control ($P < 0.05$).

samples measured separately at pH 6.35 were 25 U/mL for striped bass and 31 U/mL for palmetto bass. However, the activities of these same samples pooled together were 29 U/mL and 40 U/mL (E. Noga and M. Yang, unpublished data), respectively.

The stimulation indices of whole blood were significantly higher for striped bass than for palmetto bass (Figure 2a). In contrast, the SI of splenic leukocytes was significantly higher for palmetto bass than for striped bass (Figure 2b). Splenocytes from palmetto bass (containing about 40% erythrocytes), had an optimal response at 3.13 µg ConA/mL (Figure 2b). This ConA concentration was much lower than that needed for whole blood (which has more than 99% erythrocytes; Figure 2a). Thus, the purity of the leukocyte preparation was negatively correlated with the optimal ConA concentration. The mitogen responses of striped bass whole blood leukocytes were significantly higher than those of palmetto bass, but the responses of striped bass splenocytes were significantly lower than those of palmetto bass with the same number of splenocytes.

Electrolyte balance changed for both taxa after confinement, as expressed by increases in plasma osmolality, potassium, and anion gap, and by decreases in total CO₂ (Table 1). Plasma chloride was depressed in striped bass but not in palmetto bass, but plasma glucose was significantly increased in both taxa. Other changes included significantly increased creatinine and calcium levels in stressed striped bass and increased creatinine,

calcium, and phosphate levels in stressed palmetto bass. The only significant enzyme change was an increased aspartate aminotransferase level in striped bass after stress.

Discussion

The type and length of stress which we used in our study is very similar to that used in many other studies of stress (e.g., Davis and Parker 1986; Pottinger et al. 1992). These studies were intended to mimic conditions that are routinely encountered in aquaculture. For example, Strange and Cech (1992) held 500–1,600-mm striped bass in a 20-L net for up to 35 min to study swimming performance after stress. Carmichael et al. (1984) held groups of 1,300–2,300-mm largemouth bass *Micropterus salmoides* in nets that placed them close enough to be in constant contact with their tankmates for up to 48 h.

Lysozyme is a leukocyte enzyme important in inflammation and bacterial killing. Lysozyme levels were significantly higher in stressed striped and palmetto bass than in unstressed controls, suggesting a protective mechanism. Mock and Peters (1990) also found that increased plasma lysozyme levels in rainbow trout *Oncorhynchus mykiss* exposed to a 30-min confinement stress. Palmetto bass had somewhat greater lysozyme activity than striped bass before and after confinement, which may mean that palmetto bass have greater disease resistance; lysozyme kills some bacterial pathogens (Grinde 1989) and probably participates in

microbe killing with other antimicrobial chemicals (Frohm et al. 1996).

The mean lysozyme concentration in the pooled samples was greater than that of the individual samples. Thus, synergism occurred when plasma samples were combined. Many compounds, especially cationic agents, can affect lysozyme's activity in the turbidimetric assay (Jenzano and Lundblad 1988) and lysozyme's activity may be potentiated in complex mixtures such as body fluids (Frohm et al. 1996). Synergism has been previously reported when clinical lysozyme samples were mixed (Gupta et al. 1987).

The optimal ConA concentration for whole-blood cells was higher than that for splenocytes. In whole blood, ConA may become bound to plasma components and cells other than lymphocytes. Competitive binding might be overcome by increasing the ConA concentration. This hypothesis is supported by our unpublished finding that palmetto bass leukocytes purified by density gradient centrifugation are even more sensitive to ConA stimulation. The significantly higher SI of striped bass whole-blood leukocytes may have been due to a higher number of leukocytes in peripheral blood. The total cell number for each whole-blood sample was not adjusted, because we wanted to compare the whole-blood response in individual fish. The greater sensitivity of palmetto bass splenocytes to ConA could be due to a number of factors, including greater affinity or receptivity of palmetto bass splenocyte membrane carbohydrates for ConA. Regardless of the molecular mechanisms, it suggests that these two taxa vary significantly in their immune response.

The clinical chemical responses of striped and palmetto bass to confinement stress were similar and mainly included changes in acid-base balance, glucose concentration, osmolality, and electrolyte concentrations. Among the most dramatic were changes in acid-base balance. Total CO₂ was severely depressed, especially in striped bass (Table 1). Cech et al. (1996) also found that total CO₂ of striped bass blood dropped to less than 3 mmol/L after 5 min of vigorous exercise. The anion gap in our fish was also very high in both taxa after stress, indicating the presence of excess acids. Harms et al. (1996) also determined very high anion gap in confined striped bass. The anion gap in our fish was due mainly to organic acids, because decreased total CO₂ with increased anion gap is a classical titration acidosis (Duncan et al. 1995). This suggests a severe metabolic acidosis, which might be caused by excessive muscle activity as-

sociated with struggling during confinement. Depressed total CO₂ also indicates a metabolic acidosis or respiratory alkalosis. Respiratory alkalosis typically results from labored breathing and hyperventilation, but our fish did not appear to struggle very vigorously during the confinement, and the changes in total CO₂ were too large to be explained by only respiratory alkalosis. Cell acidosis and necrosis was also suggested by the hyperkalemia and elevated aspartate aminotransferase; the latter is a general indicator of tissue necrosis (Duncan et al. 1995).

As expected, glucose was highly elevated after confinement, and it was the major contributor to heightened osmolality. Hyperproteinemia and azotemia, seen with hemoconcentration and shock, also contributed to the elevated osmolality. Even very short (90-s) net confinement causes increased plasma osmolality in striped bass (Young and Cech 1993a, 1993b).

Confinement brought significantly higher plasma potassium and calcium in both taxa and slightly lower chloride in striped bass. These results are similar to those reported previously by others for both striped bass and their hybrids (Tomasso et al. 1980; Davis and Parker 1990) as well as other fish species (Carmichael et al. 1984) after an acute confinement stress. The hypochloremia could be due to either malfunction in gill osmoregulatory pumps or leakage from epithelial damage. The former is more likely because sodium levels were unchanged after stress (leakage would be expected to cause losses of both sodium and chloride). Hyperosmolality may be due to hemoconcentration, which is also suggested by the hyperproteinemia in striped bass; this is typical of a shock response. A possible shock response is also suggested by the increased plasma creatinine, which is almost always caused by depressed glomerular filtration rate from decreased peripheral vascular perfusion.

The acute stress we used in our experiments also results in sloughing of the fin epithelium (Noga et al. 1998), which might cause hemodilution due to loss of this epithelial barrier. However, a shutdown in peripheral vascular perfusion might prevent this, and we have evidence that this epidermal damage is associated with elevated catecholamine (Noga et al. 1998), which can cause peripheral vascular shutdown (Wahlqvist 1980). Acute confinement also causes other profound hormonal changes in *Morone*, including elevated plasma cortisol, which rises higher in striped bass than in hybrid bass (Noga et al. 1994). Elevated cortisol

can cause hyperglycemia. Although plasma glucose did not differ significantly between striped and palmetto bass in the present study, the difference approached significance and may not have been demonstrated due to insufficient sample size.

The overall results of our studies indicate that the clinicopathological response to acute confinement stress was similar in striped bass and palmetto bass, although some variations may at least partly explain the different abilities of these two closely related fish taxa to adapt to culture conditions.

Acknowledgments

This research was supported by Binational U.S.–Israel Agricultural Research and Development Project US-2206-92; by grant NA46RG0087 from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, to the North Carolina Sea Grant College Program; by Saltonstall–Kennedy projects NA67FD00500 and NA67FD0131; and support from the North Carolina State University College of Veterinary Medicine. We thank M.-S. Yang for excellent technical assistance and D. Wilson for assistance with statistical analysis.

References

- Blazer, V. S., D. L. Higginbotham, and J. W. Fournie. 1995. Serum factors as indicators of environmental stress: optimization of methodologies for striped bass serum. Pages 443–457 in J. S. Stolen, T. C. Fletcher, C. J. Bayne, and C. J. Secombes, editors. *Modulators of immune responses: the evolutionary trail*, volume 2. SOS Publications, Fair Haven, New Jersey.
- Carmichael, G. J., J. R. Tomasso, B. A. Simco, and K. B. Davis. 1984. Confinement and water quality-induced stress in largemouth bass. *Transactions of the American Fisheries Society* 113:767–777.
- Cech, J. J., Jr., S. D. Bartholow, P. S. Young, and T. E. Hopkins. 1996. Striped bass exercise and handling stress in freshwater: physiological responses to recovery environment. *Transactions of the American Fisheries Society* 125:308–320.
- Davis, K. B., and N. C. Parker. 1986. Plasma corticosteroid stress response of fourteen species of warm-water fish to transportation. *Transactions of the American Fisheries Society* 115:495–499.
- Davis, K. B., and N. C. Parker. 1990. Physiological stress in striped bass: effect of acclimation temperature. *Aquaculture* 91:349–358.
- Duncan, J. R., K. W. Prasse, and E. A. Mahaffey. 1995. *Veterinary laboratory medicine*, 3rd edition. Iowa State University Press, Ames.
- Frohm, M., and eight coauthors. 1996. Biochemical and antibacterial analysis of human wound and blister fluid. *European Journal of Biochemistry* 237:86–92.
- Grinde, A. 1989. Lysozyme from rainbow trout, *Salmo gairdneri* Richardson, as an antibacterial agent against fish pathogens. *Journal of Fish Diseases* 12:95–104.
- Gupta, D. K., K. von Figura, and A. Hasilik. 1987. Conditions for a reliable application of the lysoplate method in the determination of lysozyme. *Clinica Chemica Acta* 165:73–82.
- Harms, C. A., C. V. Sullivan, R. G. Hodson, and M. K. Stoskopf. 1996. Clinical pathology and histopathology characteristics of net-stressed striped bass with “red-tail.” *Journal of Aquatic Animal Health* 8:82–86.
- Jenzano, J. W., and R. L. Lundblad. 1988. Effects of amines and polyamines on turbidimetric and lysoplate assays for lysozyme. *Journal of Clinical Microbiology* 26:34–37.
- Kerby, J. H. 1993. The striped bass and its hybrids. Pages 251–306 in R. R. Stickney, editor. *Culture of nonsalmonid freshwater fishes*, 2nd edition. CRC Press, Boca Raton, Florida.
- Luft, J. C., L. W. Clem, and J. Bly. 1991. A serum-free medium for bony fish leucocyte *in vitro* mitogen-induced proliferation. *Fish and Shellfish Immunology* 1:233–235.
- Mock, A., and G. Peters. 1990. Lysozyme activity in rainbow trout, *Oncorhynchus mykiss* (Walbaum), stressed by handling, transport and water pollution. *Journal of Fish Biology* 37:873–885.
- Neter, J., W. Wasserman, and M. H. Kutner. 1990. *Applied linear statistical models*, 3rd edition. Irwin, Homewood Illinois.
- Noga, E. J., S. Botts, M.-S. Yang, and R. Avtalion. 1998. Acute stress causes skin ulceration in striped bass and hybrid bass (*Morone*). *Veterinary Pathology* 35:102–107.
- Noga, E. J., J. H. Kerby, W. King, D. P. Aucoin, and F. Giesbrecht. 1994. Quantitative comparison of the stress response of striped bass (*Morone saxatilis*) and hybrid bass (*Morone saxatilis* × *Morone chrysops* and *Morone saxatilis* × *Morone americana*). *American Journal of Veterinary Research* 55:405–409.
- Parry, R. M., Jr., R. C. Chandan, and K. M. Shahani. 1965. A rapid and sensitive assay of muramidase. *Proceedings of the Society of Experimental Biology and Medicine* 119:384–386.
- Pottinger, T. G., A. D. Pickering, and M. A. Hurley. 1992. Consistency of the response of individuals of two strains of rainbow trout, *Oncorhynchus mykiss*. *Aquaculture* 103:275–289.
- Strange, R. J., and J. J. Cech, Jr. 1992. Reduced swimming performance of striped bass after confinement stress. *Transactions of the American Fisheries Society* 121:206–210.
- Tomasso, J. R., K. B. Davis, and N. C. Parker. 1980. Plasma corticosteroid and electrolyte dynamics of hybrid striped bass (white bass × striped bass) during netting and hauling. *Proceedings of the World Mariculture Society* 11:303–310.
- Wahlqvist, I. 1980. Effects of catecholamines on iso-

- lated systemic and branchial vascular beds of the cod, *Gadus morhua*. *Journal of Comparative Physiology B* 137:139–143.
- Wang, C., E. J. Noga, R. Avtalion, and M. G. Levy. 1997. Whole blood assay for examining lymphocyte blastogenesis of percichthyid bass (*Morone*). *Veterinary Immunology and Immunopathology* 58: 355–362.
- Young, P., and J. J. Cech, Jr. 1993a. Effects of exercise conditioning on stress responses and recovery of cultured and wild young-of-the-year striped bass *Morone saxatilis*. *Canadian Journal of Fisheries and Aquatic Sciences* 50:2094–2099.
- Young, P., and J. J. Cech, Jr. 1993b. Physiological stress responses to serial sampling and confinement in young-of-the-year striped bass, *Morone saxatilis* (Walbaum). *Comparative Biochemistry and Physiology* 105A:239–244.