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THE EFFECTS OF SEASONAL CHANGES AND TURBIDITY ON SWIMMING  
PERFORMANCE IN WHITE CRAPPIE *POMOXIS ANNULARIS* AND BLACK  
CRAPPIE *POMOXIS NIGROMACULATUS*.

A Thesis

presented in partial fulfillment of requirements

for the degree of Master of Science in the Department of Biology

The University of Mississippi

By

Caleb J. Gaston

December 2011

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## ABSTRACT

Factors that affect swimming performance in fish can also affect fitness. I tested the effects of time of day, season and turbidity on swimming performance in black crappie *Pomoxis nigromaculatus* and white crappie *Pomoxis annularis*. These closely related fish co-occur and their relative abundance is thought to be governed by the levels of turbidity in the form of suspended sediments. Black crappie predominate in clear bodies of water and exhibited significantly greater critical swimming speeds in clear water than did white crappie during spring days and winter nights. A significant reduction in critical swimming speed was observed in black crappie as turbidity increased. White crappie predominate in turbid bodies of water and exhibited no significant reduction in critical swimming speed in relation to increasing turbidity. Both species displayed a significant increase in oxygen consumption in response to elevated turbidity. There were no differences in oxygen consumption rates between the two species within any of the four seasons or at the three levels of turbidity tested.

## ACKNOWLEDGEMENTS

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## **1. SWIMMING PERFORMANCE**

Swimming performance describes the locomotor ability of fish and other aquatic animals and is key to the survival of a wide variety of taxa (as reviewed by Plaut 2001). Swimming is often the main defense against predation (Reidy et al. 1995). Drucker (1996) suggests that swimming performance may influence the ability of a fish to obtain food, locate a mate and avoid unfavorable conditions. Given that swimming capability is a trait affecting Darwinian fitness (Reidy et al. 2000), it can be assumed that factors affecting swimming performance will also affect fitness.

Swimming performance studies have improved our understanding of the physiology (Parsons and Carlson 1998, Reidy et al. 2000, Beecham et al. 2007), ecology (Facey and Grossman 1990), habitat constraints (Adams et al. 2003) and behavior of fish (Parsons and Carlson 1998, Adams et al. 2003, Parsons and Smiley 2003, Parsons and Foster 2007). As swimming requires the cooperation of the musculoskeletal, digestive, circulatory, endocrine, and respiratory systems (Beamish 1978), swimming performance serves as an overall indicator of fish health.

When variables such as pollutants (Beaumont et al. 1995, McKenzie, et al. 2007), salinity (Randall and Brauner 1991), temperature (Jones et al. 1974, Adams and Parsons 1998), photoperiod (Smiley and Parsons 1997), dissolved oxygen (Parsons and Carlson 1998), digestive state (Niimi and Beamish 1974) and nutrition (Regan et al. 2010) are manipulated, their effects may be manifested in swimming performance changes (Parsons

and Smiley 2003). Differences in swimming performance may also be found between size classes (Parsons 1990), populations (Taylor and McPhail 1985), genders (Adams and Parsons 1998) or behavioral tactics (Boyd and Parsons 1998) within the same species.

### Measures of Swimming Performance

There are several measurements of swimming performance, including oxygen consumption rate ( $VO_2$ ), cost of transport analysis (Schmidt-Nielsen 1972), energetic range (Parsons 1990), and critical swimming speed ( $U_{crit}$ ) (Brett 1964). Kolok (1999) defined  $U_{crit}$  as an estimate of the maximum velocity at which a fish can swim aerobically. Critical swimming speed is recognized as the “best ecophysiological measurement to estimate swimming performance capability and to predict ecological consequences” (Plaut 2001).

Oxygen consumption rates ( $VO_2$ ) can be measured by using a Blazka-type respirometer (Blazka et al. 1960), which monitors dissolved oxygen levels in the water as a fish swims in a sealed tunnel.  $VO_2$  is calculated as the change in oxygen concentration over time. Knowing the oxygen consumption rate of a fish allows cost of transport analysis, which incorporates the energy (calories) required to move a gram of body mass one kilometer (Parsons 1990). Through careful monitoring of oxygen consumption, the most efficient swimming speed of a particular fish is identified, providing insights about ideal flow conditions, migratory capacity (based on energetic range) and foraging strategies.

### Study Organisms

White crappie *Pomoxis annularis* Rafinesque

The white crappie is a sunfish of the family Centrarchidae that can be distinguished by its 6 dorsal spines and dorsal pigmentation dominated by vertical bars on a silvery background (Ross 2001). Sexes are similar in appearance, but mature males display a darker pigmentation around the head and breast during the spawning season (Ross 2001). It is native to North America and the Mississippi River drainage, but has been successfully introduced in waters throughout the United States (Lee 1980a). The white crappie is most common in oxbow lakes, pools of large rivers and reservoirs (Ross 2001) and prefers low velocity areas with gradients of less than 0.5 m/km (Edwards et al. 1982a).

No directional migration has been observed, but adults do move from open water into shallow spawning areas in the spring. Fryda et al. (2008) observed high fidelity to particular spawning coves. Spawning occurs in March to May (Ross 2001) and timing is dependent upon water temperatures reaching the preferred range of 16 to 20° C (Siefert 1968). Of fish collected in Sardis Lake, Mississippi, 100% were mature by 241 mm total length (TL) and age 3 years (Schultz 1967). Gonad growth occurs during the fall (Morgan 1951). Males prepare a shallow nest by sweeping an ill-defined depression on a firm substrate, in water usually less than 1.5 m deep (Siefert 1968). Flooded terrestrial vegetation is an important component of nest sites and juvenile abundance is positively related with increasing water levels during the spring and summer (Mitzner 1991). Males defend territories of about 1 m<sup>2</sup> around their nest sites while courting and spawning with one or more females (Siefert 1968). A female can lay up to 264,000 eggs (Schultz 1967) that are fertilized by the male in up to 50 spawning bouts (Siefert 1968). The demersal, adhesive eggs attach to submerged objects and are guarded by the male (Hansen 1943).

Larvae leave the nest area 2 to 6 days after hatching after reaching a size of 4.1 to 4.6 mm TL (Siefert 1968). Meals and Dunn (2006) report that white crappie reach an average of 117 mm TL in the first year and can grow to an average of 365 mm by age 6 in Sardis Lake, Mississippi.

After hatching, larvae feed primarily on zooplankton, while juveniles incorporate aquatic insect larvae in their diet as they increase in size (Ross 2001). When feeding on planktonic prey, crappie remain stationary while searching for prey, then move a short distance and stop to search again (O'Brien et al. 1986). Adults feed primarily on small fishes, especially in the summer months, but the diet includes some zooplankton (Mathur 1972). The transition to a diet mainly consisting of fishes occurred as white crappie reached 200 mm TL in a Nebraska lake (Ellison 1984) and at 160 mm TL in a Kansas reservoir (O'Brien et al. 1984).

Parsons and Sylvester (1992) examined the swimming efficiency and metabolic rate of white crappie using swim tunnel respirometry. The fish tested were in the range of 165-175 mm standard length and had optimal efficiency (lowest net cost of transport) at 20-25 cm/sec and highest energetic range at 25 cm/sec. Later testing by Parsons and Smiley (2003) showed that season and size significantly altered  $U_{crit}$ , such that winter swimming speeds were lower than summer speeds. They also found an interesting interaction between low water temperature and darkness, where a state of torpor may have been induced in some fish.

Field observations of adult white crappie by Markam et al. (1991) in an Ohio reservoir showed that movement peaked at night and remained low throughout the day during the summer. Guy et al. (1994) found that adult white crappie movement was

highest in May in a South Dakota glacial lake. They also found that movement seemed to be greatest at dawn throughout the year.

Black crappie *Pomoxis nigromaculatus* (Lesueur)

The black crappie is closely related and very similar in appearance to the white crappie. The distinguishing features of the black crappie are its 7 dorsal spines and numerous dark spots against a silvery background on its sides, which are not arranged into vertical bars (Ross 2001). Sexes are similar in appearance, but breeding males tend to have a much darker coloration during the breeding season than females or immature fish (Ross 2001). The black crappie is native to eastern North America from the Atlantic coastal drainages of Virginia south to Florida, west to central Texas and north to North Dakota and southern Canada (Ross 2001). Its present distribution includes suitable habitat throughout the United States due to widespread introductions (Lee 1980b). The black crappie is common in slower sections (< 10 cm/sec, Edwards et al. 1982b) of large streams, oxbow lakes and reservoirs (Ross 2001), and generally occurs in cooler, deeper and clearer water than white crappie (Carlander 1977). In reservoirs, black crappie are typically associated with inundated terrestrial vegetation. As this material degrades after inundation, black crappie abundance may decline relative to white crappie (Ball and Kilambi 1972).

As with white crappie, no directional migration has been observed, but adults do move from open water into shallow spawning areas in the spring. Fryda et al. (2008) observed high fidelity to particular spawning coves. Gonad development occurs in the fall in preparation for the spring spawning season (Morgan 1951). Black crappie typically spawn earlier in the spring than white crappie (Ross 2001) and the timing of

reproduction is governed by water temperatures reaching 14 to 22° C, with spawning activity peaking at 18° C (Warren 2009) usually in late February or March in Mississippi (Ross 2001). Males move into shallow (< 1m depth) spawning areas that are protected from wind and wave action (Pope and Willis 1997). Males prepare shallow nest depressions by sweeping loose sediment off of firmer substrates (Edwards et al. 1982b, Phelps et al. 2009). Colonial nesting has been observed at one small Illinois impoundment (Phelps et al. 2009). Published accounts on spawning behavior and early development are rare, but it is assumed that the black crappie is similar to the white crappie in these aspects (Ross 2001, Warren 2009).

Meals and Dunn (2006) report that black crappie reach an average of 87 mm TL at the end of the first year and reach an average of 233 mm TL by age 4 years in Sardis Lake, Mississippi. Ross (2001) states that larval black crappie feed primarily on zooplankton while juveniles 60-115 mm TL incorporate insect larvae into their diets. Black crappie over 140 mm standard length consistently select fish as food (Van Engle, 1941).

Allen et al. (1998) found that black crappie density was positively correlated with zooplankton density in Florida lakes. Neal (1963) observed a shift in predominance by black crappies to white crappies as the turbidity level increased in an Iowa lake. The mechanism causing this shift is unclear as Spier and Heidinger (2002) found similar growth rates between black crappies and white crappies across a wide range of turbidities in a controlled setting with high prey density. It has been proposed that adult black crappie are less adapted to capturing fish in turbid water (Ellison 1984). Barefield and Ziebell (1986) found no difference between feeding rates of juvenile white and black

crappie on the zooplankton *Daphnia pulex* at 80 or 160 nephelometric turbidity units (NTU). Spier and Heidinger (2002) suggest “that factors correlated with turbidity, not turbidity itself, influence the distribution of crappies.”

Field observations of movement patterns of adult black crappie by Guy et al. (1992) suggest that hourly movement is highest in April and July and lowest during the June spawning season. Guy et al. (1992) also found that movement was greatest in the morning and lowest at midday throughout the year. Currently there are no published data on black crappie swimming performance in the laboratory.

#### Applications of Swimming Performance

Water temperature is strongly related to season and is an important factor affecting fish physiology (Schaeffer 1986.) Adams and Parsons (1998) observed a reduction in swimming performance related to cooler water temperatures in smallmouth buffalo *Ictiobus bubalus*. Parsons and Sylvester (1992) found that white crappie *Pomoxis annularis* had optimum efficiency (lowest cost of transport) at 25 cm/sec. Parsons and Smiley (2003) found that white crappie winter critical swimming speeds were 35 to 52% of summer critical swimming speeds. A reduction in swimming performance related to falling water temperature may explain why white crappie have been observed being swept from reservoirs during cold winter nights (K. Meals, pers. comm.).

Knowledge gained from swimming performance studies can be applied to commercial fisheries. Parsons and Foster (2007) used swimming performance and behavior to reduce bycatch of juvenile red snapper *Lutjanus campechanus* by shrimp trawlers. The device they developed to reduce bycatch exploits the behavioral tendencies of juvenile red snapper that were discovered using a swim tunnel. Winger et al. (1999)

examined swimming endurance in American plaice *Hippoglossoides platessoides* and found that larger fish in warmer waters had a better chance of escaping bottom-trawl sweeps.

Swimming performance can be used as an indicator of post-release survivability for hatchery raised fish. Beecham et al. (2007) found that swimming performance of juvenile pond-cultured and wild-caught channel catfish *Ictalurus punctatus* was not different, meaning that pond cultured catfish can be expected to have about the same ability to escape predators as wild fish.

Swimming performance studies can also provide insights into habitat utilization. Adams et al. (2003) performed a comparative study of swimming performance in juvenile shortnose sturgeon *Scaphirhynchus platyrhynchus* and pallid sturgeon *S. albus*. Because their swimming performance is similar, Adams et al. (2003) suggested that the two species “probably do not segregate in rivers due to different swimming or station-holding abilities.” Juvenile shortnose sturgeon and pallid sturgeon likely utilize similar habitat.

Swimming performance studies can be used to analyze the effectiveness of fish passage structures. Peake (2004) found that critical swimming speed of smallmouth bass *Micropterus dolomieu* was useful in setting a maximum flow velocity for culverts. If the goal is for a fish to be able to swim up a culvert, managers should note that the maximum velocity within the culvert should be less than the critical swimming speed of that fish. Cheong et al. (2006) used swimming performance experiments to identify 0.33 m/s as the optimal flow velocity for white sturgeon *Acipenser transmontanus* on approach to a fish

ladder to go around a dam. This information allows engineers to design structures that enable fish to complete their migrations.

Since swimming performance is an indicator of whole-body health, McKenzie et al. (2007) used swimming performance to evaluate the effects of various sub-lethal toxicants on chub *Leuciscus cephalus* in Europe. Fish in polluted rivers swam well in an initial performance test but were unable to repeat this performance after a brief recovery period. The metabolic effects of pollutants were measurable and significant in just three weeks of inhabitation of the polluted rivers.

O'Brien et al. (1989) modeled net energy gains in relation to foraging strategy and prey size. They predicted that energy gains would increase with increasing swimming speed when pursuing large prey. Applying this model to crappie, adult fish in pursuit of fish prey would experience energy gains from higher swimming speeds.

Comparative analysis of swimming performances of any closely related fish species may further our understanding of the life histories and adaptations of both species and provide some clues to the mechanism for their differentiation. This knowledge can be applied to management, conservation and utilization of those species.

## Research Justification

White crappie *Pomoxis annularis* and black crappie *Pomoxis nigromaculatus* are worthwhile research subjects due in part to the considerable economic impact of the recreational fishery which targets them in Mississippi's flood control reservoirs and other places. In a recent survey compiled by the Human Dimensions and Conservation Law Enforcement Laboratory at Mississippi State University, 79% of anglers at Sardis Lake (average area: 28,900 acres, Schultz 1967) in north-central Mississippi specifically targeted crappie on their trip (Hunt 2008). Anglers' "expenditures had a total impact of \$23,368,000 on the economy of Mississippi, and supported 283 full-time and part-time jobs throughout the state" (Hunt 2008).

Meals and Dunn (2006) estimated that white crappie made up 93% of the crappie harvested by Sardis Lake anglers. Trap netting, however, resulted in a capture rate for black crappie three times that of white crappie (Meals and Dunn 2009). Interestingly, sampling via electrofishing yields a catch rate for white crappie eight times that of black crappie (Meals and Dunn 2006). The discrepancy is likely due to the species selectivity of these sampling methods. Miranda et al. (1996) suggest that the tendency of black crappie to closely associate with heavy cover may expose them to less angling effort. Furthermore, Ball and Kilambie (1972) suggest that the deterioration of inundated terrestrial vegetation leads to the decline of black crappie relative to white crappie. Much of Sardis Lake's terrestrial vegetation has been lost since its creation in 1940 and severe water level fluctuations (approximately 20 feet of elevation lost from summer to winter) likely retard the growth of new vegetation. At present it is believed that white crappie predominate in Sardis Lake (K. Meals, pers. comm.).

I am interested in examining the role that swimming performance plays in determining the distribution of *P. annularis* and *P. nigromaculatus* in large reservoirs such as Sardis Lake. I followed the approach of Adams (1996) and Adams et al. (2003) in using swim tunnel respirometry to investigate the role of swimming performance in governing the interaction of two closely related and co-occurring fish. Adams (1996) found that two species of buffalo (*Ictiobus spp.*) have different physiological responses to the stresses of migration. Adams et al. (2003) analyzed swimming performance in two sturgeon species and suggested that the two species likely utilize similar habitat. At present, there is data on the swimming performance of white crappie (Parsons and Sylvester 1992, Smiley and Parsons 1997 and Parsons and Smiley 2003) and no data on laboratory swimming performance of black crappie.

Kolok (1999) points out that variability in testing procedures and equipment design can limit comparisons between swimming performance studies. To remove any confounding factors that may prohibit useful comparisons between the two crappie species, I tested the swimming performance of both white crappie and black crappie at the same time and made comparisons using my data only.

The objectives of this study were to determine whether there is variation in swimming performance between black crappie and white crappie in relation to season and time of day. The measures of swimming performance used were critical swimming speed ( $U_{crit}$ , cm/sec) and oxygen consumption rate ( $VO_2$ , mg/kg/hr). Smiley and Parsons (1997) documented an effect of photoperiod on swimming performance of white crappie. This study, however, was based on an acclimation protocol where the conditions of photoperiod and temperature under which the fish were tested were not representative of

conditions at collection. I argue that an acclimatization protocol, where testing conditions are representative of field conditions (Facey and Grossman 1990), presents a more useful examination of seasonal variation in swimming performance based on photoperiod and temperature. Acclimatization allows a more accurate reflection of the swimming ability of fish *in situ*, as in Parsons and Smiley (2003) and Adams and Parsons (1998). The former study found that white crappie  $U_{crit}$  was lowest during winter and highest during summer, while data on black crappie is lacking. I expect  $U_{crit}$  for both species to be low during the fall because physiological resources will be diverted to gonad growth (Morgan 1951). Adams and Parsons (1998) observed lower fall  $U_{crit}$  in two species of buffalo and attributed the difference to the initiation of gonadal growth in the fall.

## **Materials and Methods**

*Capture and Housing:* Procedures closely followed the protocol used by Facey and Grossman (1990) and Parsons and Smiley (2003). All specimens were collected and housed in accordance with Protocol 10-020 approved by The University of Mississippi's Institutional Animal Care and Use Committee.

Fish were collected from Sardis Lake by trap netting and angling during each of the four seasons. For the purposes of this study, the seasons were as follows: Spring, March 15 to April 30; Summer, May 15 to September 30; Fall, October 10 to November 20; and Winter, January 1 to February 28. Specimens of both species were collected at the same time and housed together. Trap netting was used extensively during the winter and spring, night angling was the preferred method during summer and day angling was used most extensively during the fall. Table 1-1 displays capture methods for each

treatment group. All tables and figures are presented in the Appendix. The fish were held in the laboratory in a 1300 L recirculating tank. The temperature and photoperiod for holding and testing were maintained to reflect ambient conditions (Spring: 16° C, 12L:12D; Summer: 26°C, 14L:10D; Fall: 16° C, 12L:12D; Winter: 6° C, 10.5L:13.5D).

Fish were fed live minnows (*Notropis spp.*) daily. Fish were not fed for 24 hours prior to testing to achieve a post-absorptive state as the digestive process has been shown to reduce swimming performance (Niimi and Beamish, 1974).

*Swimming Performance:* Fish were tested within a few days of capture at water temperatures and photoperiods approximating conditions in Sardis Lake at the time of capture. Treatment parameters are displayed in Table 1-2. Approximately half of the individuals within each treatment group were tested at 1300 h and half at 2230 h. Table 1-3 displays numbers of individuals tested within each treatment group.

A Blazka type swim tunnel (Blazka et al. 1960) was used to examine the swimming performance of the fish in an increasing velocity test as described in Parsons and Smiley (2003). The swim tunnel was constructed from clear plexiglass with working section inside dimensions of 20 cm diameter and 90 cm length. The total volume of the swim tunnel was 109 L. An electric motor was used to drive a propeller to produce flow and flow filters were used to reduce turbulence by promoting rectilinear flow. The flow filters also served to confine the fish within the working section of the tunnel. Flow velocity was measured using a Marsh-McBirney electronic flow meter (model #2000). Dissolved oxygen concentration and water temperature were measured using a Thermo Orion electronic meter (model #862A).

One fish per test was transferred from the holding tank to the swim tunnel test chamber, which was filled from the holding tank with well aerated, clear water at the prescribed temperature. The fish was allowed to habituate to the swim tunnel and recover from handling stress at a flow rate of 5 cm/sec for approximately three hours prior to the prescribed start time (1300 h or 2330 h). Cooke et al. (2003) showed that black crappie recovered from exhaustive exercise within 100 minutes at 3° C. I assumed that the fish used in the present study would be able to recover from handling stress in 180 minutes at temperatures warmer than the extremes documented by Cooke et al. During the habituation period, the swim tunnel was continuously aerated. At the prescribed time, all air pockets were removed and the tunnel was sealed.

Critical swimming speed was found by forcing the fish to swim against a flow for a 30 minute swimming bout. The swimming bout ended after 30 minutes or when the fish failed to maintain station and was impinged against the screen at the back of the tunnel. Dissolved oxygen concentration was measured three times per bout, at 0, 15 and 30 minutes. The first swimming bout for each fish was conducted at a flow velocity of 10 cm/sec for 30 min. Beamish (1978) reports that on occasion individual fish do not perform well in swimming chambers. These non-performers were recognized by their inability to swim for at least one minute at 10 cm/sec. Non-performers were excluded from analysis of critical swimming speeds. Immediately after each successful swimming bout, the flow velocity was increased by 5 cm/sec and a new swimming bout began. This process was repeated until the fish failed to maintain station and was impinged on the screen at the back of the swimming chamber. The velocity, dissolved oxygen concentration and time at failure to maintain station were recorded.

Critical swimming speeds were calculated according to the formula described by Brett (1964):

$$U_{crit}=U_1+(U_2/U_3*U_4)$$

where  $U_1$  is the highest velocity maintained for the entire 30 minute bout,  $U_2$  is the amount of time the fish swam at fatigue velocity,  $U_3$  is the prescribed duration of each swimming bout and  $U_4$  is the velocity increment. For individuals that were greater than 10% of the cross-sectional area of the swim chamber (Brett 1964), speeds were corrected for the effect of the fish's body on flow velocity using the equation given by Smit et al. (1971):

$$U_c=U_s(1+A_i/A_{ii})$$

where  $U_c$  is the corrected velocity,  $U_s$  is the velocity in the absence of a fish,  $A_{ii}$  is the cross-sectional area of the swimming chamber, and  $A_i$  is the cross-sectional area of the fish. The cross-sectional area of the fish is assumed to approximate an ellipse and thus equal:

$$A_i= \pi/0.5d/0.5w$$

where  $d$  is the maximum body height and  $w$  is the maximum body width (Beamish 1978).

Oxygen consumption rates ( $VO_2$ ) at each swimming speed were calculated using the dissolved oxygen measurements and equation given in Cech (1990):

$$VO_2= [(cO_2(A) - cO_2(B))V]/T$$

where  $cO_2(A)$  is the oxygen concentration in water (mg  $O_2/L$ ) at the start of the measurement period;  $cO_2(B)$  is the oxygen concentration in water (mg  $O_2/L$ ) at the end of the measurement period;  $V$  is the volume of the respirometer (L) and  $T$  is the time elapsed during the measurement period (h).

Each individual was tested only once to eliminate any effect of training (Hochachka 1961, Parsons and Foster 2007). At the conclusion of each test, the fish were euthanized by an overdose of MS-222 anesthetic in accordance with Protocol 10-020 approved by The University of Mississippi's Institutional Animal Care and Use Committee. After euthanasia, the fish's total length, maximum body height, maximum body width, and body mass were measured. A necropsy was performed to confirm the sex of the fish by visual inspection of the gonads.

The statistical program JMP was used to apply a stepwise multiple regression to the data set in which  $U_{crit}$  and  $VO_2$  were the dependent variables and the predictor variables were species (black or white crappie), season (summer, fall, winter or spring), total length (cm), duration of captivity (days), sex (male, female or immature), time of day (day or night) and capture method (trap net, day angling or night angling). Further examination of the differences between treatments was performed using ANOVA. I used ANOVA to compare TL of fish between treatment groups and all comparisons were made between fish of similar TL. The level of significance for all tests was  $P < 0.05$ .

## **Results**

### Critical Swimming Speed

Non-performers (n=17) were excluded from analysis, leaving critical swimming speed measurements for 149 fish. A stepwise multiple regression indicated that species ( $P < 0.0001$ ), season ( $P = 0.016$ ), and capture method ( $P < 0.0001$ ) were significant predictors of critical swimming speed. The regression equation produced was:  $U_{crit} = 21.25 + 3.16(\text{Species}) - 2.08(\text{Season}) - 4.53(\text{Capture Method})$  cm/sec and  $R^2 = 0.33$ . The Shapiro-Wilk Goodness-of-Fit Test indicated that the residuals were normally distributed

( $W=0.985674$ ,  $P=0.135$ ) and the Durbin-Watson Test indicated that the residuals were not auto-correlated ( $DW=1.8971257$ ,  $P=0.176$ ). It was not possible to use a factorial ANOVA to check for interactions between capture method and season because not all possible combinations of season and capture method were present within the data set.

### *Effects of Season and Time of Day*

#### *Black Crappie*

There were no significant differences in  $U_{crit}$  based on time of day, so day and night test results were pooled for greater statistical power. Figure 1-1 displays mean and standard error of black crappie  $U_{crit}$  during the day and at night.  $U_{crit}$  in summer ( $n=24$ ,  $mean \pm standard\ error = 24.15 \pm 10.69$  cm/sec) was significantly greater ( $P=0.036$ ) than in winter ( $n=14$ ,  $15.32 \pm 1.41$  cm/sec). There were no other significant differences between seasons. Mean  $U_{crit}$  in spring was  $22.97 \pm 2.49$  cm/sec ( $n=15$ ) and was  $19.63 \pm 2.59$  cm/sec ( $n=12$ ) in fall. Figure 1-2 displays mean and standard error of black crappie  $U_{crit}$  for each season after pooling day and night data.

#### *White Crappie*

Winter  $U_{crit}$  was significantly higher ( $P=0.028$ ) in the day ( $n=7$ ,  $12.39 \pm 0.90$  cm/sec) than at night ( $n=6$ ,  $8.86 \pm 1.04$  cm/sec). Because of this difference, day and night test results were analyzed separately. Figure 1-3 displays mean and standard error of white crappie  $U_{crit}$  during the day and at night. Daytime  $U_{crit}$  was significantly higher in summer ( $n=19$ ,  $22.48 \pm 1.80$  cm/sec) than in winter ( $P=0.004$ ,  $n=7$ ,  $12.39 \pm 0.94$  cm/sec) or spring ( $P=0.005$ ,  $n=8$ ,  $11.99 \pm 2.66$  cm/sec). When limited to a range of 22.6 to 38.6 cm TL to allow a comparison of similarly sized fish, daytime  $U_{crit}$  was significantly higher in summer ( $n=10$ ,  $21.32 \pm 2.37$  cm/sec) than in fall ( $P=0.019$ ,  $n=8$ ,  $11.99 \pm 2.66$  cm/sec). At

night, summer  $U_{crit}$  ( $n=14$ ,  $22.50\pm 2.28$  cm/sec) was significantly higher than each of the other seasons: fall ( $P=0.017$ ,  $n=8$ ,  $13.95\pm 1.66$  cm/sec), winter ( $P=0.004$ ,  $n=7$ ,  $8.86\pm 1.04$  cm/sec) and spring ( $P=0.048$ ,  $n=8$ ,  $15.53\pm 2.06$  cm/sec). Also at night, fall  $U_{crit}$  ( $n=8$ ,  $13.95\pm 1.66$  cm/sec), was significantly greater than winter ( $P=0.034$ ,  $n=7$ ,  $8.86\pm 1.04$  cm/sec). Because of a size discrepancy between the two groups, it was not informative to compare spring and winter night  $U_{crit}$ .

#### *Differences between Species*

During the day in spring, black crappie  $U_{crit}$  ( $n=8$ ,  $21.18\pm 2.89$  cm/sec) was significantly greater than white crappie  $U_{crit}$  ( $P=0.035$ ,  $n=8$ ,  $11.99\pm 2.66$  cm/sec, Figure 1-4). Winter  $U_{crit}$  at night was significantly greater ( $P=0.034$ ) for black crappie ( $n=9$ ,  $14.67\pm 1.85$  cm/sec) than white crappie ( $n=6$ ,  $8.86\pm 1.04$  cm/sec, Figure 1-5). All other comparisons were not significantly different.

#### Oxygen Consumption Rate

##### *Seasonal Effects*

###### *Black Crappie*

There were no significant differences between day and night  $VO_2$  values within any of the four seasons, so it was possible to pool the data for additional power prior to making seasonal comparisons. Spring  $VO_2$  at 10 cm/sec ( $n=12$ , mean $\pm$ standard error= $115.6\pm 16.2$  mg  $O_2$ /kg/hr) was significantly less than winter ( $P=0.041$ ,  $n=13$ ,  $208.0\pm 38.1$  mg  $O_2$ /kg/hr) and fall ( $P=0.027$ ,  $n=12$ ,  $263.9\pm 60.5$  mg  $O_2$ /kg/hr). Spring  $VO_2$  at 25 cm/sec ( $n=9$ ,  $83.7\pm 5.6$  mg  $O_2$ /kg/hr) was also significantly less than fall ( $P=0.015$ ,  $n=4$ ,  $165.0\pm 43.1$  mg  $O_2$ /kg/hr, Figure 1-6). All other comparisons between seasons were not statistically significant.

### *White Crappie*

Again, there were no significant differences between day and night VO<sub>2</sub> values within any of the four seasons, so it was possible to pool the data for additional power prior to making seasonal comparisons. Spring VO<sub>2</sub> at 10 cm/sec (n=15, 72.1±10.4mg O<sub>2</sub>/kg/hr) was significantly less than summer (P=0.003, n=29, 229.0±34.5mg O<sub>2</sub>/kg/hr), winter (P=0.003, n=14, 155.2±23.5mg O<sub>2</sub>/kg/hr) and fall (P=0.001, n=17, 168.7±23.4mg O<sub>2</sub>/kg/hr). Spring VO<sub>2</sub> at 15 cm/sec (n=9, 75.7±12.0mg O<sub>2</sub>/kg/hr) was also significantly less than summer (P=0.039, n=29, 201.8±32.3mg O<sub>2</sub>/kg/hr), winter (P=0.012, n=9, 174.1±32.5mg O<sub>2</sub>/kg/hr) and fall (P=0.005, n=12, 222.4±38.5mg O<sub>2</sub>/kg/hr, Figure 1-7). There were no significant seasonal differences in VO<sub>2</sub> at 20 or 25 cm/sec.

### *Differences between Species*

There were no significant differences between black crappie and white crappie VO<sub>2</sub> within any of the four seasons (Figures 1-8, 9, 10 and 11). Only in spring at 10 cm/sec did the difference between black crappie VO<sub>2</sub> (n=14, 105.4±15.5mg O<sub>2</sub>/kg/hr) and white crappie VO<sub>2</sub> (n=15, 72.1±10.4mg O<sub>2</sub>/kg/hr) approach significance (P=0.081). For comparison with previously published data, VO<sub>2</sub> values for summer white crappie 15 to 20 cm TL are shown in Table 1-4. Outliers were rejected using Grubbs' Test leaving a sample size of 16 fish.

### **Discussion**

To my knowledge, the only previously published estimates of black crappie swimming performance come from field measurements of hourly movement made using radio telemetry (Guy et al. 1992). The present study provides original data on the laboratory swimming performance of black crappie. It allows direct comparison with

swimming performance data on white crappie, expanding upon the work of Parsons and Sylvester (1992), Smiley and Parsons (1997), and Parsons and Smiley (2003). These data also supplement Parsons and Smiley's (2003) work in winter, spring, and summer while creating entirely new data sets for white crappie in fall and for black crappie in all four seasons.

As expected, I found that white crappie  $U_{crit}$  was greater during the summer than the three other seasons, with winter  $U_{crit}$  being the lowest of all. The general trend of summer performance being greater than spring and winter is similar to that shown in Parsons and Smiley (2003). I also found black crappie  $U_{crit}$  to be greatest in summer, though the difference was significant only when compared to winter. This result is not unexpected because of the poikilothermic nature of these fish, with performance being dependent upon water temperature. Spring and fall tests were both conducted at the same temperature (16°C) and similar  $U_{crit}$  was observed in both black crappie and white crappie, suggesting that water temperature, and not season, may be the driving factor determining  $U_{crit}$ . However, the observation that  $VO_2$  was lowest during spring for both species suggests that seasonal changes in physiology may contribute to performance differences. Blood chemistry testing, beyond the scope of this project, may confirm this suspicion.

The higher  $U_{crit}$  values I observed for black crappie in summer are supported by Guy et al.'s (1992) South Dakota field observations of black crappie movement rates. In that study, movement rates increased during mid-summer and the authors attributed the movements to feeding behavior.

It is interesting to note that black crappie  $U_{crit}$  was significantly higher than that of white crappie in spring tests during the day and in winter tests at night. It would appear that black crappie are adapted to a more active lifestyle than white crappie at these times. Guy et al. observed that black crappie movement was higher in April (1992) than was white crappie movement (1994). Guy et al. (1992, 1994) also reported that black crappie median movement rates reached a higher maximum ( $131.7 \pm 28.56$  m/h) than did white crappie (102.1 m/h, no SE provided), though it is not known whether this difference is significant. Black crappie may be more actively pursuing prey or avoiding predators during winter nights while white crappie may be inclined to enter a state of torpor as suggested by Parsons and Smiley (2003).

Variation in swimming performance related to season or water temperature has been observed in other species of fish. Facey and Grossman (1990) used an acclimatization protocol and observed that maximum swimming speeds were highest in fall for rainbow trout, lowest in winter for rosyside dace, highest in summer for mottled sculpin, and showed no significant seasonal variation in longnose dace. Adams et al. (2003) used an acclimation protocol and observed that both pallid sturgeon and shovelnose sturgeon had higher  $U_{crit}$  at 20°C in March than at 10°C in April. Red snapper tested by Parsons and Foster (2007) were all acclimated to 17°C. These fish showed no effect of time of day on  $U_{crit}$  but fish tested in October swam fastest and fish tested in February swam slowest. Lacking a temperature differential, it would appear that there was an effect of season on red snapper swimming performance as the authors suggested.

The comparison of summer white crappie  $VO_2$  values from the present study and those predicted by Parsons and Sylvester (1992) showed a trend of increasing  $VO_2$  with increasing swimming speed, despite the difference in absolute values. Kolok (1999) points out the difficulty of direct comparisons of respirometry data between studies due to differences in respirometers, instrumentation and other factors. One can not expect to reliably duplicate absolute values in  $VO_2$  without using the same swim tunnel and measurement equipment, but the trends within the data remain.

In smallmouth buffalo, Adams and Parsons (1998) observed that active metabolic rates ( $VO_2$ ) were higher in spring than in fall and scope for activity was lower in fall, suggesting that the fish had little energy available for swimming in fall. This was attributed to the fall initiation of gonad growth. Smallmouth buffalo spawn in the spring and early summer. The low spring  $VO_2$  values observed for black crappie and white crappie suggest that both species may be physiologically adapted to the stresses of spawning at this time.

There are several possible problems that should be mentioned. First, hourly  $VO_2$  rates were extrapolated from 30 minute swims in the best case and from swims as short as six minutes in the worst case. Such a brief swim may have yielded elevated or variable  $VO_2$  values as the fish approached exhaustion. Second, the relationship between capture method and swimming performance was difficult to define. Capture methods were selected that most efficiently provided healthy fish for testing during each time of year. Night angling appeared to cause the least stress on fish, especially in summer, but was not effective in winter. Trap netting is the most stressful capture method, but was also the most efficient method during the winter.

The results of this study indicate that black crappie enjoy an advantage in swimming ability over white crappie in clear waters during spring and winter. This advantage may contribute to the ability of black crappie to competitively displace white crappie in clear waters. Further study of swimming performance in the crappies relating to turbidity (see Chapter 2) may provide insights into the relationship between crappie population dynamics and habitat characteristics.

## 2. TURBIDITY EFFECTS

Many economically and/or ecologically important fish are impacted by water quality characteristics. Turbidity, a key indicator in water quality, is a measure of the particles suspended in water and can be an important factor determining the distribution of fish (Trebitz et al. 2007). The crappies, *Pomoxis annularis* and *P. nigromaculatus*, present an interesting model for studying the response of fishes to turbidity. The ecology of these closely related species suggests that there is a connection between turbidity and the predominance of one species over another. Neal (1963) observed a shift in predominance from black crappies to white crappies as the turbidity level increased in an Iowa lake. Carlander (1977) reported that white crappie are more tolerant of turbidity and siltation than black crappie, while Barbour et al. (1999) classified both species as having an intermediate tolerance for turbidity.

The effects of turbidity on crappie distributions may be related to prey capture efficiency. Ellison (1984) suggested that black crappie are less adapted to capturing fish in turbid water. Spier and Heidinger (2002) found similar growth rates between black crappies and white crappies across a wide range of turbidities in a controlled setting with high prey density, although the prey density in their study may have been higher than what can be expected in the wild, thereby obscuring any possible effects of differences in prey capture ability.

A study of turbidity effects on prey consumption by planktivorous and piscivorous fish revealed that planktivores may experience an advantage in turbid water related to reduced vulnerability to predation by piscivores without a substantial decrease in their own ability to capture zooplankton prey (De Robertis et al. 2003). Van Engle (1941) used analysis of stomach contents to classify juveniles of both crappie species as planktivores and adults as piscivores. Barefield and Ziebell (1986) found no difference between laboratory feeding rates of juveniles on *Daphnia pulex* at 80 or 160 NTU in either species.

Visual prey detection distance may explain some of the effects of turbidity. In the rosyside dace *Clinostomus funduloides*, Hazelton and Grossman (2009) noted that a 10 NTU increase in turbidity reduced reactive distance by 9%. Walleye *Stizostedion vitreum* in clear lakes tend to feed at dawn and dusk, while walleye in turbid lakes feed during the day when more light is available (Ryder 1977).

Mitzner (1987) found a negative relationship between turbidity and crappie (*Pomoxis spp.*) abundance in an Iowa lake. He suggested that embryonic development is impaired by silt due to suffocation and infection. Mitzner (1987) also stated that larval feeding rates may decrease with increasing turbidity. Vasey (1973) reported that white crappie spawned at shallower depths as turbidity increased.

Spier and Heidinger (2002) suggested that the distribution of crappies is influenced by factors correlated with turbidity rather than turbidity itself. The present study investigated whether swimming performance is correlated with turbidity. Because critical swimming speed is considered a measure of the maximum speed for prolonged aerobic swimming (Kolok 1999), respiratory efficiency must be an important factor in

determining  $U_{crit}$ . Moyle and Cech (1988) describe “coughing” in fish where brief reversals of flow over the gills are used to clear foreign matter from the gills. It is not known whether crappie exhibit this behavior. The suspended sediments that cause elevated turbidity may obstruct gas exchange across the surface of the gill filaments and cause a reduction in respiratory efficiency resulting in reduced  $U_{crit}$ . Because crappie in the wild are likely swimming great distances in pursuit of prey, at least during some times of the year (Guy et al. 1992, 1994), any significant effect of turbidity on swimming performance could be expressed in factors that affect fitness such as prey capture efficiency or the ability to escape predators.

The objective of this study was to determine the effects of turbidity on swimming performance in crappie. I tested swimming performance of both species at 0 Jackson Turbidity Units (JTU), at a low turbidity level (25 JTU) and at a turbidity level (75 JTU) higher than the optimum range indicated by Edwards et al. (1982a, b). JTU is a measure of light penetration through a sample and is directly comparable to NTU (USEPA 1983).

### **Materials and Methods**

During the spring, black crappie and white crappie were captured and housed as described in Chapter 1. Photoperiod was maintained at 12 hours dark and 12 hours light. Water temperature was maintained at 16°C. Swimming performance testing was conducted as outlined in Chapter 1 with sediment added to the swim tunnel to bring the turbidity level up to the prescribed value. Sediment was collected from clay deposits at Sardis Lake, MS along with water samples. Analysis of particle size in laboratory water and samples of Sardis Lake water was conducted with the help of Sam Testa, Biologist at the USDA National Sedimentation Lab in Oxford, MS. Samples were tested on a Horiba

model LA-910 laser scattering particle size analyzer to obtain particle size distribution data. Sample material was dispersed in approximately 200 ml water with 0.02% Sodium Hexametaphosphate (calgon) surfactant to aid dispersion, and then subjected to 30seconds of ultrasonic treatment (40W, 39 kHz) by the Horiba LA-910 prior to measurement. Light scattering was measured using both a He-Ne laser (632.8nm, 1mW) and tungsten halogen lamp (50W) with a set of six 18-division, ring shaped silicone photo-diode detectors. Particle sizes were calculated based on Mie scattering theory, using a relative refractive index of 1.32-000, with calculated sizes of particles assigned to one of 81 size bins, ranging between 0.0 and 1020 micrometers ( $\mu\text{m}$ ). Mean particle size for water samples from Sardis Lake was approximately 8  $\mu\text{m}$  while mean particle size for water samples taken from the swim tunnel was approximately 6  $\mu\text{m}$ . Particle size variance was higher in Sardis Lake samples ( $\pm 128 \mu\text{m}^2$ ) than in laboratory samples ( $\pm 33 \mu\text{m}^2$ ).

Following the procedures described in Chapter 1, swimming performance tests were conducted in clear water (0 JTU) during the day and at night. All turbid water tests were conducted during the day at 25 JTU and 75 JTU. Table 2-1 displays treatment conditions. Turbidity was measured using a Hach Turbidimeter (model #16800) at a flow velocity of 20 cm/sec prior to introducing the fish.

Swimming performance tests were initiated for white crappie (N=34) and black crappie (N=36). Of the 34 white crappie, nine were tested in clear water during the day (lights on, 1330 hrs) while eight were tested in clear water during the night (lights off, 2230 hrs). Turbid water tests were conducted during the day with 10 white crappie at 25 JTU and the remaining seven white crappie at 75 JTU. Of the 36 black crappie, eight

were tested during the day and eight were tested during the night in clear water. Turbid water tests were conducted during the day with nine black crappie at 25 JTU and 11 black crappie at 75 JTU. No fish was tested more than once to avoid training effects (Hochachka 1961, Parsons and Foster 2007). Dissolved oxygen concentrations in the testing chamber were maintained  $>5.7$  mg/l at the start of each test and never fell lower than 5.38 mg/l during any test. Weight specific oxygen consumption rates ( $VO_2$  per kilogram of fish wet weight) were calculated for each fish at each swimming speed tested. Fish that failed to maintain station for at least one minute at 10 cm/sec were considered non-performers.

The statistical program JMP was used to apply a stepwise multiple regression to the data set in which critical swimming speed was the dependent variable and the predictor variables were species (black or white crappie), turbidity (0, 25 or 75 JTU), total length (cm), duration of captivity (days), sex (male, female or immature), time of day, and capture method (trap net or angling). The student's *t*-Test for two samples assuming unequal variances was used to check for differences in total length and  $U_{crit}$  between treatments. All comparisons were made between groups of similar lengths. Weight specific oxygen consumption was analyzed using ANOVA.

## **Results**

### **Critical Swimming Speed**

After excluding non-performers ( $n=7$ ) and two outliers from analysis using Grubbs' Test, the sample size was 61. Non-performers were as follows: one white crappie during the day in clear water, one black crappie in clear water at night, one black crappie at 25 JTU and four black crappie at 75 JTU (Table 2-2). A multiple regression

indicated that species ( $P=0.007$ ) and turbidity ( $P=0.003$ ) were the significant predictors of critical swimming speed. The derived equation was:  $U_{crit}=16.88 - 6.05(\text{Species}) - 0.10(\text{Turbidity Level})$  cm/sec and  $R^2=0.23$ . The Shapiro-Wilk Goodness-of-Fit Test indicated that the residuals were normally distributed ( $W=0.962826$ ,  $P=0.140$ ) and the Durbin-Watson Test indicated that the residuals were not auto-correlated ( $DW=2.4005602$ ,  $P=0.890$ ).

### *Turbidity Effects*

#### *Black Crappie*

At 0 JTU, black crappie day  $U_{crit}$  ( $n=8$ , mean $\pm$ standard error= $21.18\pm66.90$  cm/sec) was similar to night  $U_{crit}$  ( $n=7$ ,  $25.01\pm121.98$  cm/sec). Because the data were not significantly different, day and night treatments at 0 JTU were pooled for later tests to allow greater power and to allow comparisons between fish of similar lengths. Black crappie mean  $U_{crit}$  at 0 JTU ( $n=7$ ,  $22.88\pm122.84$ cm/sec) was significantly higher ( $P=0.006$ ) than at 75 JTU ( $n=4$ ,  $8.36\pm36.30$ cm/sec) for fish 20-27 cm TL. This represents a 63% reduction in swimming performance from 0 JTU to 75 JTU. Also, four of 11 black crappie at 75 JTU were non-performers while there was only one non-performer out of 16 black crappie at 0 JTU. Black crappie mean  $U_{crit}$  at 25 JTU ( $n=5$ ,  $23.16, \pm13.66$ cm/sec) was not significantly different than mean  $U_{crit}$  at 0 JTU ( $n=9$ ,  $24.59\pm6.80$ cm/sec) for fish 20-30 cm TL. Black crappie  $U_{crit}$  was not significantly different at 25 and 75 JTU ( $P=0.080$ ). ANOVA confirmed that  $U_{crit}$  at 0 JTU was not significantly different than  $U_{crit}$  at 25 JTU ( $P=0.786$ ) and significantly higher than  $U_{crit}$  at 75 JTU ( $P=0.024$ ). Figure 2-1 displays black crappie critical swimming speeds for each turbidity level.

### *White Crappie*

At 0 JTU, white crappie day mean  $U_{crit}$  (n=8, 11.99±56.78cm/sec) was not significantly different than night  $U_{crit}$  (n=8, 15.53±33.88cm/sec). Because the data were similar, day and night treatments at 0 JTU were pooled for later tests to allow greater power and to allow comparisons between fish of similar lengths. For fish 20-27 cm TL,  $U_{crit}$  at 0 JTU (n=6, 13.81±44.93cm/sec) was not significantly different than  $U_{crit}$  at 25 JTU (n=7, 14.30, ±68.46cm/sec). For fish 17-35.5 cm TL,  $U_{crit}$  at 0 JTU (n=16, 13.76±45.63cm/sec) was not significantly different than  $U_{crit}$  at 75 JTU (n=5, 11.69±4.24cm/sec). Figure 2-2 displays white crappie critical swimming speeds for each turbidity level.

### *Differences between Species*

Overall black crappie critical swimming speeds (n=22, 20.50±125.20cm/sec) were significantly greater than white crappie critical swimming speeds (n=15, 13.97±45.69cm/sec) for fish 20 to 29.9 cm TL (*t*-Test for two samples assuming unequal variances, P=0.017). At 0 JTU, black crappie mean critical swimming speeds were significantly higher than white crappie critical swimming speeds (*t*-Test for two samples assuming unequal variances, P=0.006). At 25 JTU, black crappie  $U_{crit}$  was not significantly different than white crappie  $U_{crit}$ . Because of a size discrepancy between the two groups, it was not possible to compare  $U_{crit}$  at 75 JTU for the two species. Figure 2-3 displays critical swimming speeds for both species at 0, 25 and 75 JTU. It is interesting to note that four of 11 black crappie refused to swim for even one minute at 75 JTU and another four black crappie swam 6 minutes or less at 75 JTU while all seven white crappie at 75 JTU swam for at least 23 minutes.

## Oxygen Consumption Rate

### *Turbidity Effects*

#### *Black Crappie*

Results of statistical comparisons using ANOVA are summarized in Table 2-3. Day  $VO_2$  (Figure 2-4) for black crappie at 0 JTU ( $n=7$ , mean  $\pm$  variance =  $120.4 \pm 2.8$  mg  $O_2$ /kg/hr at 10 cm/sec) was not significantly different than  $VO_2$  at night ( $n=7$ ,  $90.5 \pm 3.9$  mg  $O_2$ /kg/hr). Therefore, day and night data at 0 JTU were pooled for comparison to the 25 and 75 JTU treatments. Figure 2-5 displays black crappie mean  $VO_2$  at 0, 25, and 75 JTU. Oxygen consumption levels were consistently lower for fish in the 0 JTU treatment than for the other two treatment groups for swimming speeds up to 30 cm/s. At 35 and 40 cm/s, comparisons were not possible due to the low numbers of fish that reached those swimming speeds.

#### *White Crappie*

Results of statistical comparisons using ANOVA are summarized in Table 2-4. Day  $VO_2$  (Figure 2-6) for white crappie at 0 JTU ( $n=8$ , mean  $\pm$  variance =  $71.9 \pm 2.1$  mg  $O_2$ /kg/hr at 10 cm/sec) was not significantly different than  $VO_2$  at night ( $n=7$ ,  $72.4 \pm 1.3$  mg  $O_2$ /kg/hr). Therefore, day and night data at 0 JTU were pooled for comparison to the 25 and 75 JTU treatments. Figure 2-7 displays white crappie weight specific  $VO_2$  at 0, 25, and 75 JTU and Table 2-4 displays the results of statistical comparisons between the treatment groups. Oxygen consumption levels at 0 JTU were significantly lower than those at 25 JTU for fish swimming at 10, 15, and 20 cm/s. The difference approaches significance at 25 cm/s ( $p=0.057$ ), but there were only three fish in

each group. Comparisons of  $\text{VO}_2$  at 0 and 75 JTU could be made only at 10 and 15 cm/s and  $\text{VO}_2$  was significantly lower in the 0 JTU treatment at 15 cm/s.

#### *Differences between Species*

ANOVA revealed that there was no significant difference in weight specific  $\text{VO}_2$  at 10 or 15 cm/s between black and white crappie at any of the three turbidity levels.

Results are summarized in Table 2-5. One difference approached significance: in the 0 JTU treatment at 10 cm/s, mean black crappie  $\text{VO}_2$  (n=14) was  $105.4 \pm 3.3$  mg  $\text{O}_2$ /kg/h while mean white crappie  $\text{VO}_2$  (n=15) was  $72.1 \pm 1.6$  mg  $\text{O}_2$ /kg/h ( $df=1$ ,  $P= 0.081$ ).

Figures 2-8, 9, and 10 display  $\text{VO}_2$  values for black and white crappie at 0, 25 and 75 JTU respectively.

#### **Discussion**

This study is the first to test the laboratory swimming performance of crappies under varying turbidity conditions. Other researchers have previously examined the effects of turbidity on spawning habits (Vasey 1973), feeding rates (Barefield and Ziebell 1986), abundance (Mitzner 1987), and growth (Spier and Heidinger 2002) of crappies, but none have published data on swimming performance.

Crappies are often exposed to wide fluctuations in turbidity. Data provided by the US Army Corps of Engineers indicate that turbidity levels at Sardis Lake, MS ranged from 1-190 JTU from 1972 to 1991 with an average of 24.236 JTU. Both white crappie and black crappie inhabit Sardis Lake and neither species showed a decline in  $U_{\text{crit}}$  from clear water to 25 JTU. As predicted by the habitat suitability index models developed by Edwards et al. (1982a, b), black crappie  $U_{\text{crit}}$  was negatively affected by high turbidity (75 JTU). Because black crappie night  $U_{\text{crit}}$  at 0 JTU was not significantly higher than

day  $U_{crit}$ , it can be assumed that light, and therefore visual acuity, is not a limiting factor in black crappie  $U_{crit}$ . This suggests that the turbidity effect observed was not due to a reduced optomotor response caused by the elimination of visual cues during swimming. Other stimuli must be enough to induce swimming. However, an obvious effect of high turbidity on  $U_{crit}$  was observed. If we follow the model of McKenzie et al. (2007) in using  $U_{crit}$  as a “biomarker” indicating sub-lethal exposure to a toxicant, the results suggest that suspended sediment is a toxicant to black crappie, but white crappie are more tolerant. Black crappie predominate in clear bodies of water and in the present study they exhibit greater critical swimming speeds than white crappie in clear water, suggesting that black crappie may be better adapted to pursuing fish prey in clear water than white crappie. This advantage seems to be lost at 25 JTU. The lack of a decline in white crappie  $U_{crit}$  from 0 to 75 JTU suggests that white crappie may be adapted to exploiting turbid habitats and have a competitive advantage over black crappie in turbid bodies of water, where white crappie predominate.

There are several possible explanations for the observation that black crappie  $U_{crit}$  decreases with increasing turbidity. Although not examined in this study, there may be differences in gill filament morphology of black crappie and white crappie that make black crappie gills more susceptible to interference by suspended sediment. The two species are closely related and have very similar morphology otherwise. The smaller particle sizes in the laboratory allowed for sediment to remain suspended at slower velocities and any difference in gill morphology may have been amplified by this effect. However, the increase in  $VO_2$  displayed by both species in response to increased turbidity indicates a stress response occurred.

Behavioral differences could also be present. The response of black crappie to acute high turbidity may be one of avoidance that is not conducive to performance in the swim tunnel. One or both species may have exhibited “coughing” (Moyle and Cech 1988) to clear the gills via a momentary reversal of water flow to force material out of the mouth, but the high turbidity and resultant low visibility prevented observation of this behavior. Finally, there may have been an effect related to the timing of spawning and testing. Black crappie are known to spawn slightly earlier in the spring than white crappie and this difference in timing may have resulted in fish being in different condition (pre- or post-spawn) despite being collected at the same time.

The increases in  $VO_2$  from 0 to 25 and again up to 75 JTU observed in both species suggest two possible explanations. First, increased turbidity may have elicited a state of excitement or panic in these fish resulting in a higher metabolic rate. It may also be possible to attribute the observed increase in  $VO_2$  from 0 to 25 and 75 JTU to an increase in ventilation effort. Parsons and Carlson (1998) observed an increase in ventilation rate and  $VO_2$  in response to hypoxia in the ram-ventilating bonnethead shark *Sphyrna tiburo*. If the crappie in the present study responded to a reduction in the availability of dissolved oxygen due to increased turbidity by increasing their ventilation rates, this extra metabolic effort could have caused the increase in  $VO_2$  that I observed.

The results of this study indicate that managers wishing to encourage healthy populations of black crappie in turbid lakes may want to examine the feasibility of reducing the sediment load. This may be accomplished by various techniques including watershed erosion control and application of gypsum or aluminum sulfate.

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## **Appendix**

**Table 1-1. Number of individuals within each treatment group by capture method.**

“White” refers to *Pomoxis annularis* and “Black” refers to *Pomoxis nigromaculatus*.

| Species | Season | Time  | Trap net | Night angling | Day angling | Totals |
|---------|--------|-------|----------|---------------|-------------|--------|
| Black   | Summer | Day   | 0        | 8             | 4           | 12     |
| Black   | Fall   | Day   | 1        | 0             | 6           | 7      |
| Black   | Winter | Day   | 6        | 0             | 0           | 6      |
| Black   | Spring | Day   | 8        | 0             | 0           | 8      |
| Black   | Summer | Night | 3        | 3             | 11          | 17     |
| Black   | Fall   | Night | 0        | 0             | 6           | 6      |
| Black   | Winter | Night | 9        | 0             | 0           | 9      |
| Black   | Spring | Night | 7        | 0             | 1           | 8      |
| White   | Summer | Day   | 0        | 17            | 4           | 21     |
| White   | Fall   | Day   | 0        | 2             | 9           | 11     |
| White   | Winter | Day   | 7        | 0             | 0           | 7      |
| White   | Spring | Day   | 8        | 0             | 1           | 9      |
| White   | Summer | Night | 0        | 16            | 1           | 17     |
| White   | Fall   | Night | 0        | 0             | 10          | 10     |
| White   | Winter | Night | 9        | 0             | 0           | 9      |
| White   | Spring | Night | 6        | 0             | 2           | 8      |
| Totals  |        |       | 64       | 46            | 55          | 165    |

**Table 1-2. Description of seasonal treatment parameters.**

| <b>Treatment</b> | <b>Water Temp.</b> | <b>Lights on</b> | <b>Lights off</b> | <b>Dates</b>       |
|------------------|--------------------|------------------|-------------------|--------------------|
| Summer           | 25 ° C             | 0530-1930        | 1931-0529         | May 20 to Sept. 24 |
| Fall             | 16 ° C             | 0600-1800        | 1801-0559         | Oct. 6 to Dec. 12  |
| Winter           | 6 ° C              | 0700-1730        | 1731-0659         | Feb. 5 to Mar. 4   |
| Spring           | 16 ° C             | 0600-1800        | 1801-0559         | Mar. 9 to April 18 |

**Table 1-3. Number of individuals tested in each treatment. Non-performers are those fish that fail to swim for at least one minute at 10 cm/sec.**

| <b>Treatment</b>     | <b>Black crappie</b> |                  | <b>White crappie</b> |                  | <b>Totals</b> |
|----------------------|----------------------|------------------|----------------------|------------------|---------------|
|                      | <b>Performers</b>    | <b>Non-perf.</b> | <b>Performers</b>    | <b>Non-perf.</b> |               |
| <b>Summer, day</b>   | <b>12</b>            | <b>0</b>         | <b>19</b>            | <b>2</b>         | <b>33</b>     |
| <b>Summer, night</b> | <b>13</b>            | <b>4</b>         | <b>14</b>            | <b>3</b>         | <b>34</b>     |
| <b>Fall, day</b>     | <b>7</b>             | <b>0</b>         | <b>11</b>            | <b>0</b>         | <b>18</b>     |
| <b>Fall, night</b>   | <b>5</b>             | <b>1</b>         | <b>8</b>             | <b>2</b>         | <b>16</b>     |
| <b>Winter, day</b>   | <b>6</b>             | <b>1</b>         | <b>7</b>             | <b>0</b>         | <b>14</b>     |
| <b>Winter, night</b> | <b>9</b>             | <b>0</b>         | <b>7</b>             | <b>2</b>         | <b>18</b>     |
| <b>Spring, day</b>   | <b>8</b>             | <b>0</b>         | <b>8</b>             | <b>1</b>         | <b>17</b>     |
| <b>Spring, night</b> | <b>7</b>             | <b>1</b>         | <b>8</b>             | <b>0</b>         | <b>16</b>     |
| <b>Totals</b>        | <b>67</b>            | <b>7</b>         | <b>82</b>            | <b>10</b>        | <b>165</b>    |

**Table 1-4. Mean and standard error of white crappie VO<sub>2</sub> in summer. Predicted values were calculated using Parsons and Sylvester's (1992) equation:**

$$VO_2 = e^{(4.8+0.034u)}$$

where VO<sub>2</sub> is in mg O<sub>2</sub>/kg/hr and u is swimming speed in cm/sec.

| <b>Swimming Speed (cm/sec)</b> | <b>Predicted VO<sub>2</sub> (mg O<sub>2</sub>/kg/hr)</b> | <b>Observed VO<sub>2</sub> (mg O<sub>2</sub>/kg/hr)</b> | <b>Standard Error of Observed VO<sub>2</sub> (mg O<sub>2</sub>/kg/hr)</b> | <b>n</b>  |
|--------------------------------|--|---|---|-----------|
| <b>10</b>                      | <b>170.7</b>   | <b>288.4</b>  | <b>40.85</b>  | <b>13</b> |
| <b>15</b>                      | <b>202.4</b>   | <b>282.4</b>  | <b>26.82</b>  | <b>10</b> |
| <b>20</b>                      | <b>239.8</b>   | <b>296.4</b>  | <b>51.24</b>  | <b>8</b>  |
| <b>25</b>                      | <b>284.3</b>   | <b>307.3</b>  | <b>44.34</b>  | <b>11</b> |

**Table 2-1. Description of turbidity treatment parameters.**

| <b>Treatment</b>   | <b>Time of day</b> | <b>Turbidity<br/>(JTU)</b> | <b>Water temp<br/>(°C)</b> | <b>Lights</b> |
|--------------------|--------------------|----------------------------|----------------------------|---------------|
| Clear water, day   | 1330               | 0                          | 16                         | On            |
| Clear water, night | 2230               | 0                          | 16                         | Off           |
| Low Turbidity      | 1000-1400          | 25                         | 16                         | On            |
| High Turbidity     | 1000-1400          | 75                         | 16                         | On            |

**Table 2-2. Number of performers and non-performers within each treatment. Non-performers are those fish that fail to swim for at least one minute at 10 cm/sec.**

| Treatment          | Black Crappie |                | White crappie |                |
|--------------------|---------------|----------------|---------------|----------------|
|                    | Performers    | Non-performers | Performers    | Non-performers |
| Clear water, day   | 8             | 0              | 8             | 1              |
| Clear water, night | 7             | 1              | 8             | 0              |
| All Clear water    | 15            | 1              | 16            | 1              |
| Low turbidity      | 8             | 1              | 10            | 0              |
| High Turbidity     | 7             | 4              | 7             | 0              |

**Table 2-3. Results of single factor ANOVA comparing black crappie weight specific oxygen consumption between treatment groups.**

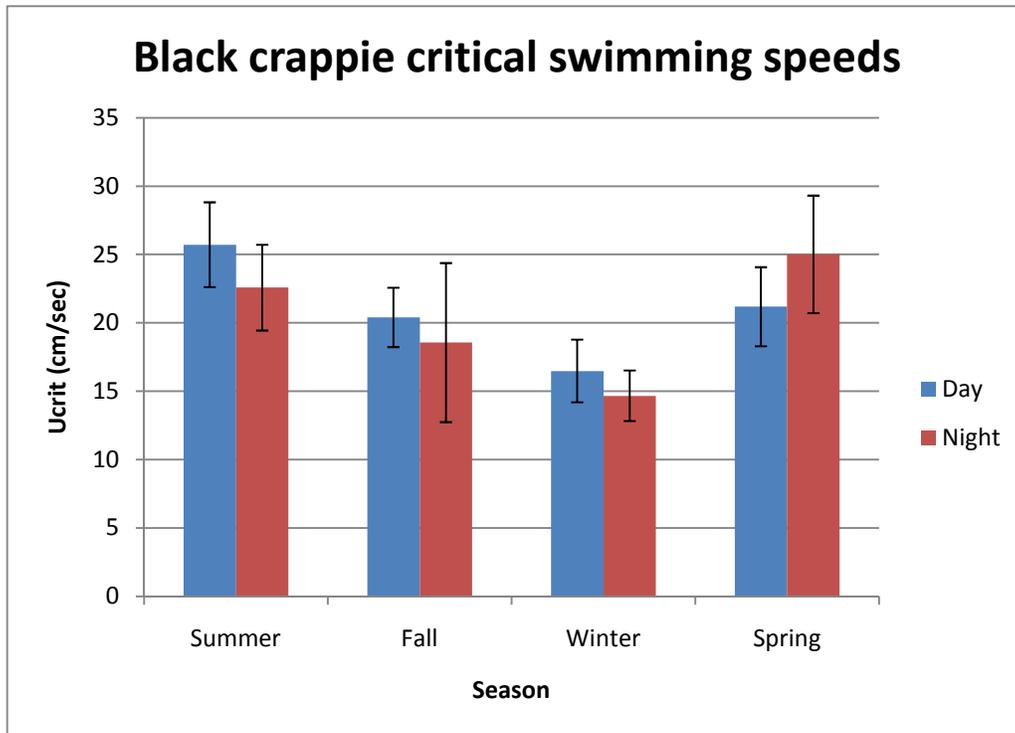
| Treatments                      | Degrees of Freedom |          |               |
|---------------------------------|--------------------|----------|---------------|
|                                 |                    | <i>F</i> | <i>P</i>      |
| Day vs. Night at 0 JTU, 10 cm/s | 1                  | 0.9344   | 0.3528        |
| 0 JTU vs. 25 JTU, 10 cm/s       | 1                  | 12.412   | <b>0.0021</b> |
| 0 JTU vs. 75 JTU, 10 cm/s       | 1                  | 10.555   | <b>0.0047</b> |
| 25 JTU vs. 75 JTU, 10 cm/s      | 1                  | 0.2096   | 0.6560        |
| 0 JTU vs. 25 JTU, 15 cm/s       | 1                  | 8.3922   | <b>0.0111</b> |
| 0 JTU vs. 75 JTU, 15 cm/s       | 1                  | 29.872   | <b>0.0002</b> |
| 25 JTU vs. 75 JTU, 15 cm/s      | 1                  | 0.5519   | 0.4856        |
| 0 JTU vs. 25 JTU, 20 cm/s       | 1                  | 2.3226   | 0.1498        |
| 0 JTU vs. 75 JTU, 20 cm/s       | 1                  | 10.737   | <b>0.0074</b> |
| 25 JTU vs. 75 JTU, 20 cm/s      | 1                  | 7.3409   | <b>0.0423</b> |
| 0 JTU vs. 25 JTU, 25 cm/s       | 1                  | 8.6054   | <b>0.0125</b> |
| 0 JTU vs. 25 JTU, 30 cm/s       | 1                  | 6.7094   | <b>0.0321</b> |

**Table 2-4. Results of single factor ANOVA comparing white crappie weight specific oxygen consumption between treatment groups.**

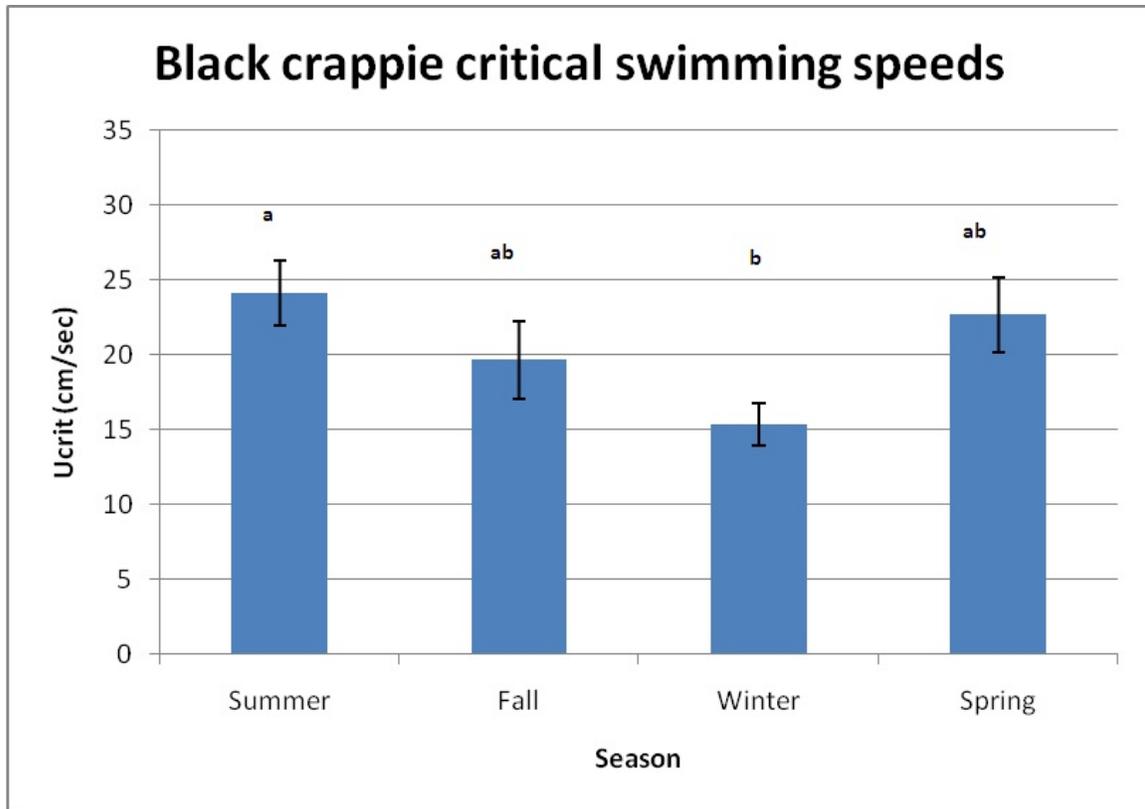
| Treatments                      | Degrees of Freedom |          |               |
|---------------------------------|--------------------|----------|---------------|
|                                 |                    | <i>F</i> | <i>P</i>      |
| Day vs. Night at 0 JTU, 10 cm/s | 1                  | 0.0005   | 0.9823        |
| 0 JTU vs. 25 JTU, 10 cm/s       | 1                  | 12.363   | <b>0.0019</b> |
| 0 JTU vs. 75 JTU, 10 cm/s       | 1                  | 2.0058   | 0.1738        |
| 25 JTU vs. 75 JTU, 10 cm/s      | 1                  | 1.1046   | 0.3124        |
| 0 JTU vs. 25 JTU, 15 cm/s       | 1                  | 4.8656   | <b>0.0460</b> |
| 0 JTU vs. 75 JTU, 15 cm/s       | 1                  | 6.6410   | <b>0.0257</b> |
| 25 JTU vs. 75 JTU, 15 cm/s      | 1                  | 0.0071   | 0.9351        |
| 0 JTU vs. 25 JTU, 20 cm/s       | 1                  | 6.1994   | <b>0.0472</b> |
| 0 JTU vs. 25 JTU, 25 cm/s       | 1                  | 7.0218   | 0.0570        |

**Table 2-5. Results of single factor ANOVA comparing white and black crappie weight specific oxygen consumption between treatment groups. Bold *P* values indicate approaching significance.**

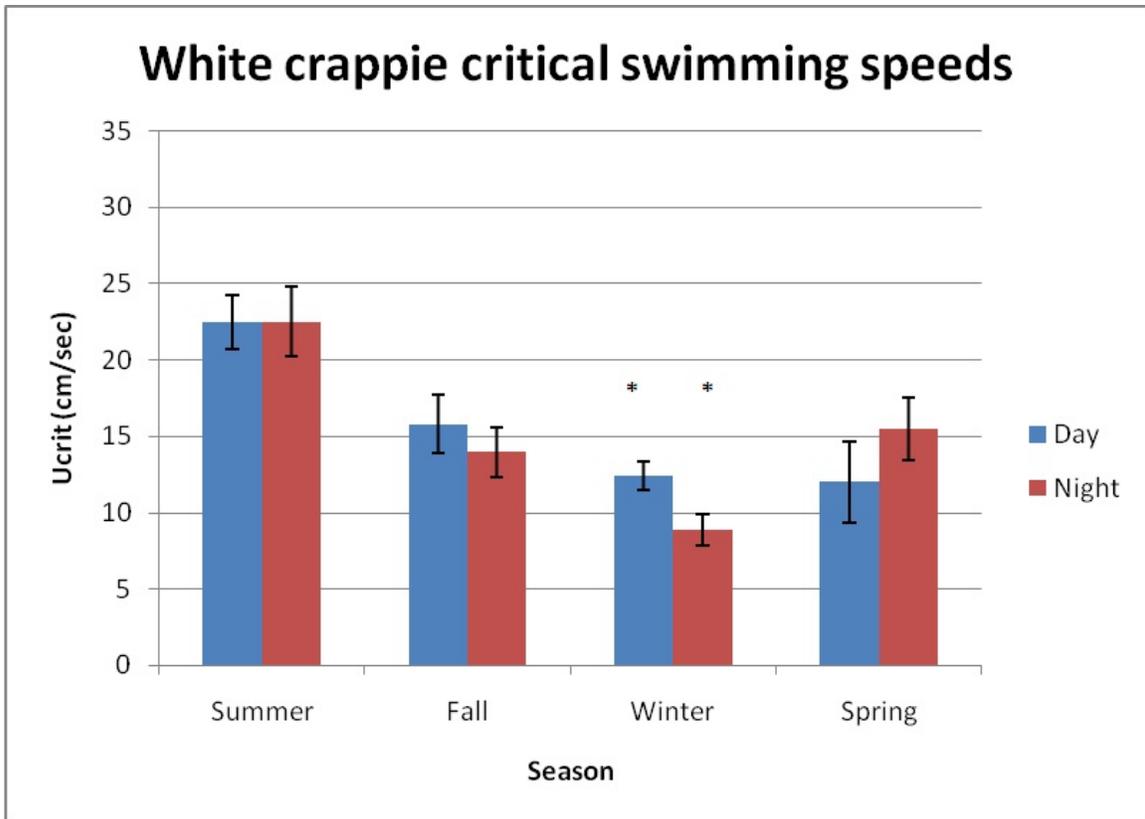
| Treatments      | Degrees of Freedom |          |               |
|-----------------|--------------------|----------|---------------|
|                 |                    | <i>F</i> | <i>P</i>      |
| 0 JTU, 10 cm/s  | 1                  | 3.2857   | <b>0.0811</b> |
| 0 JTU, 15 cm/s  | 1                  | 0.8045   | 0.3816        |
| 25 JTU, 10 cm/s | 1                  | 0.3102   | 0.5853        |
| 25 JTU, 15 cm/s | 1                  | 0.0596   | 0.8121        |
| 75 JTU, 10 cm/s | 1                  | 2.0103   | 0.1940        |
| 75 JTU, 15 cm/s | 1                  | 0.1662   | 0.7044        |



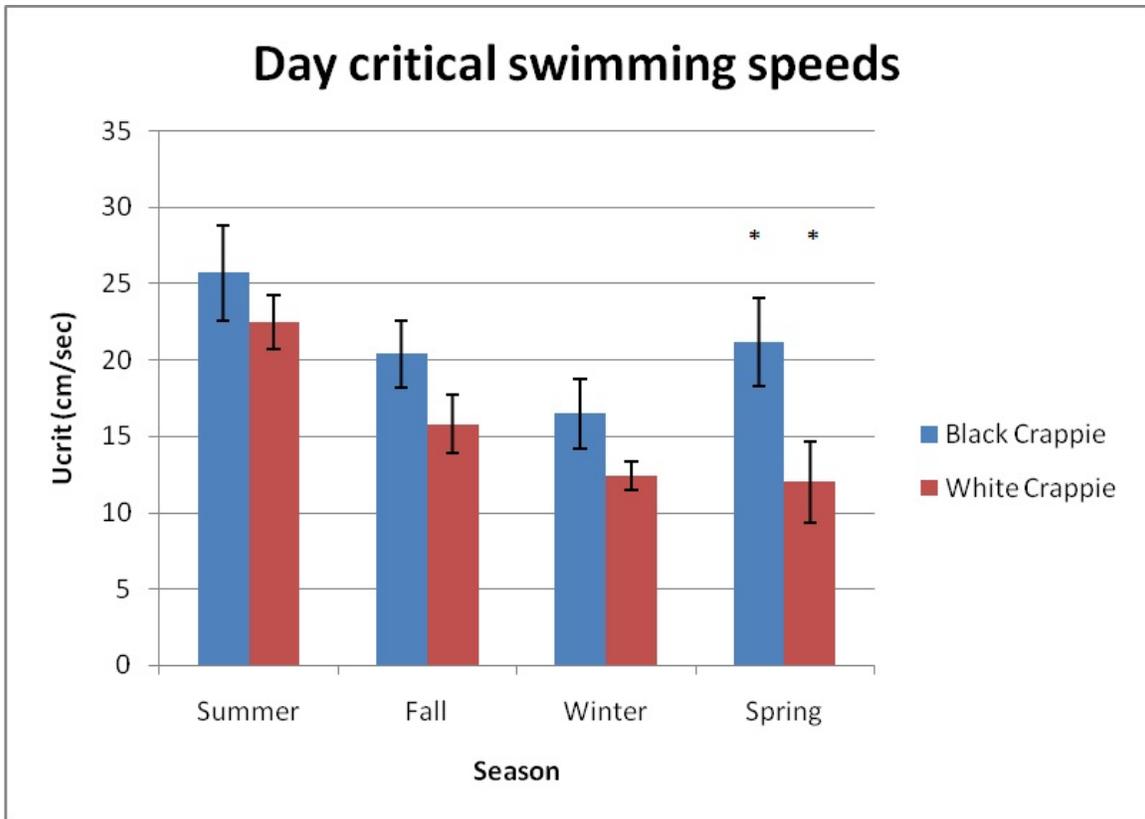
**Figure 1-1. Mean and standard error of black crappie  $U_{crit}$ . Values within seasons are not significantly different.**



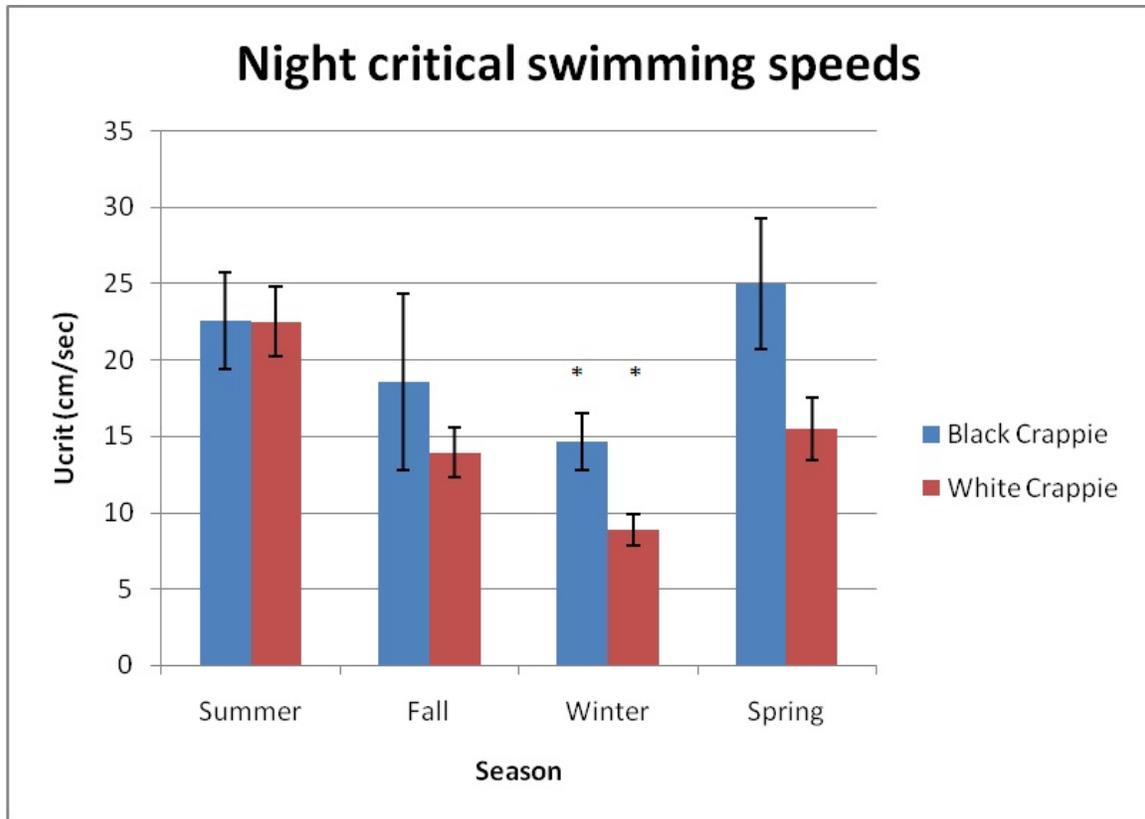
**Figure 1-2. Mean and standard error of black crappie  $U_{crit}$ . Day and night tests were pooled for this comparison. Winter  $U_{crit}$  was significantly different from that in summer. All other values were not significantly different.**



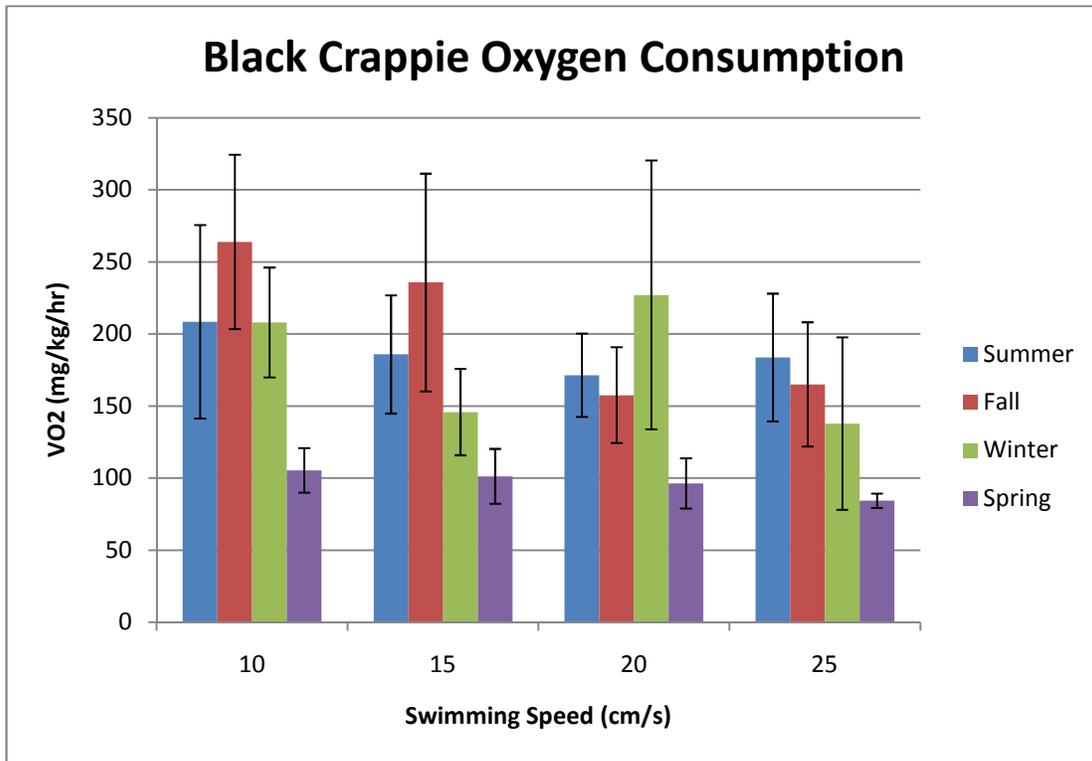
**Figure 1-3. Mean and standard error of white crappie  $U_{crit}$ . Asterisks indicate values within a season that were significantly different.**



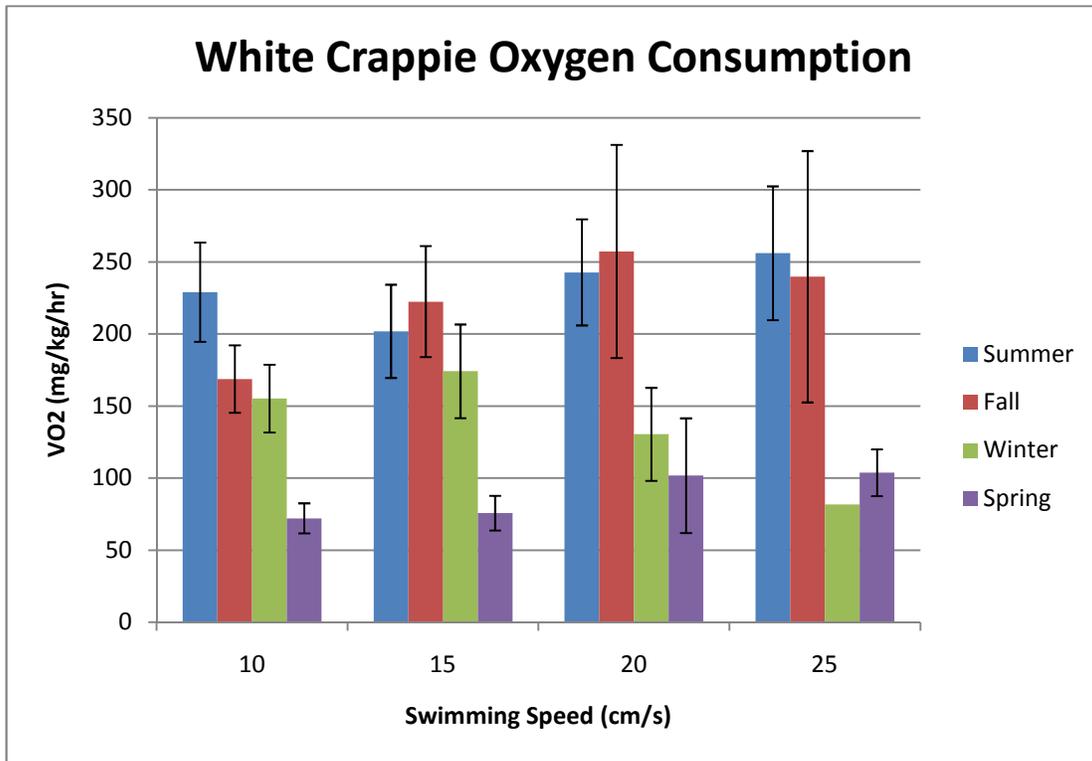
**Figure 1-4. Mean and standard error of critical swimming speeds during the day. Asterisks indicate values within a season that were significantly different.**



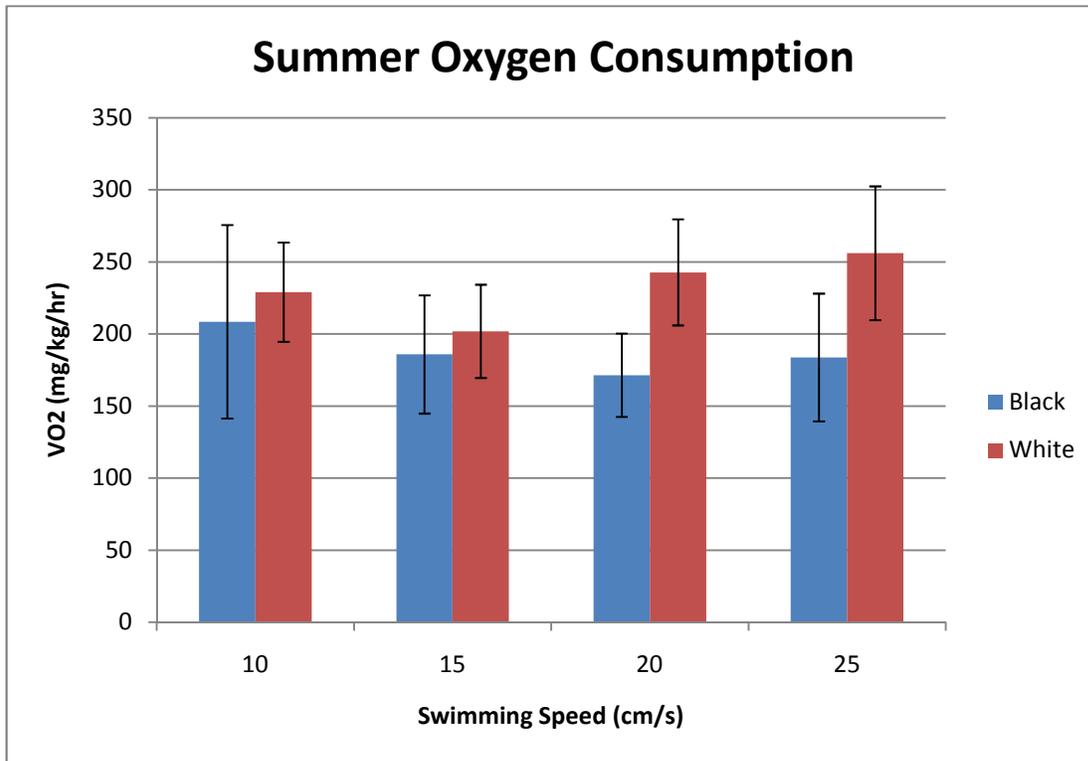
**Figure 1-5. Mean and standard error of critical swimming speeds during the night. Asterisks indicate values within a season that were significantly different.**



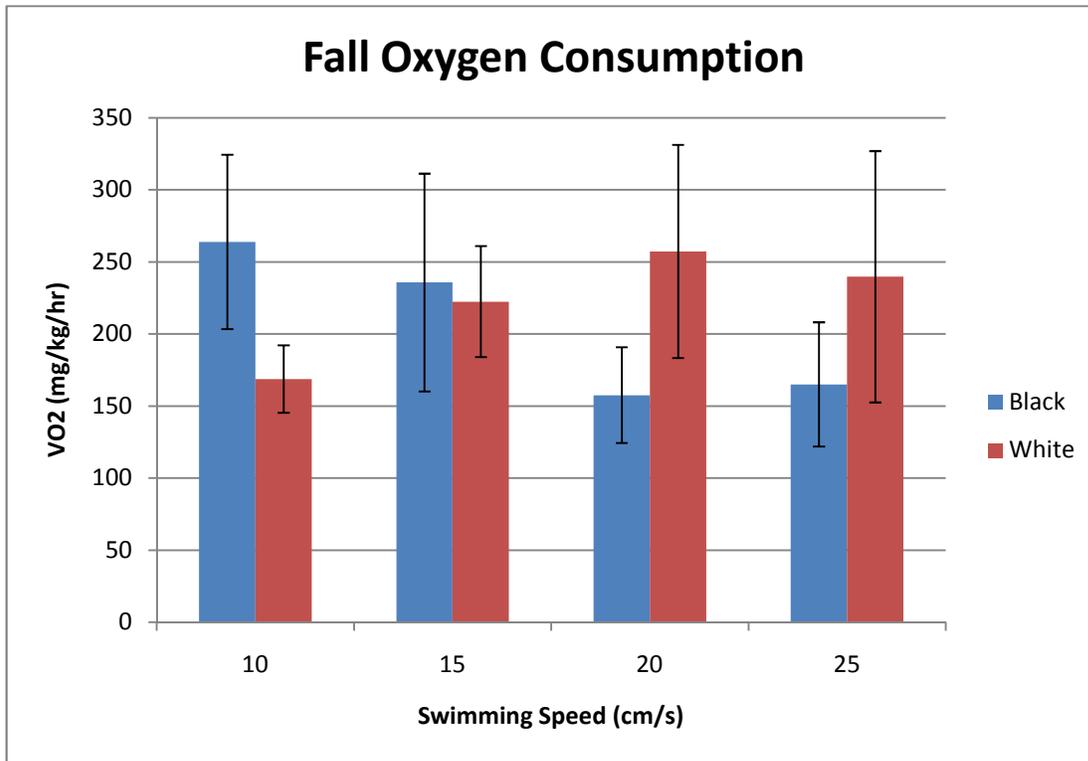
**Figure 1-6. Mean and standard error of black crappie VO<sub>2</sub>. VO<sub>2</sub> at 10 cm/sec was significantly lower in spring than in fall or winter. VO<sub>2</sub> at 25 cm/sec was significantly lower in spring than in fall. All other values within a swimming speed were not significantly different.**



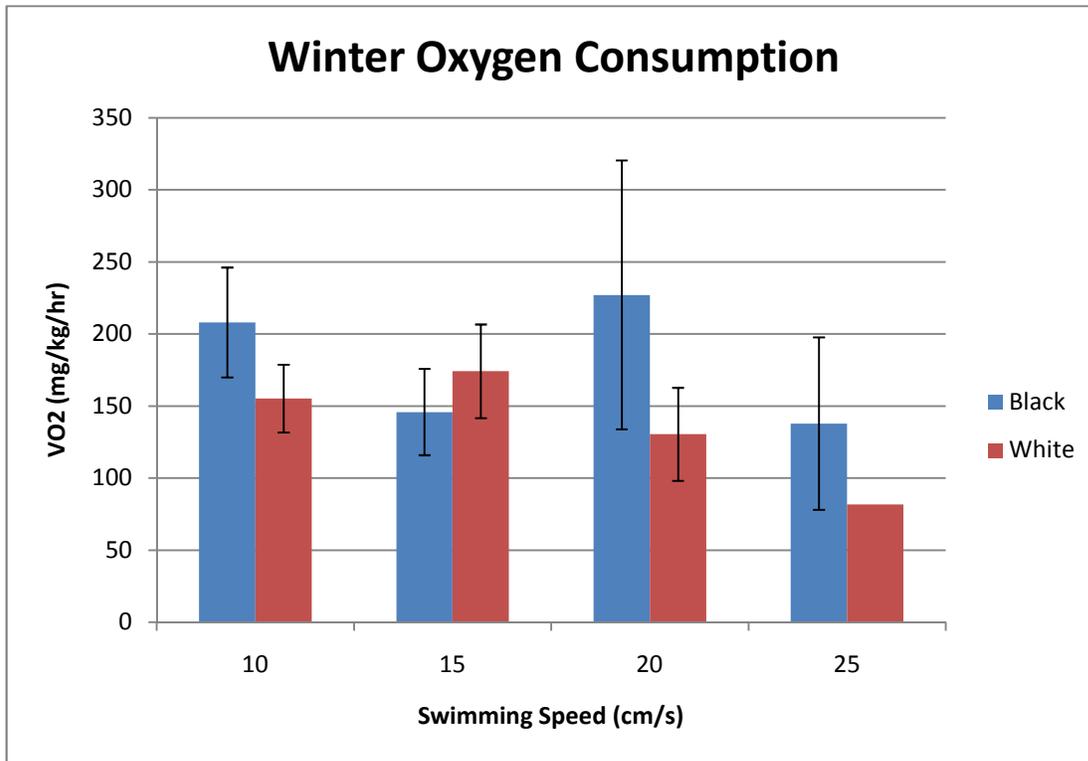
**Figure 1-7. Mean and standard error of white crappie VO<sub>2</sub>. VO<sub>2</sub> at 10 and 15 cm/sec was significantly lower in spring than in summer, fall or winter. All other values within a swimming speed were not significantly different.**



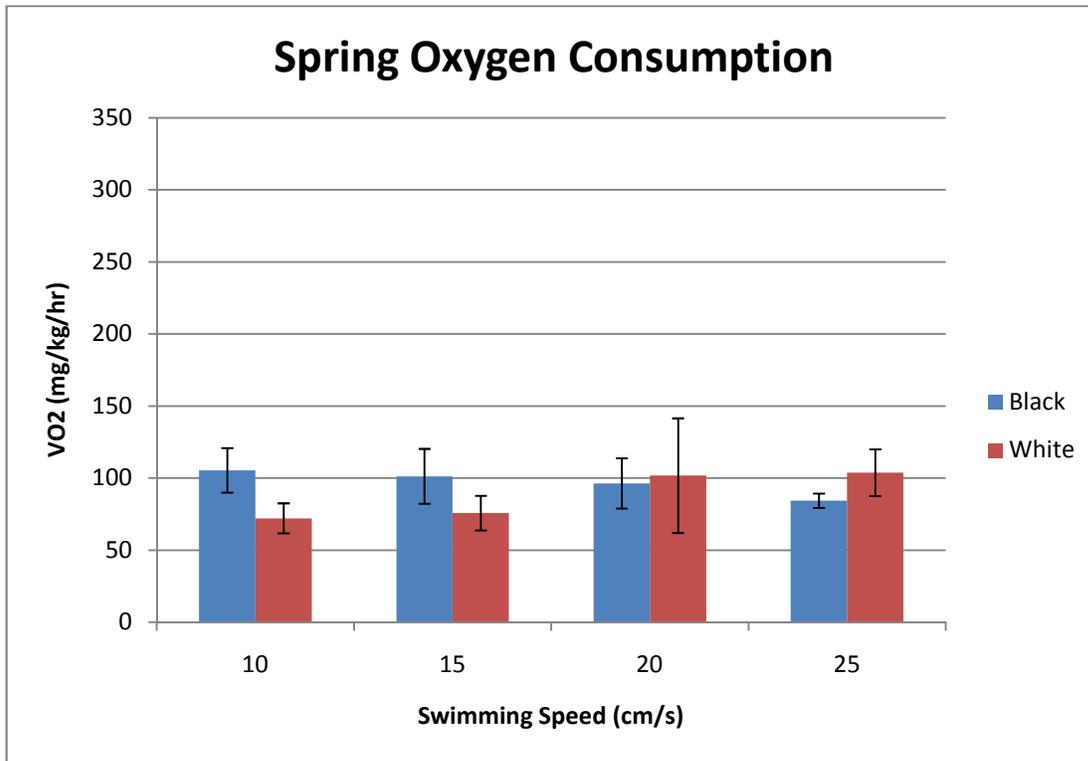
**Figure 1-8. Mean and standard error of  $VO_2$  for black and white crappie in summer. There were no significant differences between the two species  $VO_2$  values at any swimming speed.**



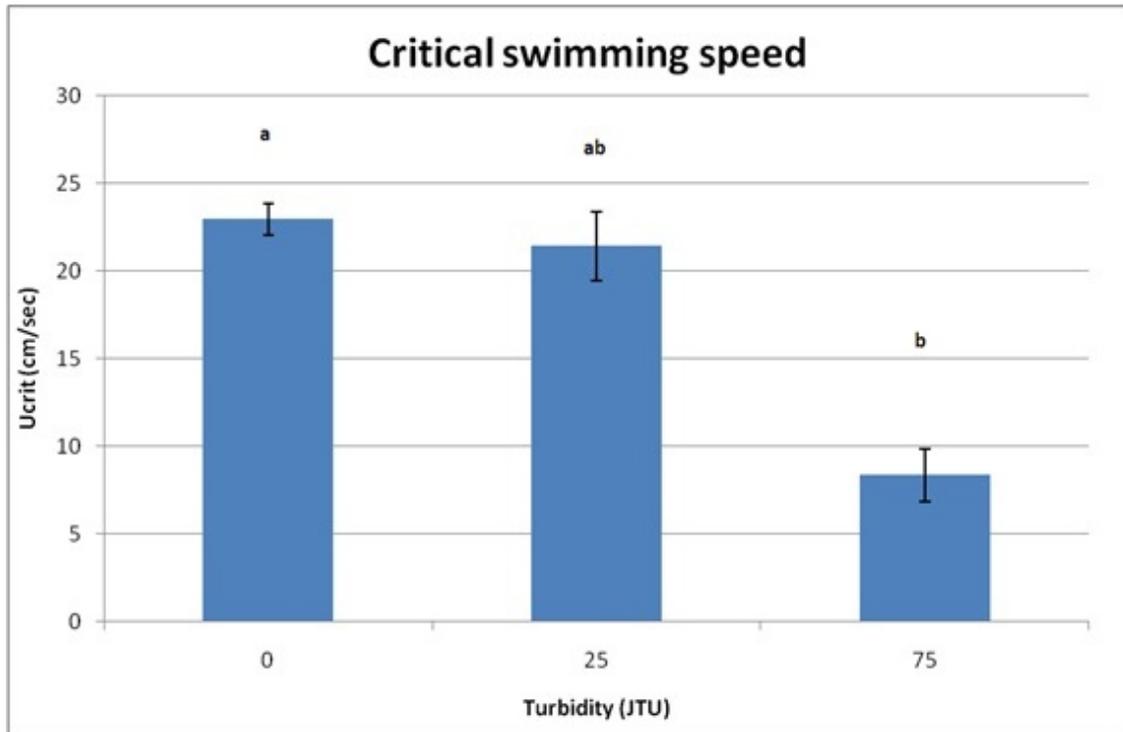
**Figure 1-9. Mean and standard error of  $VO_2$  for black and white crappie in fall. There were no significant differences between the two species  $VO_2$  values at any swimming speed.**



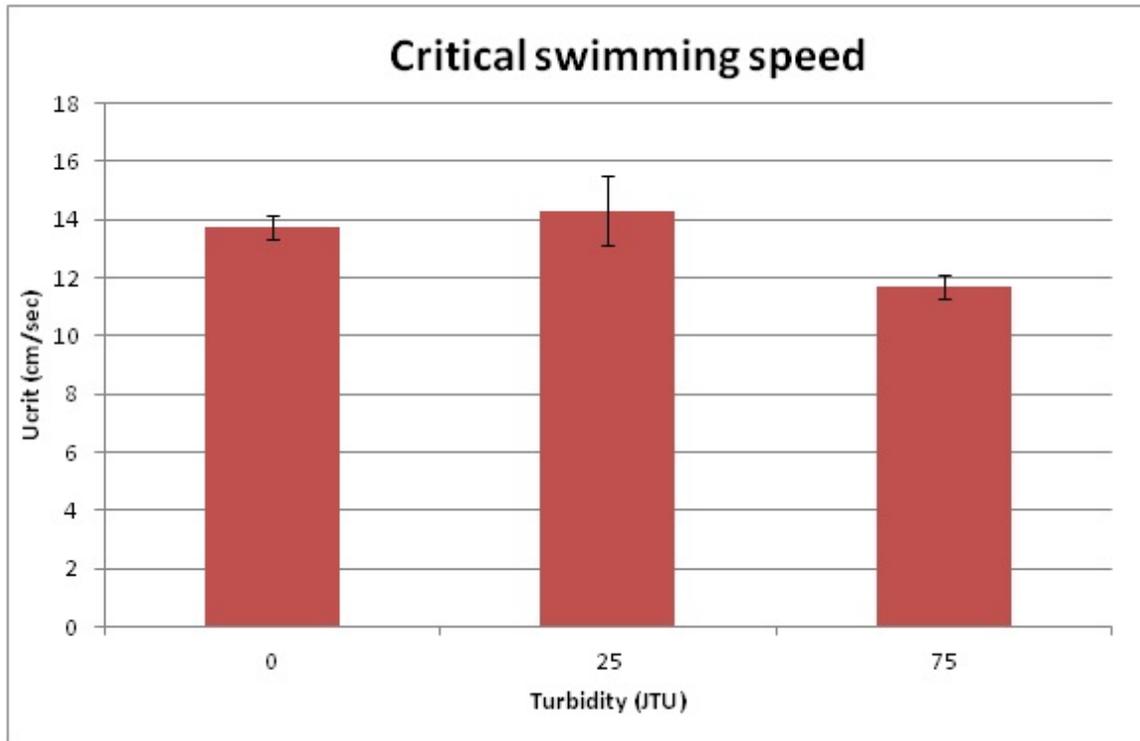
**Figure 1-10. Mean and standard error of  $VO_2$  for black and white crappie in winter. The column for white crappie at 25 cm/sec represents only one value. There were no significant differences between the two species  $VO_2$  values at any swimming speed.**



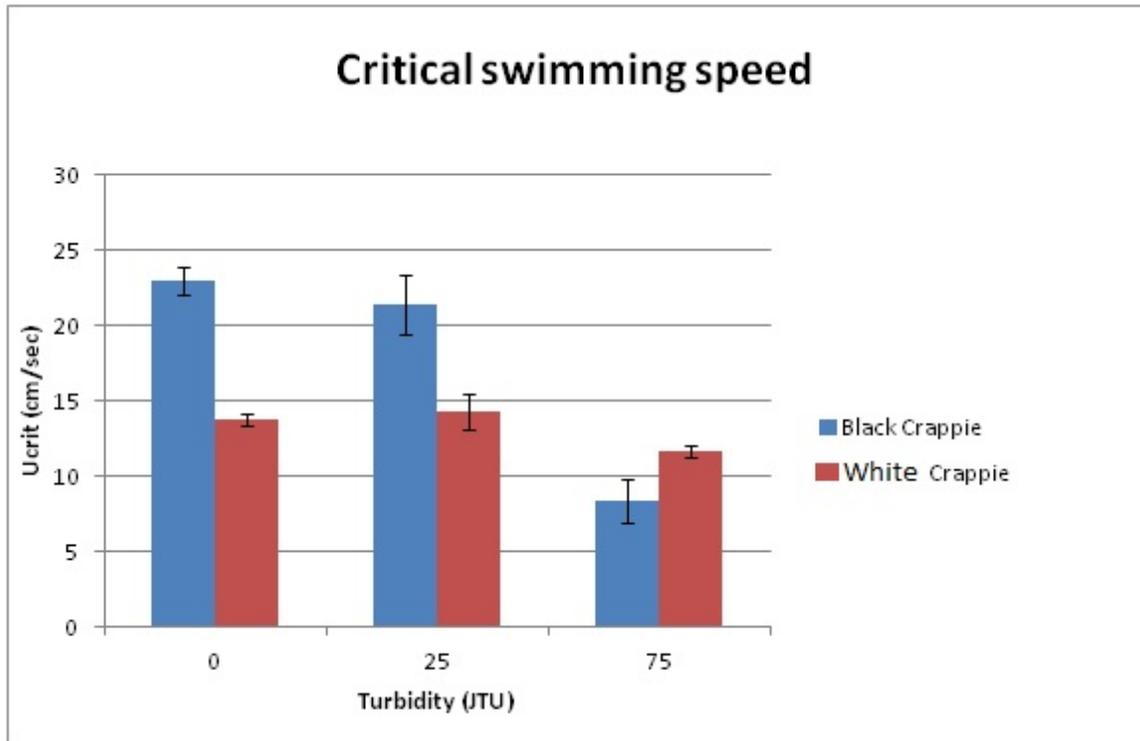
**Figure 1-11. Mean and standard error of  $VO_2$  for black and white crappie in spring. The difference between  $VO_2$  values for the two species approached significance at 10 cm/sec ( $P=0.0810$ ). There were no significant differences between the two species  $VO_2$  values at any swimming speed.**



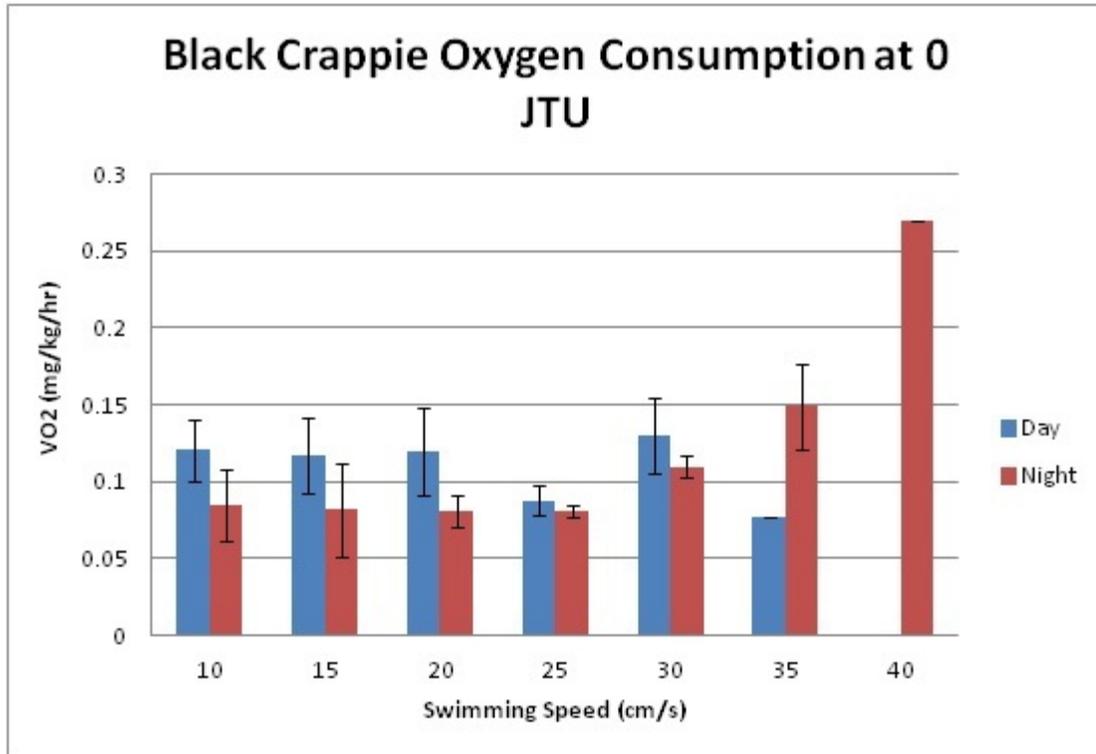
**Figure 2-1. Mean and standard error of black crappie  $U_{crit}$  at three levels of turbidity.  $U_{crit}$  at 75 JTU was significantly lower than at 0 JTU.**



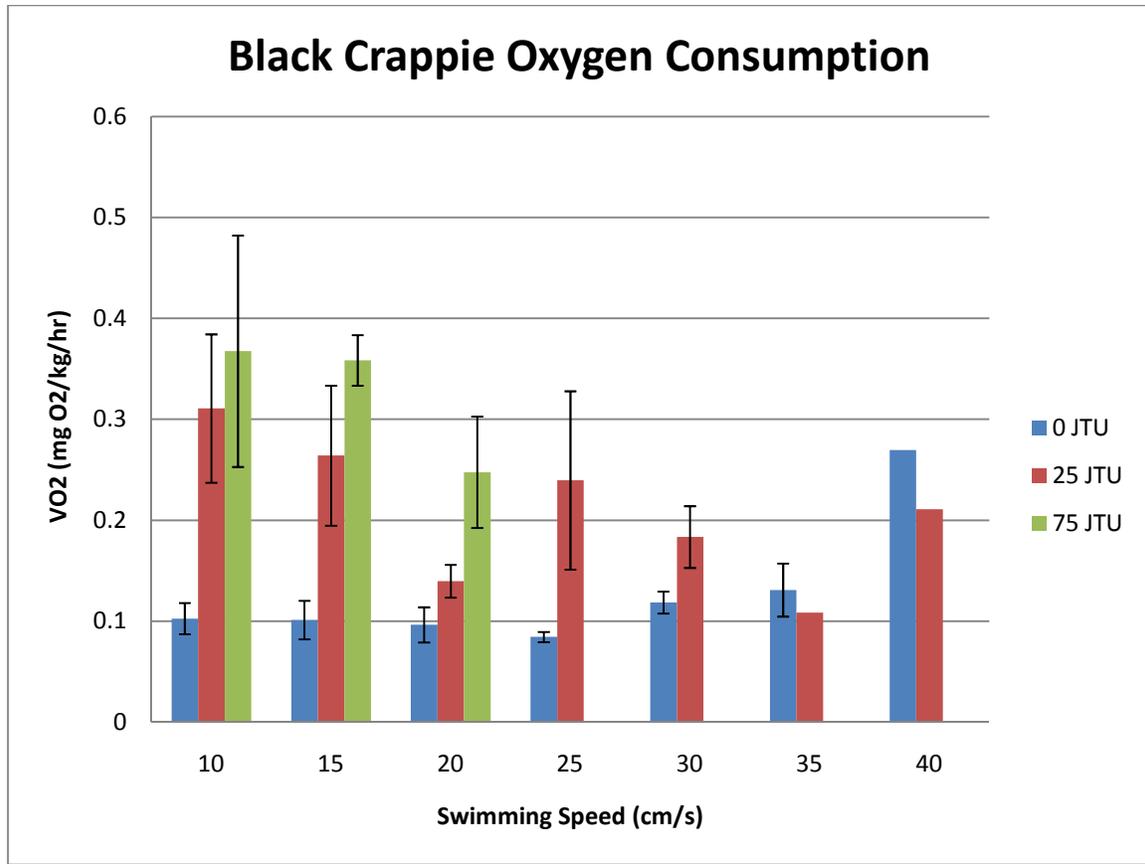
**Figure 2-2. Mean and standard error of white crappie  $U_{crit}$  at three levels of turbidity. There were no significant differences in  $U_{crit}$  between the three levels of turbidity.**



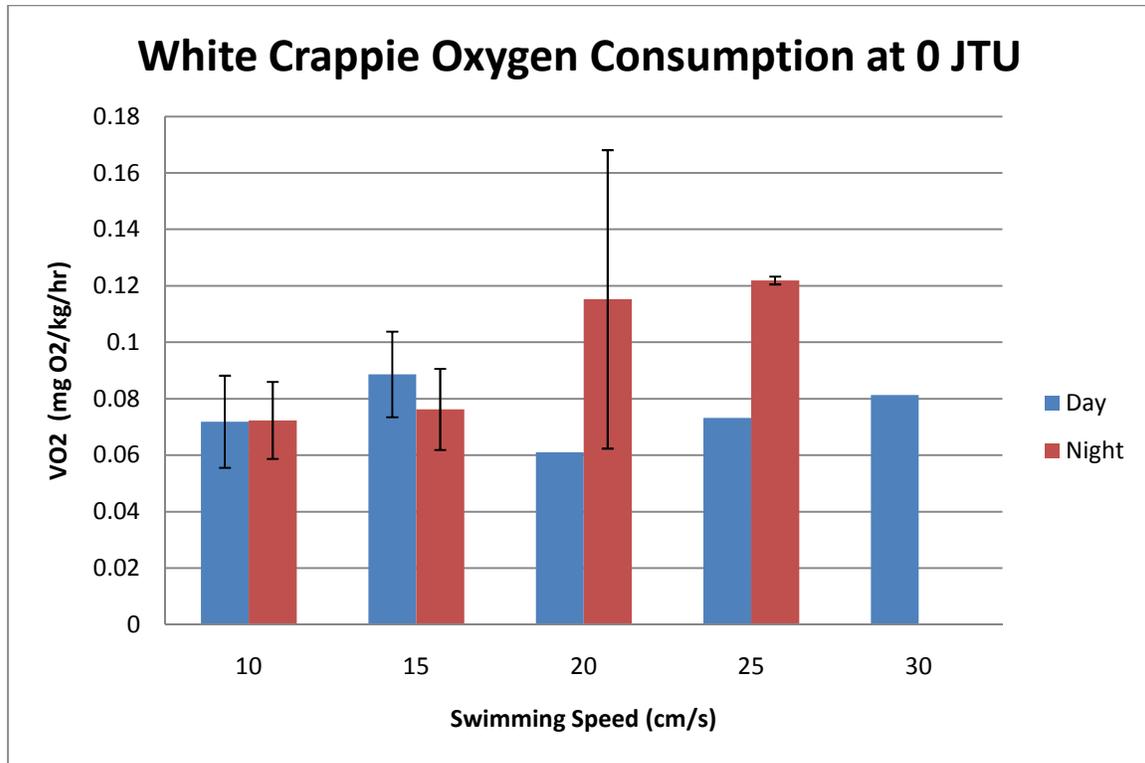
**Figure 2-3. Mean and standard error of white and black crappie  $U_{crit}$  at three levels of turbidity. Black crappie  $U_{crit}$  at 0 JTU was significantly greater than that of white crappie. White crappie used in the 75 JTU treatment were significantly larger than black crappie so no statistical comparison of  $U_{crit}$  could be made.**



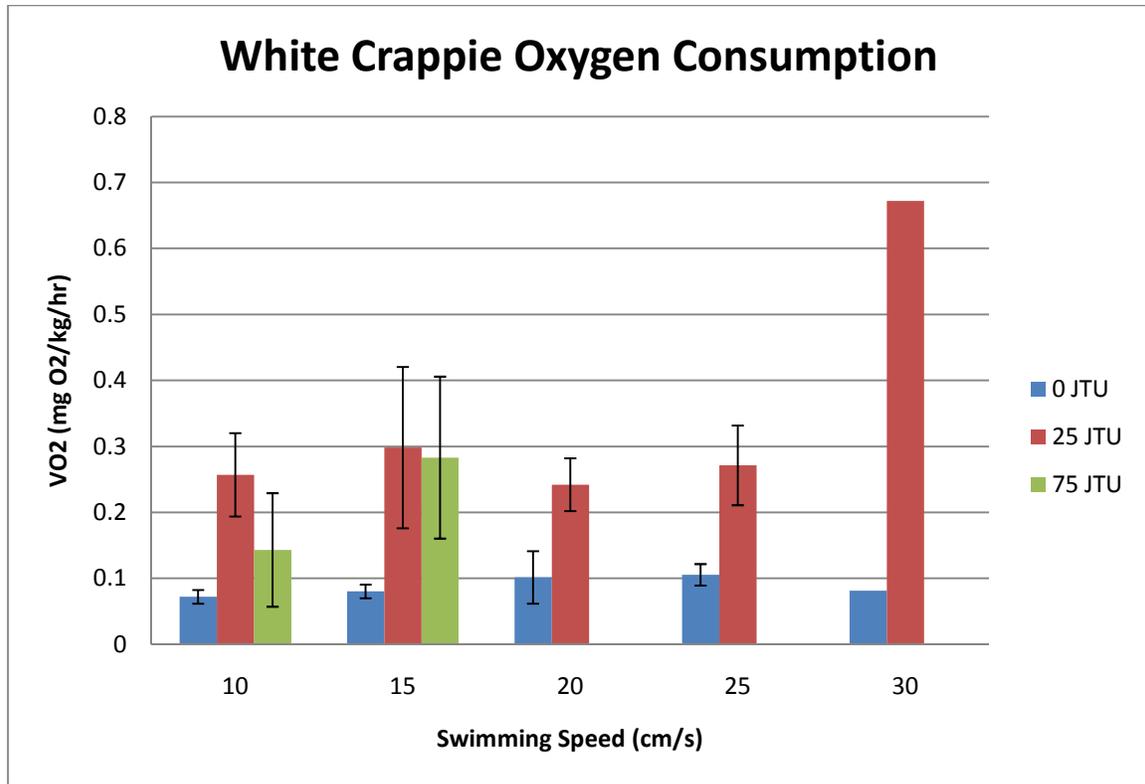
**Figure 2-4. Mean and standard error of black crappie Weight Specific Oxygen Consumption at 0 JTU. Columns without error bars represent only one sample. There were no significant differences in VO<sub>2</sub> between day and night treatments.**



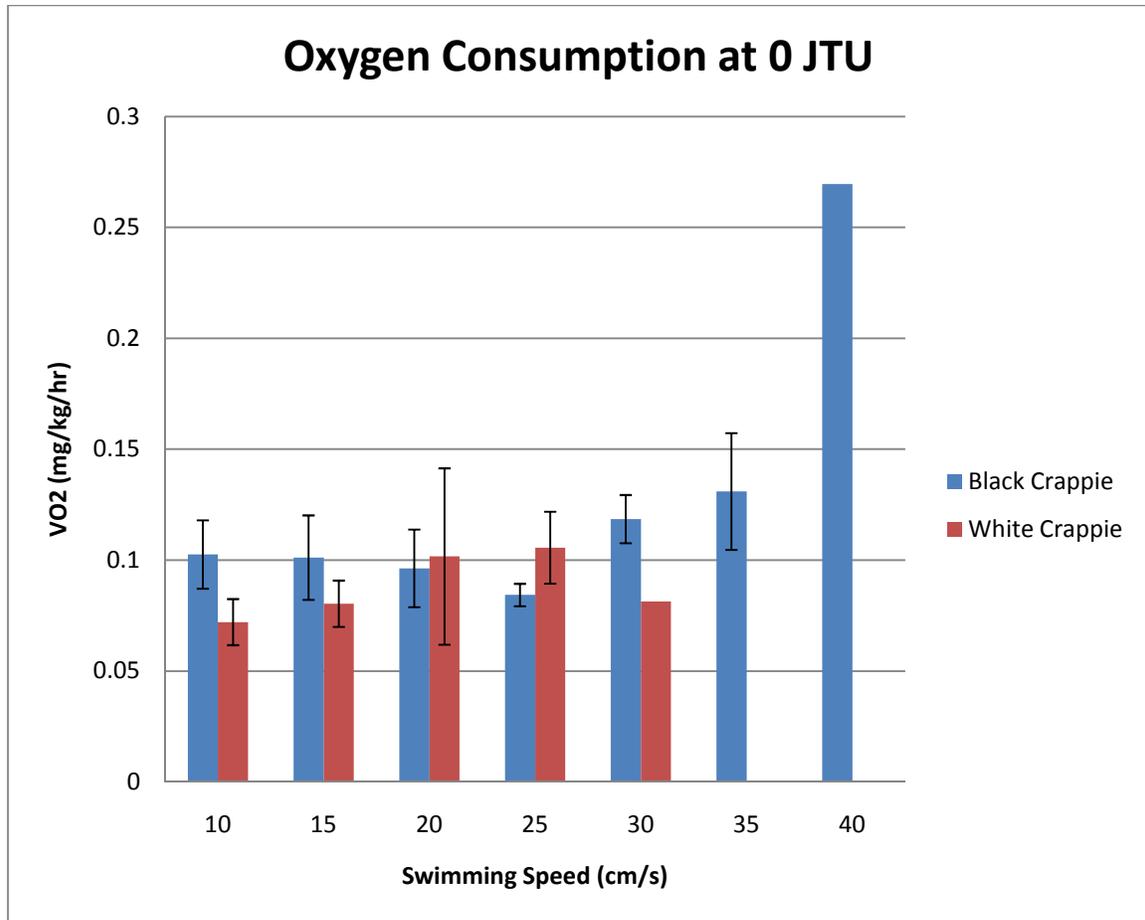
**Figure 2-5. Mean and standard error of black crappie weight specific oxygen consumption at three levels of turbidity. Columns without error bars represent only one sample. VO<sub>2</sub> was significantly lower in the 0 JTU treatment than in the 25 JTU treatment at 10, 15, 25, and 30 cm/sec. VO<sub>2</sub> was significantly lower in the 0 JTU treatment than in the 75 JTU treatment at 10, 15, and 20 cm/sec. Black crappie at 75 JTU did not swim past 20 cm/s, so no data were available for comparison at 25-40 cm/s.**



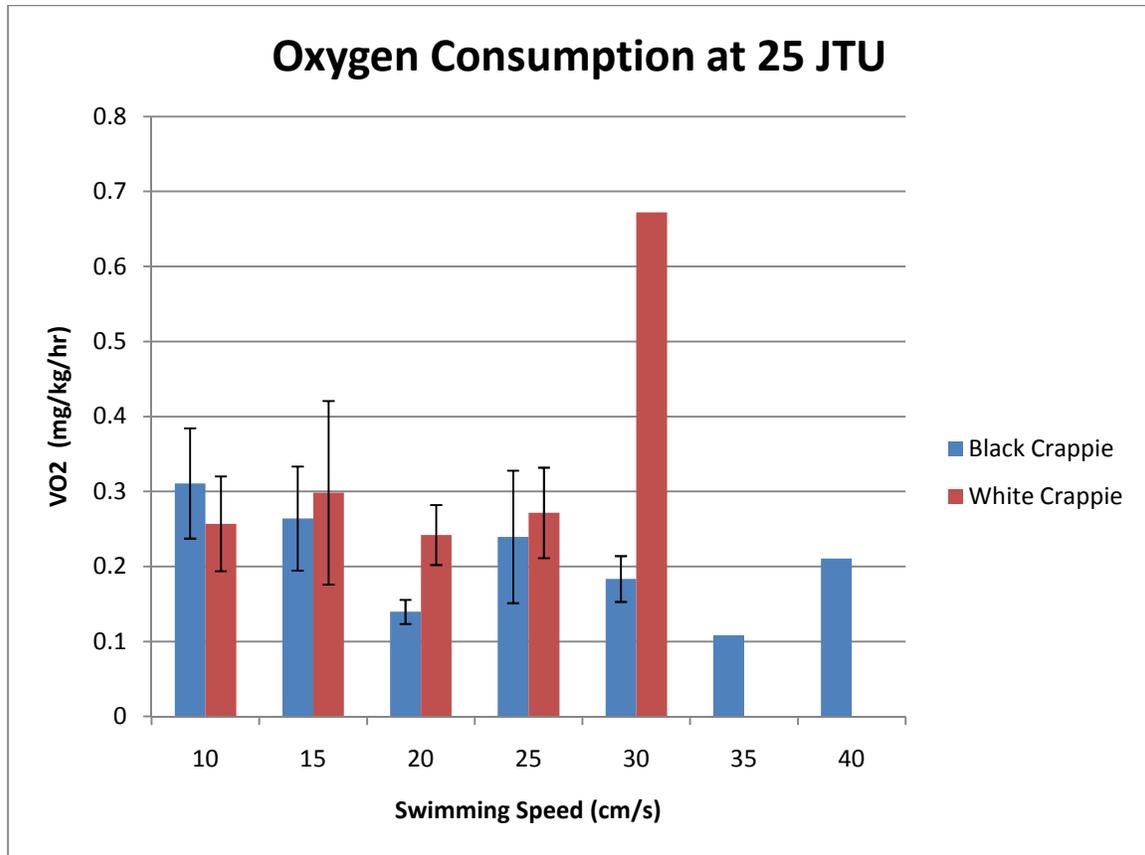
**Figure 2-6.** Mean and standard error of white crappie weight specific oxygen consumption at 0 JTU. Columns without error bars represent only one sample.  $VO_2$  was not significantly different between the two treatment groups at any swimming speed.



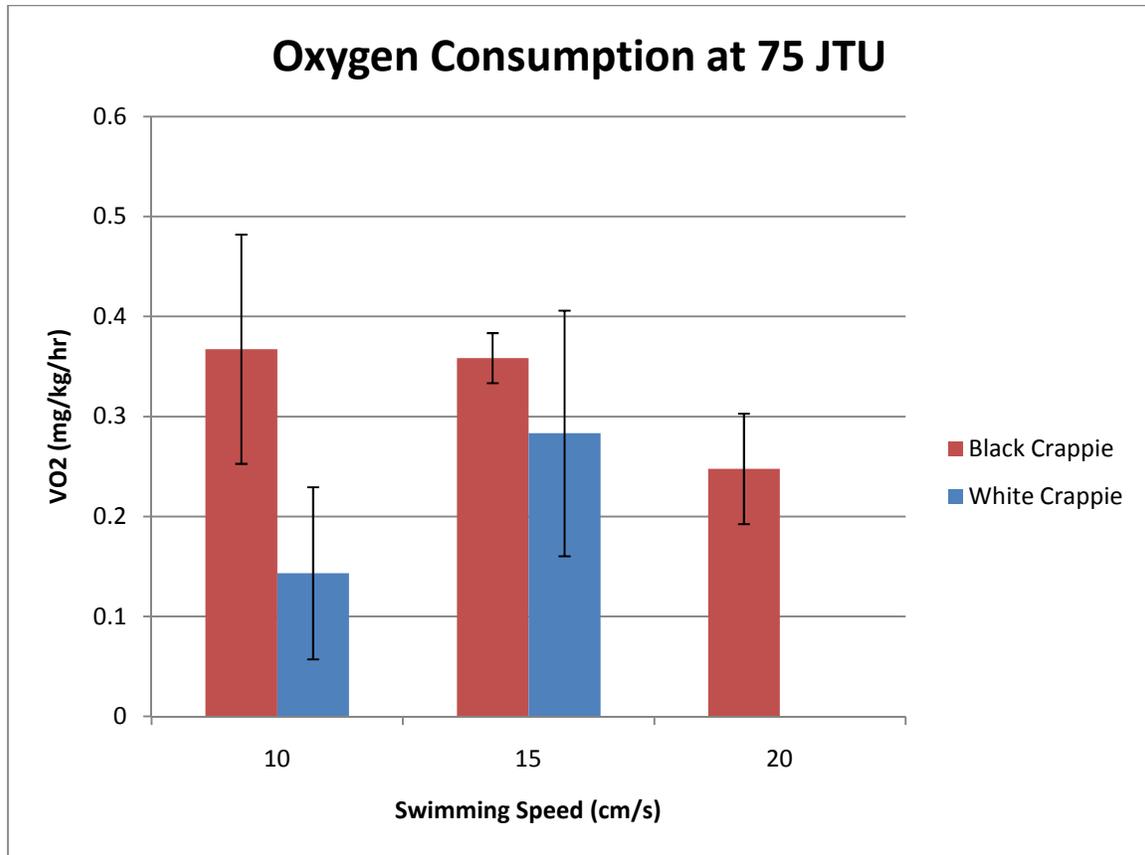
**Figure 2-7. Mean and standard error of white crappie weight specific oxygen consumption at three levels of turbidity. Columns without error bars represent only one sample. VO<sub>2</sub> at 0 JTU was significantly lower than at 25 JTU for the 10, 15, and 20 cm/sec swimming speeds. This difference approached significance at 25 cm/sec (P=0.0570). VO<sub>2</sub> at 0 JTU was significantly lower than at 75 JTU for the 15 cm/sec swimming speed. White crappie at 75 JTU did not swim past 15 cm/s, so no data were available for comparison at 20-30 cm/s.**



**Figure 2-8. Mean and standard error of crappie weight specific oxygen consumption 0 JTU. Columns without error bars represent only one sample. The difference between black crappie and white crappie  $VO_2$  values approached significance at 10 cm/sec ( $P=0.0810$ ). There was no significant difference at any swimming speed.**



**Figure 2-9. Mean and standard error of crappie weight specific oxygen consumption at 25 JTU. Columns without error bars represent only one sample. There was no significant difference at any swimming speed.**



**Figure 2-10. Mean and standard error of crappie weight specific oxygen consumption at 75 JTU. There was no significant difference at any swimming speed.**

## VITA

Caleb Joseph Gaston, son of Dr. Joseph and Karen Gaston, was born May 3, 1986 in Rock Hill, South Carolina. Caleb graduated from Liberty High School in Bedford, Virginia in 2004 and began studying at Clemson University in Clemson, SC in August of that year. He graduated from Clemson *Cum Laude* in December 2008 with a Bachelor of Science degree in Wildlife and Fisheries Biology. Caleb entered the Graduate School at the University of Mississippi in August 2009 and worked as a graduate research assistant for Dr. Glenn Parsons. Caleb is currently employed as a Natural Resource Technician at Fort Jackson, Columbia, SC.