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Scaling of Feesing Behavior and Performance in the Goliath Grouper, Epinephelus itajara

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SCALING OF FEEDING BEHAVIOR AND PERFORMANCE IN THE GOLIATH GROUPER, *EPINEPHELUS ITAJARA*

by

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Under the Direction of Dr. Steve Huskey

ABSTRACT

Scaling is defined as the changes related to body size an animal undergoes during its life history. This change in body size can have implications for habitat use, prey consumed, and predatory threats, among others. The goliath grouper, *Epinephelus itajara*, undergoes one of the greatest amounts of scaling of any animal known, growing from 3mm at hatching to 2.3 m as adults. This tremendous change has implications for their development and niche as a top-level predator in their habitats. However, the consequences of their drastic change in body size for feeding performance have never been quantified. Here, a juvenile goliath was recorded using high-speed video (500 frames per second) in the lab and sequences were compared to videos collected on adults feeding in their natural habitat in the wild.

INDEX WORDS: Scaling, Kinematics, Goliath Grouper, *Epinephelus itajara,* Feeding Performance

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TABLE OF CONTENTS

LIST OF TABLES AND GRAPHS

LIST OF FIGURES

INTRODUCTION

Background

The goliath grouper *Epinephelus itajara,* formerly known as the jewfish, is the largest grouper species found in the Americas and one of two of the largest grouper species found worldwide (Eklund and Sadovy, 1999). Specimens have been collected ranging up to 2.2 meters long, and at a maximum of 37 years of age. They were already known to grow at a rate of over 100 mm per year within the first 6 years (Eklund and Sadovy, 1999), and this was confirmed by recordings of video footage in the lab. They are assumed to have a maximum weight near 320 kg (Smith, 1971), though some estimate up to 455 kg (Robins et al., 1986).

Along coastlines, large adults of the species are generally found on ledges with high relief, deep crevices, holes, or wrecks; places that provide shelter (Nagelkerken, 1981; Smith, 1976). Juveniles, generally less than 6 years old and smaller than 100 cm, are found in shallow bays, estuaries, or invading tidal streams (Odum et al., 1971). They have been collected from inshore, shallow water, 2 to 3 meter deep habitats such as mangroves swamps, bridges, and poorly oxygenated canals (Springer and Woodburn, 1960; Lindall et al., 1975; Thompson and Munroe, 1978; Bullock and Smith, 1991). Mangrove habitats afford shelter from predators, increase availability of prey, and offer shading. Loss of these environments by human pollution is thought to directly impact grouper populations (NMFS, 2006). Adult goliath groupers can be solitary or found in groups of up to 100 specimens (Eklund and Sadovy, 1999). Large adults are relatively sedentary and rarely move between reefs once they establish their territory (NMFS, 2006;

Smith, 1976). Little is known about the spawning or larvae stage of these groupers (Eklund and Sadovy, 1999).

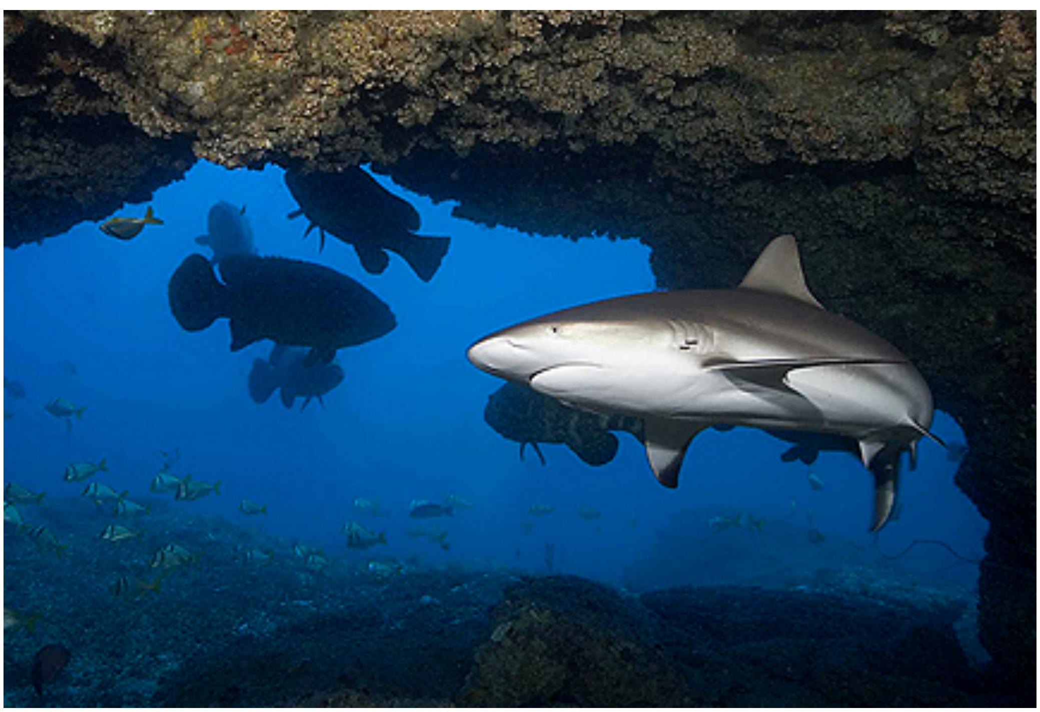
Goliath groupers are able to accelerate from a still position with explosive speed in order to feed (Bullock and Smith, 1991). As such, they are classified as ram feeders that use ambush tactics. Adults typically prey on fish, juvenile turtles, small sharks, squid, and sting rays but they have also been known to eat crustaceans such as lobsters, crabs, etc. Juveniles prey on shrimp, crab, and sea catfish (Longley and Hildebrand, 1941; Randall, 1983; Bullock and Smith, 1991). Their lack of large canine teeth reflects a diet of mainly crustaceans (Eklund and Sadovy, 1999).

Figure 1: Goliath groupers show no fear towards humans. (Photograph by Robin Tackett- http://www.rnrscuba.net/Wreckdiving.html)

One reason for their susceptibility to fishing is their lack of fear. Large goliaths have been known to closely approach divers (Zinkowski, 1971) thus making them susceptible to spearfishing. As a result of their unwary nature, and intensive fishing of goliath aggregation sites, their populations faced severe decline starting in the 1950's (Eklund and Sadovy, 1999). By 1990, they were granted protection from harvesting in US waters and in the Caribbean since 1993 (NMFS, 2006).

Mortality for juveniles and small adults is the result of natural predators such as sharks, moray eels, barracudas, and other grouper species (Eklund and Sadovy, 1999). Large goliath specimen do not have any natural predators (other than humans) and are often top level predators on reefs or their native habitat.

Figure 2: Sharks shown with goliath groupers in the background. Adult goliaths have no natural predators.



Scaling and Kinematics

Goliath groupers grow and develop from a 3 millimeter larvae to adults that can obtain lengths of nearly 3 meters. From an evolutionary and ecological standpoint, body size is one of the most important characteristics of an organism. Studies of scaling in organisms analyze the structural and functional results of changes in size through development (Richard and Wainwright, 1994).

Figure 3: Kite-shaped *Epinephelus* larvae

(courtesy National Marine Fisheries Service)

The developmental impact of changes in body mass of organisms has been the subject of numerous prior studies, in relation to metabolism (Clarke and Johnston, 1999), mitochondrial enzyme activity (Pelletier et al., 1993), and oxygen uptake (Zeuthen, 1953). Body size also is important when considering an animal's ability to function within its environment (Richard and Wainwright, 1994).

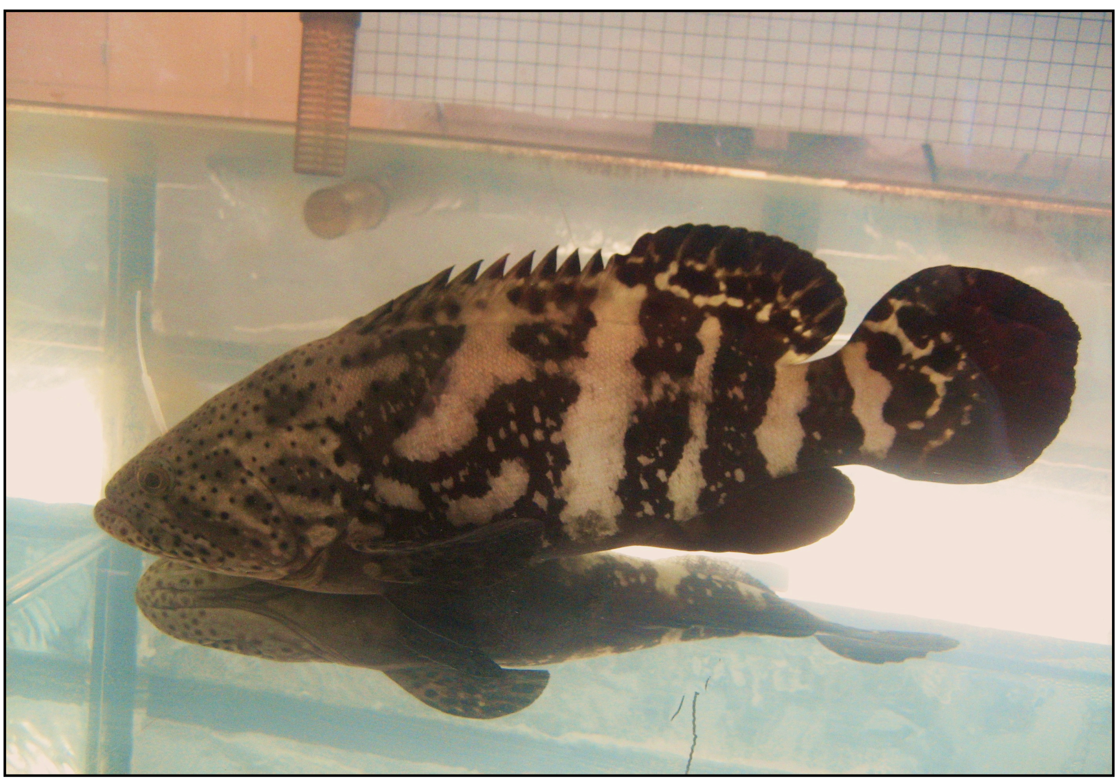
Analysis of the kinematics of an organism includes variables such as velocities and accelerations, timing of movements of the organism or parts of the organism, and measurements of displacement (Richard and Wainwright, 1993). The measurement and comparison of kinematics can detect if an organism displays scaling of feeding performance throughout its ontogeny.

Materials and Methods

Experimental Set Up

The juvenile grouper used in this study was housed in the WKU Functional Morphology Laboratory in a 170 liter saltwater aquarium. The water was regularly changed and maintained. Temperature in the lab was maintained at constant 20 degrees Celsius. A piece of paper with 50 by 26, 1-cm squares was taped to the back of the aquarium to serve as a scale during video footages. A mirrored piece of glass was placed diagonally at a 45 degree angle in the bottom of the aquarium to provide a ventral view of the grouper during feeding footages.

Figure 4: Juvenile Goliath Grouper Used for Data Collection



The set up for filming involved two 250-watt Lowell Pro light sources which illuminated the tank and prevented shadows. Video was recorded using a Redlake MotionPro high-speed digital video camera at 500 frames per second. Videos were analyzed using the MiDAS software program.

The grouper was fed regularly using small, peeled, cooked shrimp. Prior to initial video shooting sequences, the high- powered lights were turned directly onto the aquarium during all regular feedings to ensure the grouper's desensitization to the light sources.

Common goldfish were used as prey items to encourage enthusiastic feeding behaviors. These fish generally ranged from 2 to 5 centimeters in length. Coloration of the goldfish made no apparent difference in feeding behaviors. During video feeding, goldfish were attached to a wire hook at the end of a long, thin glass probe. The probe with attached goldfish could be moved throughout the tank to encourage feeding at angles most beneficial for data collection.

Forty-one individual video sequences were recorded over a 15 month period. The best videos were used; those that showed a clear lateral view of the grouper while feeding, with no severe twisting or rotation of the fish's head or body. This ensured that accurate measurements could be made.

Analysis

Measurements obtained from the MiDAS program included: time to maximum gape, time to maximum hyoid depression, time to maximum cranial elevation, maximum gape distance, hyoid depression distance, and total time of the gape cycle. All distance

measurements were recorded in centimeters, and all timings were recorded in seconds. To ensure consistency, each video was set at a zero point defined as the moment right before jaw opening began for the feeding cycle. The maximum gape was the frame in the footage in which there was no more visible increase in the width of the fish's jaw expansion around the goldfish. Maximum hyoid depression was the frame in the footage in which the hyoid bone reached the farthest depressed point visible. Maximum cranial elevation was the frame in which no more upward movement of the head relative to the body could be observed. Gape cycle was measured from the zero point to the exact moment the jaws closed after feeding. The centimeter grid placed on the back of the tank served as a reference for the program to calculate the length of the fish, maximum distance of the fish's gape, and distance the hyoid depressed during feeding relative to its relaxed state.

Hyoid depression is measured in this study because it is an indication of the extent of buccal expansion while feeding. Increase in cranial elevation contributes to increasing mouth gape while feeding (Richard and Wainwright, 1994). Gape distance is important for determining the size of prey that can be consumed. Analyses of these factors are essential in determining the kinematics of feeding in fishes. These measurements, coupled with timings, are used to determine the extent of scaling, if any, found in a species during its ontogeny.

All data was recorded into an Excel spreadsheet. The 41 video footages were gathered from numerous dates spanning the 15 month period. To obtain a comparison of how these measurements changed in the juvenile, averages were calculated for dates that were within one month of each other and that were at least two months different from

other video footages. This yielded four distinct data sets for each variable, each one organized according to total body length of the fish which gradually increased during the duration of the experiment.

Results

Data analysis compared measurements from the juvenile grouper to those obtained from five different groupers of varying sizes out in the wild using the same high resolution, 500 frames per second camera. These videos were recorded by Dr. Steve Huskey, Dr. Andrew Rhyne, and Dr. Nicolai Konow, and were then analyzed by Maria Hougland and Emily Gilson at WKU.

Figure 5: Still- frame shot from video footage obtained of feeding of wild goliath groupers

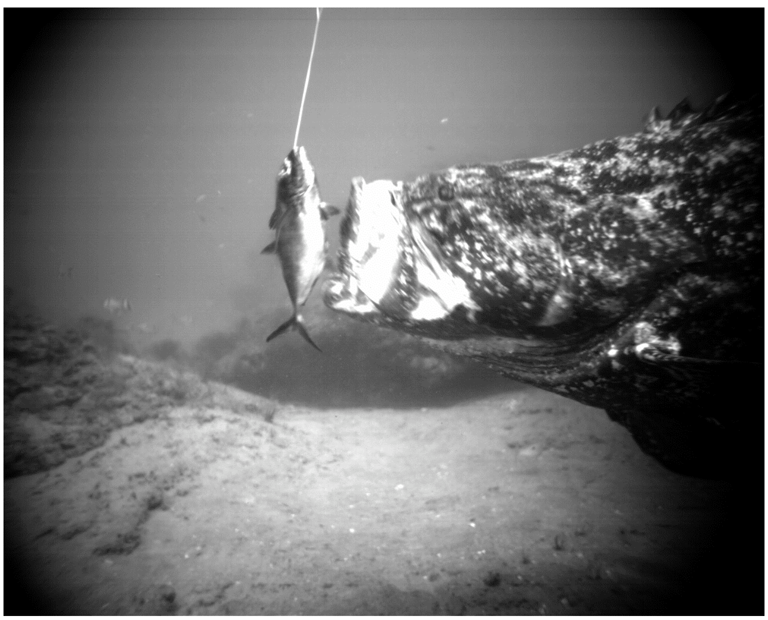


Table 1 lists the factors used for comparison and the scaling analysis of the goliath grouper. Table 2 summarizes average values for both juveniles and adults. This table shows that the timing measurements were very close between the two. Graphs 1, 2, and 3 were made by plotting the data points for each of the different adult goliaths versus those obtained from the juvenile as it grew over the course of 15 months.

Table 1: Summary of Data Averages Spanning Several Grouper Body Lengths

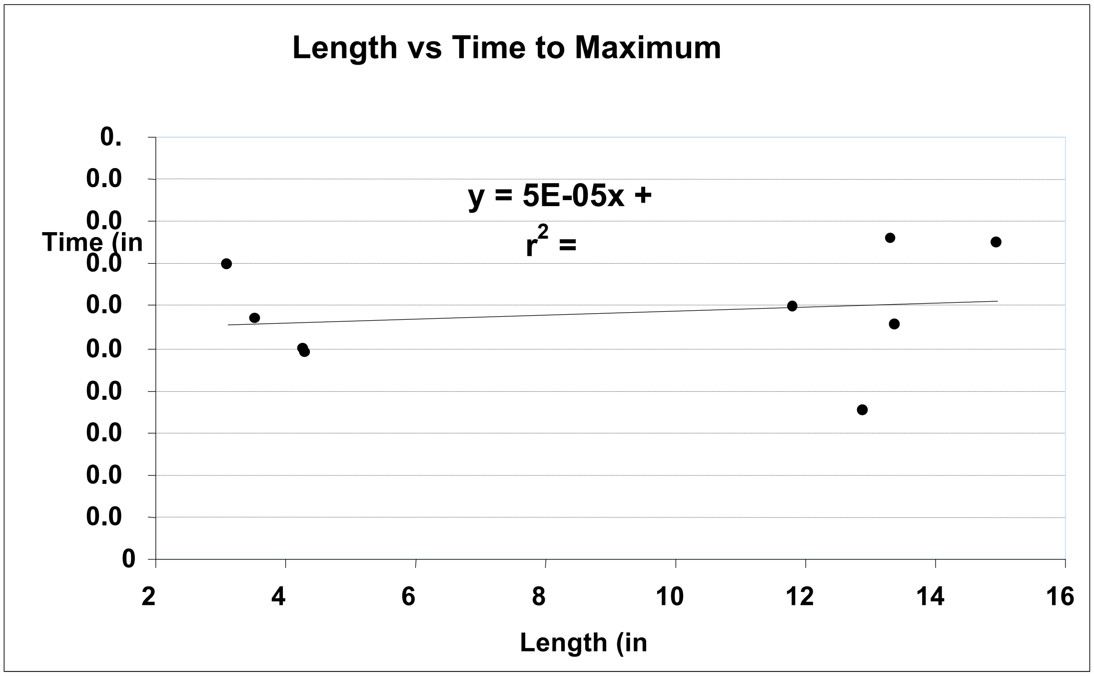
Length (cm)	Avg. Max. Gape (cm)	Time to Max. Gape (seconds)	Hyoid Depression (cm)	Time to Hyoid Depression (s)	Time to Max. Cranial Elevation (s)	Gape Cycle (s)
31.1	4.722	0.0697	1.97	0.0677	0.0777	0.155
35.43	5.383	0.0567	3.555	0.064	0.0615	0.141
42.9	6.397	0.05	4.193	0.049	0.0515	0.127
43.13	5.412	0.0487	3.345	0.0563	0.0533	0.115
118.22	20.448	0.0597	7.274	0.0652	n/a	
128.94	16.105	0.035	5.955	0.042	n/a	
133.38	19.705	0.0756	n/a	0.0763	0.07	
133.95	18.996	0.0555	8.441	0.0716	0.0676	
149.51	20.39	0.075	10.054	0.086	0.07	

Table 2: Juveniles vs. Adults Table of Averages

	Length (cm)	Avg. Max. Gape (cm)	Time to Max. Gape (seconds)	Hyoid Depression (cm)	Time to Hyoid Depression (s)	Time to Max. Cranial Elevation (s)
Juvenile	**38.22**	5.471	0.0563	3.266	0.0593	0.0608
Adult	**132.8**	19.063	0.0598	7.924	0.0682	0.0692

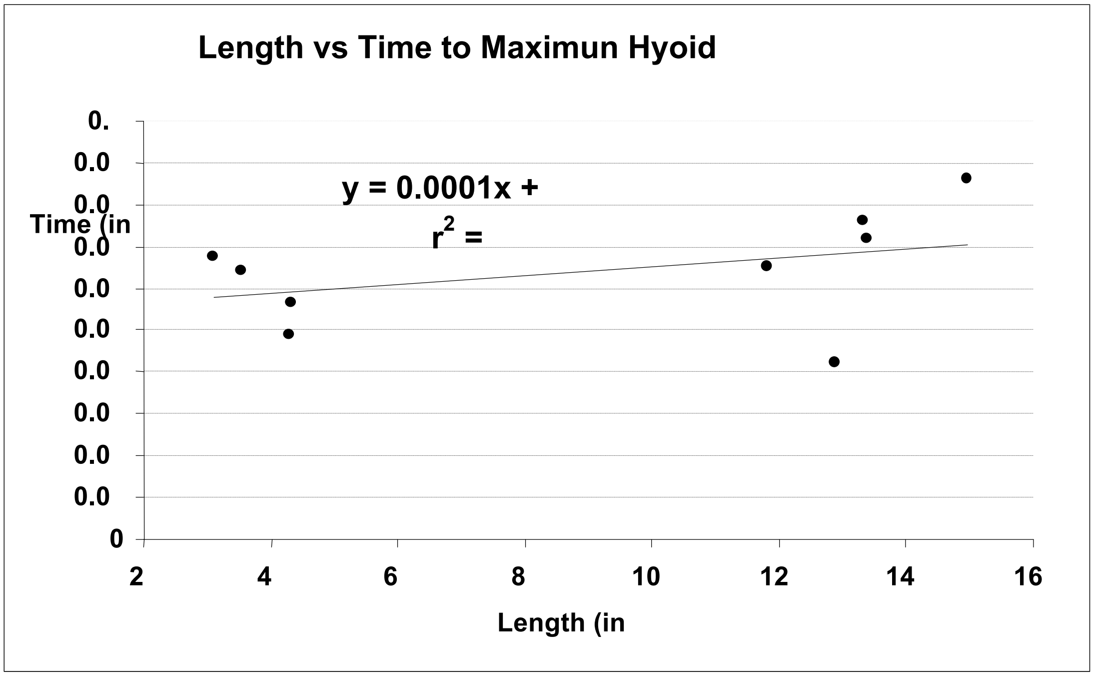
To determine if these differences were significant enough to indicate scaling patterns, graphs were plotted for each of these variables and a regression line was obtained.

Graph 1: Comparison of body length to time taken to achieve maximum gape



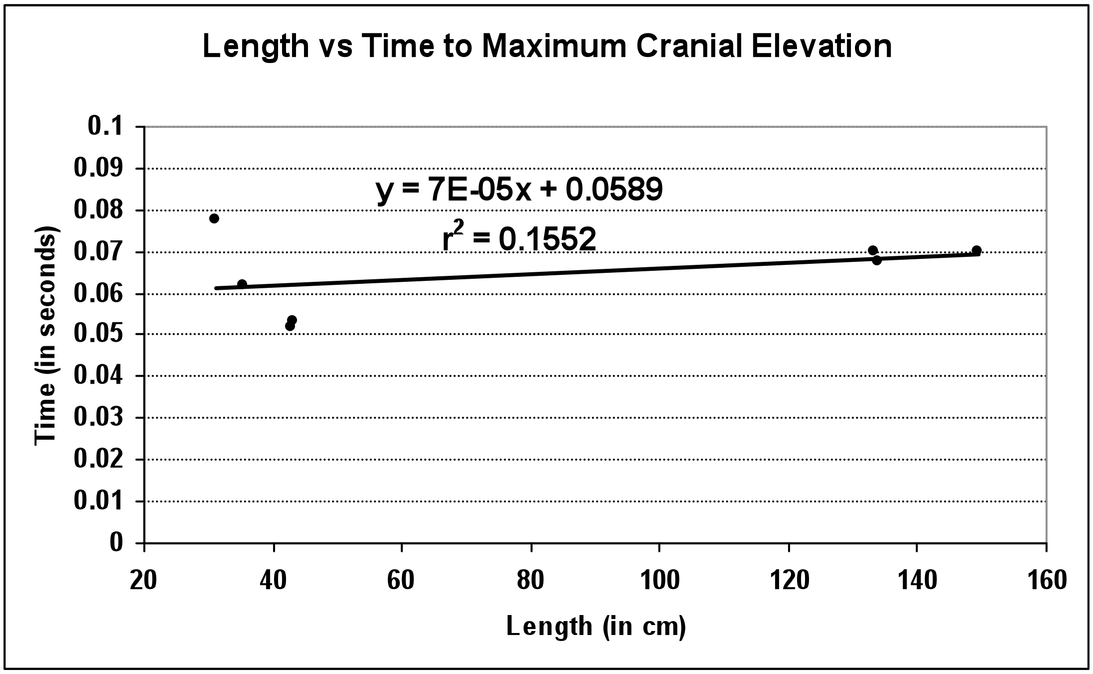
A slope of 1 would indicate a perfectly linear relationship of timing variables to body length, thus indicating a clear pattern of scaling of kinematics. A slope of 0 would indicate no scaling of kinematics. The obtained slope of 5.0×10^{-5} indicates that there is no pattern of scaling for the time it takes to attain maximum gape between juveniles and adults.

Graph 2: Comparison of body length to time taken to achieve maximum hyoid depression



For body length versus time taken to achieve maximum hyoid depression, the slope was found to be 1.0×10^{-4} indicating that there is no significant pattern of scaling between juveniles and adults.

Graph 3: Comparison of body length to time taken to achieve maximum cranial elevation



For a comparison of body length to time taken to achieve maximum cranial elevation, the slope was found to be 7.0×10^{-7} indicating that there is no significant pattern of scaling between juveniles and adults.

Despite the fact that adult goliath groupers have a larger gape, heavier bone structure, and a greater amount of water to displace during feeding, one must conclude that they develop, throughout their ontogeny, the cranial and jaw musculature to allow them to maintain the speed and force required for effective suction feeding speeds. Due to the threatened status of the species, harvesting these fish is illegal and the availability of goliath carcasses for scientific research is limited. To accurately study the relationship between bone structure and muscle mass would require several specimens spanning an extensive collection of body sizes for comparison, which was not possible for this study.

Discussion

Fish typically change their feeding habits as they grow; types of prey consumed, feeding kinematics used, or their habitats (Wainwright et al., 2006). Data suggests that the goliath grouper is an exception to this, despite the fact that it changes feeding and ecological niches as it grows from a juvenile to an adult. Wainwright and Richard (1994) found that largemouth bass undergo kinematic scaling as they grow from juveniles to adults with a mean slope of 0.343. The larger they grow, the longer it takes for them to open and close their mouths during feeding. This fits their ecology. Largemouth bass change their feeding strategy from suction feeders as juveniles, using suction pressure to pluck small insects and fish from underwater foliage, to adult ram feeders, who rely on speed and momentum to chase their prey while suction plays a lesser role (for review, see Huskey and Turingan 2001).

Wainwright and Richard (1994) suggest one might expect a larger fish to have slower movements based solely on body size differences. It seems apparent from the study of goliath groupers that a fish's ecological niche and ontogeny must also play a role. To explain the results of this study, they must maximize their feeding efforts at all stages of their ontogeny. For goliath groupers, they remain ram feeders that rely heavily on suction feeding for the duration of their life cycle, switching from predation on shrimp and small crabs as juveniles in estuaries, to adults that feed on spiny-shelled lobsters and anything that happens to pass too close to their mouths (NMFS, 2006). As goliaths grow, so does the size of their prey. Their ability to maintain the same rates of buccal expansion during feeding (indicated by the near-zero slopes obtained for the three comparative

measures) for all, certainly gives them an evolutionary advantage towards being top-level predators in their natural habitats. Organisms that are capable of capturing and consuming a large variety of prey items have a distinct advantage over those who are specialized to only one or two. By maximizing feeding kinematics and maintaining explosive feeding speeds and suction power at all stages of their ontogeny, adult goliath groupers have the capabilities to prey on invertebrates such as spiny lobsters, shrimp, crabs, stingrays, hard-headed catfish, various fish species, octopus, gastropods, as well as juvenile sea turtles and sharks (NMFS, 2006).

The implications of the goliath grouper as being a top-level predator that is rebounding from its endangered status is yet unknown. Their territoriality and sedentary nature undoubtedly impacts small fish and invertebrate population densities on coral reefs (Eklund and Sadovy, 1999). The following is quoted from the January 2006 National Marine Fisheries Service Status Report on the continental United States distinct population segment for the goliath grouper, *Epinephelus itajara*:

> "The loss of the goliath grouper, a high trophic level predator within marine communities, would represent a direct loss of species diversity and could potentially present significant, yet unforeseeable, ecological ramifications (e.g. changes within existing predator-prey relationships)".

While the goliath is thus-far a success-story of environmental protection, it is important for future research to attempt to establish the ecological ramifications of the

population rebound, and whether or not they could survive the reinstating of commercial or individual fishing.

The next step for the current project includes suction pressure data collection by means of an implanted cannula in the juvenile grouper. This cannula can be connected to a catheter transducer in order to measure changes in pressure within the buccal cavity during feeding. Such a procedure is delicate however, and places significant stress on the fish since it must be caught and briefly removed from the tank in order to place the pressure transducer within the cannula. After such stress, the grouper thus far has not performed in order to collect data. Methods are still being devised to more efficiently carry out this process.

In the event that another live juvenile goliath grouper specimen could be obtained, further measurements and data collection could be used to verify the accuracy of the results presented.

References

Bullock, L. H., and Smith, G. B. 1991. Seabasses (Pisces: Serranidae). Memoirs of the Hourglass Cruises. Florida Marine Research Institute Department of Natural Resources. St. Petersburg, FL.

Bullock, L. H., Murphy, M. D., Godcharles, M. F., and Mitchell, M. E. 1992. Age, growth, and reproduction of jewfish *Epinephelus itajara* in the eastern Gulf of Mexico. Fishery Bulletin. 90: 243-249.

Clarke, A. and Johnston, N.M. Scaling of Metabolic Rate with Body Mass and Temperature in Teleost Fish. 1999. Journal of Animal Ecology. 68: 893-905.

Huskey, S. H. and Turingan, R. G. 2001. Variation in prey-resource utilization and oral jaw gape between two populations of largemouth bass, *Micropterus salmoides*. Environmental Biology of Fishes. 61: 185-194.

Longley, W.H., and Hildebrand, S.F. 1941. Systematic catalog of the fishes of Tortugas, Florida, with observations on color, habits, and local distribution. Papers Tortugas Lab.

Nagelkerken, W.P. Distribution and ecology of the groupers (Serranidae) and snappers (Lutjanidae) of the Netherlands Antilles. 1981. Foundation Scientific Research Surinam and the Netherland Antilles. 107.

NMFS. 2006. Status report on the continental United States distinct population segment if the goliath grouper (*Epinephelus itajara)*. January 12, 2006. 49 pp.

Odum, W.E. 1971. Pathways of energy flow in a southern Florida estuary. University of Miami Sea Grant Program. Sea Grant Technical Buletin.

Pelletier, D., Guderly, H., and Dutil, J.-D. 1993. Does the aerobic capacity of fish muscle change with growth rates? Fish Physiology and Biochemistry. 12(2).

Porch, C. E., Eklund, A.-M., and Scott, G. P. 2003. An assessment of rebuilding times for goliath grouper. Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149.

Porch, C. E., and Eklund, A.-M. 2003. Standardized visual counts of goliath grouper off South Florida and their possible use as indices of abundance. Sustainable Fisheries Division Contribution SFD-0017. Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149.

Richard, B. A., and Wainwright, P. C. 1994. Scaling the feeding mechanisms of largemouth bass (*Micropterus salmoides)*: kinematics of prey capture. The Journal of Experimental Biology. 198:419-433.

Sadovy, Y. and Eklund, A,-M., 1999. Synopsis of Biological Data on the Nassau Grouper, *Epinephelus striatus* (Bloch, 1792), and the Jewfish, *E. itajara* (Lichtenstein, 1822). NOAA Technical Report NMFS 146. U.S. Department of Commerce. Seattle, Washington.

Springer, V.G., and Woodburn, K.D. 1960. An ecological study of the fishes of the Tampa Bay area. Florida Board of Conservation Marine Lab. Professional Paper Series.

Wassenberg, S.V., Aerts, P., and Herrel, A. 2005. Scaling of suction feeding performance in the catfish *Clarias gariepinus*. Physiological and Biochemical Zoology. 79(1): 43-56.

Weaver, D. C. 2001. Feeding ecology and functional morphology of western Atlantic groupers (Serranidae: Epinephelinae). United States Geological Survey. Gainesville, FL.

Zeuthen, E. 1953. Oxygen uptake as related to body size in organisms. The Quarterly Review of Biology 28: 1-12.