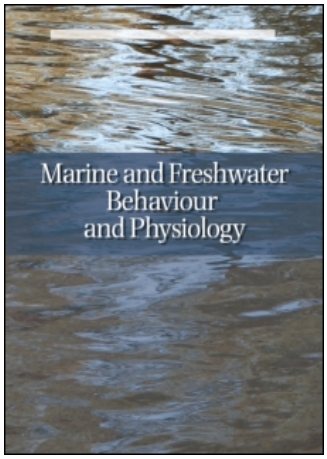

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Short Communication

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Short Communication

BEHAVIOR, OXYGEN CONSUMPTION AND SURVIVAL OF STRESSED JUVENILE SAILFISH (*ISTIOPHORUS PLATYPTERUS*) IN CAPTIVITY

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The sailfish (*Istiophorus platypterus*) is one of the four billfish species (Family Istiophoridae) that inhabit the pelagic, subtropical waters of the western Atlantic Ocean (Robins and Ray, 1986). The western Atlantic sailfish stock supports multi-million dollar recreational fisheries, but is depleted mostly as bycatch in the commercial tuna and swordfish longline fisheries (NMFS, 1999). Despite its economic value, many fundamental questions surrounding the biology of the sailfish remain unresolved. To our knowledge, there are no physiological data on the larval and juvenile stages of this species in the scientific literature. This is mainly because these stages are rarely encountered, difficult to capture uninjured and pose numerous challenges to researchers interested in maintaining them alive under laboratory conditions.

Recently, Post *et al.* (1997) held live sailfish larvae in the laboratory, albeit briefly. Using plankton nets in the Straits of Florida (SOF), USA, they collected larvae averaging 5.1 mm total length (TL) and maintained seven alive in aquaria for 48 h. Typical behavior of captive sailfish larvae was rapid, sustained swimming against the bottom and sides of their holding containers until exhaustion, and eventually, death. Although one larva was induced to feed on *Artemia*, none survived beyond 72 h. The goal of the present study was to gain insight into the behavior, physiology and survivorship of juvenile (i.e., >35 mm TL) sailfish in captivity as a step toward filling long-standing gaps in our knowledge of early growth, development and swimming capability of istiophorid fishes. A primary objective was to measure

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oxygen consumption of juvenile sailfish in relation to water temperature. In the process, we also obtained qualitative observations of juvenile sailfish behavior in captivity and examined relationships between fish size and time of survival in the laboratory.

Sampling for juvenile sailfish was conducted at night within a 40 km radius of Miami, Florida, from a 20.4 m research vessel from 27 June to 1 July 1998. Prior to fish collection, the vessel's main engines were switched off and the ship drifted (north) in the SOF with minimum lights required for safety. Two to four collectors assembled on the fantail of the vessel; a "night-light" and long-handled (3 m) dip-nets were used to attract and capture fish. The night-light consisted of a single, 100-W incandescent bulb within a clear, waterproof housing, which was lowered using the ship's A-frame about 2 m off the stern and to a depth of about 1 m. The light served to rapidly attract numerous species of fish and invertebrates within dip-net range.

Each suspected juvenile sailfish captured was rapidly transferred into a 50 L cooler filled with surface water from the capture location. If visually identified as a sailfish, time of capture was recorded and the individual was transferred (using small, plastic-bottomed dip-nets) into clear, round, 19 L plastic containers. The containers were equipped with air stones and were housed in pairs within 200 L coolers that served as water baths. Various potential food organisms (i.e., live pelagic copepods and unidentified fish larvae) were introduced into the containers; these were collected by making diurnal plankton net tows (0.333 mm mesh) before and after billfish were captured. Billfish were kept in darkness through the following morning when they were transported via small boat to the laboratory. Also transported to the laboratory was a 400 L supply of aerated surface water and potential food organisms collected from the same general area that individuals were captured.

Fish respiration was measured in the laboratory with a Strathkelvin Instruments^{TM} 928 system consisting of two microelectrodes, two 0.7 L experimental chambers and an interface that allowed communication between each electrode and a laptop computer. Throughout the experiments, one of the electrode-chamber combinations was used as a control blank. Upon arrival at the laboratory, fish were acclimated to desired water temperatures for 2 h by placing their containers into a circulating water bath (Forma Scientific^{TM}, model 2095). This system kept the chamber water within 0.2°C of experimental temperatures. After acclimation, each fish was gently transferred to its experimental chamber, which was then sealed for respiration measurements over 10 to 15 min periods. Each fish was exposed to either two or three of six different water temperatures (i.e., 23, 24, 26, 27, 28, and 29°C); temperature change from one trial to the next was 1.0 ± 0.2°C. Respiration rate estimates were expressed in units of mL O_2 per g (dry weight) per h where dry weight was assumed to be 20% of wet weight. One of two apparent stress levels was assigned to each respiration estimate based on fish behavior within the chamber: fish that consistently swam (i.e., pushed) against the chamber were characterized as under "low stress"; those that moved erratically (i.e., thrashed) about the chamber were characterized as under "high stress".

After oxygen measurements were made, fish were transferred back to their respective 19 L containers with live food organisms and their behavior and survival monitored thereafter until their death. Total length (mm TL) and wet weight (mg wwt) measurements were made within an hour of their mortality. Collected fish not used in the

TABLE I Juvenile sailfish (*Istiophorus platypterus*) respiration rates at temperature in comparison to those of other species reported in the literature. Asterisks indicate values on "highly stressed" individuals (see text for details)

Species	*Weight* (mg)	QO_2 (mL O_2 g^{-1} h^{-1}) *at Temperature* (°C)									
		18	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*Reference*
Istiophorus platypterus	199			3.19	3.92						Present study
Istiophorus platypterus	251							3.00	6.96	11.00	Present study
Istiophorus platypterus	238			33.01*	14.21*						Present study
Istiophorus platypterus	121						14.53*	10.12	9.99		Present study
Coryphaena hippurus	1.075						11.34				Benetti, 1992
Coryphaena hippurus	4230–43700						1.01				Benetti, 1992
Coryphaena hippurus	20 000–40 000					0.6					Morgan *et al.*, 1996
Scomber japonicus	0.06	6.11	11.41								Hunter and Kimbrell, 1980
Sciaenops ocellatus	60,000–76,600							0.195			Serafy *et al.*, 1995

respiration experiments were similarly acclimated to laboratory water temperatures, provided potential food items and also observed until their mortality. To examine relationships between survivorship and fish size, times that fish survived in captivity were plotted and regressed against fish length and weight. Further confirmation of species identity was conducted postmortem. Because the white marlin (*Tetrapturus albidus*) is very similar in appearance to the sailfish as juveniles (de Sylva, 1963), the identities of a subset (i.e., seven) of collected juveniles were tested molecularly. A small piece of muscle was cut from the caudal peduncle of each fish for high molecular weight DNA extraction. A single copy anonymous nuclear gene (MN32-2) was amplified and subsequently digested by the restriction endonucleases *DraI* and *DdeI*, which yielded species-specific restriction fragment patterns, as described for positively identified adult tissues by McDowell and Graves (2002).

A total of 13 juvenile sailfish were captured between 2100 and 2350 h on the nights of June 27, June 30, and July 1, 1998. Captured fish measured from 39.3 to 130.5 mm TL and weighed from 65 to 1474 mg wwt. Surface water temperatures ranged from 28.9 to 31.0°C, salinity from 36.0 to 36.1 psu and dissolved oxygen levels from 5.8 to 6.2 mg L^{-1}. All fish were transported ashore and monitored alive in the laboratory for periods ranging from 12 to 110 h. Oxygen consumption measurements were obtained on four individuals, which together yielded three "high stress" and seven "low stress" respiration measurements (Table I). All juveniles molecularly tested were confirmed to be sailfish.

Immediately upon collection and thereafter, juvenile sailfish displayed essentially the same behavior in captivity as was previously described for larval sailfish (Post *et al.*, 1997). Specifically, immediately upon collection and when held at temperatures ≥ 26°C, all captive juveniles pushed bill-first against the bottom of their holding containers until eventual death. However, two individuals, upon exposure to our lowest experimental temperatures (i.e., 23 and 24°C), changed their orientation and pushed upwards against the top of their chamber. Eliminating, or at least minimizing, these reactions to confinement appears to be the first step toward holding young sailfish alive long enough to obtain useful physiological data that can be applied to fish in their natural environment. This includes experiments that aim to determine otolith increment

deposition rate via staining. On the other hand, the sustained, directional (i.e., upward or downward) swimming behavior might represent an opportunity to gain insight into locomotory strength and endurance following Stobutzki and Bellwood (1997). This might be approached by immediately placing field-caught larvae and juveniles in a swimming respirometer in which water flow is directed (and speed controlled) vertically. Experimentation also seems warranted with a fish holding container that is several meters deep and that maintains from bottom to top, low to high gradients of temperature and light. Unfortunately, the greater the container's volume, the more difficult it becomes to observe the fish in question.

Neither feeding nor any attempt to do so was observed in juveniles and this remains the ultimate barrier to holding young istiophorids for extended periods of time. Solving this problem requires that appropriate food items are identified, acquired and provided in sufficient quantities soon after sailfish capture. Insight into the identity of sailfish prey (and thus food while in captivity) might be gained by collecting plankton concurrently with nightlight operations, but this tends to be impractical from drifting vessels and might interfere with sailfish collection itself. In our experience, the convergence of juvenile istiophorids, calm weather conditions (for efficient nightlighting) and being prepared with an (apparently) appropriate quantity and quality of food was very difficult to "orchestrate". The laboratory culture of pelagic copepods and larval flyingfishes (Exocoetidae) is planned, but these no doubt will present serious maintenance and timing challenges from one sailfish encounter to the next. Again, even if sailfish, favorable weather and appropriate food coincide, it is unrealistic to expect the induction of feeding behavior in animals that appear to be devoting virtually all of their energy to escape. For this reason, at least in the short term, performing swimming respirometry seems to be the most practical pursuit for gaining realistic insight into young sailfish behavior and physiology in the wild.

Respiration rates measured on the specimens collected in this study are considered to represent active metabolism since the fish were in continuous motion, although swimming velocity was not specifically measured. For comparative purposes, measurements are presented as weight-specific respiration rates (QO_2: mL O_2 g dry weight^{-1} h^{-1}). The QO_2 values obtained for juvenile sailfish are within the range of measurements found in the literature for other pelagic fishes [larval *Scomber japonicus*: Hunter and Kimbrell (1980); larval and juvenile *Coryphaena hippurus*: Benetti (1992); Table I]. Measurements on larger juveniles of other species are a magnitude less – a difference that can be attributed to the effect of weight on metabolic rates [e.g., juvenile *Sciaenops ocellatus*: Serafy *et al*. (1995); juvenile *C. hippurus*: Morgan *et al*. (1996); Table I].

Temperature appears to have an effect on the rate of metabolism in juvenile sailfish (Fig. 1), although the degree of temperature-dependence cannot be accurately defined due to small sample size. In developing the temperature-dependent respiration rate for juvenile sailfish, we excluded measurements on highly stressed individuals following Brett (1964). The slope of the temperature-dependent regression is higher (1.18) than extrapolated regressions developed by Houde and Zastrow (1993), recognizing the latter were made at much lower temperature ranges. From these regressions, the highest slope belonged to larval Gadiformes (0.8), with generally higher QO_2 values than those measured for juvenile sailfish (Fig. 1).

Metabolic Q_{10} values for sailfish were greater than those for marine larval fishes (4.7 and 1.3, respectively). The Q_{10} values estimated during this study indicate respiratory

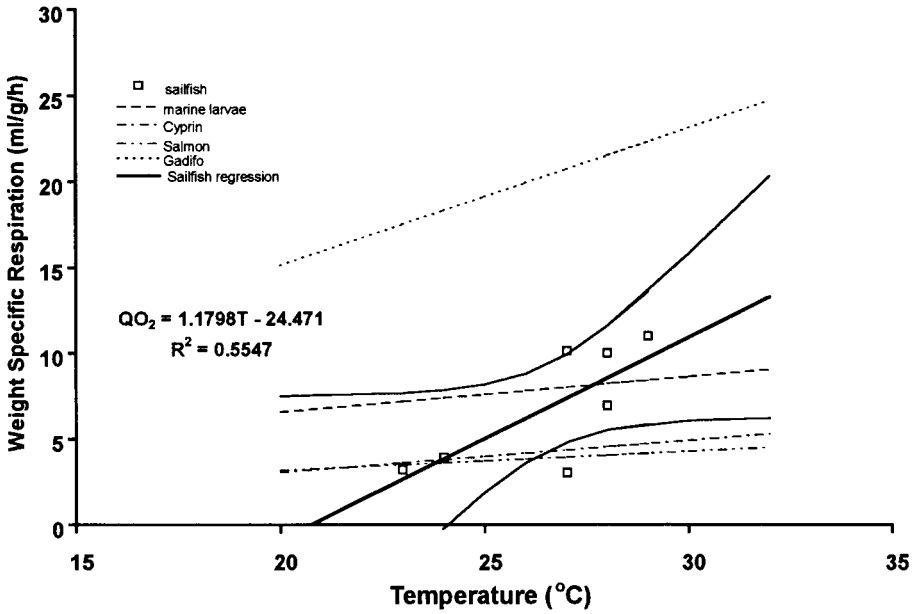

FIGURE 1 Weight specific respiration rate *versus* temperature for juvenile *Istiophorus platypterus*. Open squares indicate individual measurements, solid line is the regression developed from measurements made in this study plus 95% confidence intervals (two thin solid lines), other regressions are from Houde and Zastrow (1993).

sensitivity to temperature, whereas the data compiled by Houde and Zastrow (1993) indicated a compensatory response. However, it is difficult to attribute the pattern observed completely to temperature-dependent respiration because of our small sample size, narrow temperature range, and the problem of stress-related behavior noted in these experimental fish. Captive individuals may have been attempting to compensate for temperature differences by seeking more optimal temperature in the water column, as indicated by their vertical orientation at different temperatures.

Fish survival was positively correlated with fish length (Fig. 2(A)) and weight (Fig. 2(B)). Since no fish were observed to feed in captivity, this likely reflects size-related differences in energy reserves as modified by precapture nutritional status (i.e., when they last fed), injury during netting, and the many other stresses associated with confinement. From our survivorship data, there was no indication that respiration measurement itself (i.e., additional handling) reduced time in captivity (Fig. 2), but this issue deserves close attention in future studies.

Based on our results and comparisons with other species, we tentatively conclude that juvenile sailfish have inherently high metabolic rates, which rapidly deplete their energy reserves and ultimately lead to death by starvation. To prolong time in captivity, metabolic activity must be reduced and feeding must occur as soon after capture as possible. Given that stressed juvenile sailfish appear temperature-sensitive, the reduction of water temperature (Hunter and Kimbrell, 1980) and/or salinity (Morgan *et al.*, 1996) may increase survival to a point where the acceptability and nutritive value of various food items can be quantitatively tested. In the meantime, however, swimming respirometry experiments are recommended.

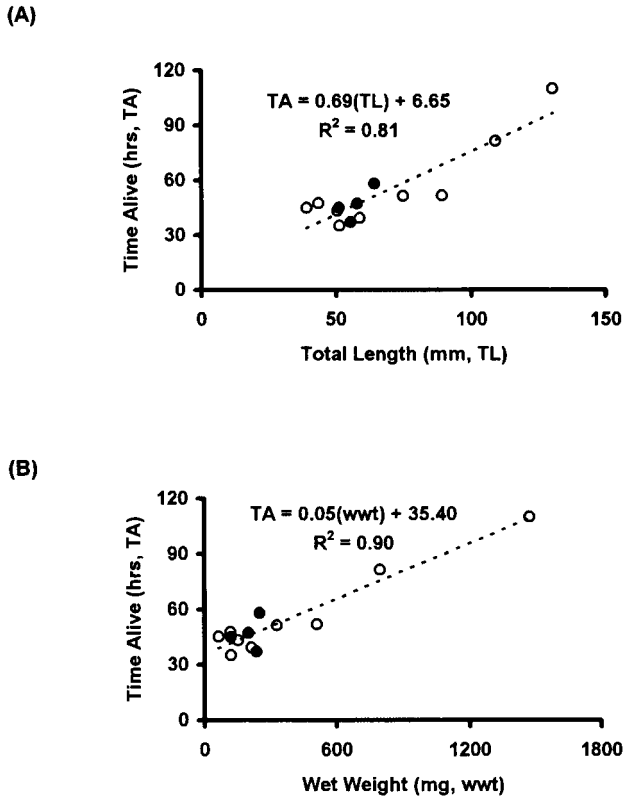

FIGURE 2 Survivorship of juvenile *Istiophorus platypterus* collected in this study *versus* (A) total length and (B) wet weight. Solid circles indicate individuals used in the oxygen consumption experiments; open circles correspond to individuals from which no respiration measurements were obtained.

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