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Habitat utilization of blackfin tuna, *Thunnus atlanticus*, in the north-central Gulf of Mexico

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Abstract Short-duration (9.5–, 18-, and 28.5-day) deployments of pop-up satellite archival tags (PSATs) on blackfin tuna, *Thunnus atlanticus* Lesson 1831, were used to evaluate the applicability of external electronic tags on small tunas. Ten tunas (71.1-86.4 cm FL) were tagged in the northern Gulf of Mexico in April 2012 after being caught on typical recreational fishing gear. PSATs recorded point measurements of temperature, pressure (depth), and light level every 90 s (n=2 tags, deployment duration 9.5 days), 180 s (n=4, duration 19 days), or 270 s (n=4, duration 28.5 days). Nine fish survived for their respective full deployment periods; one fish died after only 5 h following release. Depths ranged from 0–217 m with a mean of 28 m (SD=8.38 m) and temperatures ranged from 13.9–32.9 °C with a mean of 23.8 °C (SD=1.3 °C) for all nine archived records. The nine blackfin spent 90 % of their time in depths from 0–57 m and 89 % of their time in temperatures from 21.9–26.6 °C. Over 87 % of the movements in the water column, either ascending or descending, were less than 12 m differences in depth between sequential short-duration data sampling. With appropriate concern regarding the matching of fish and PSAT sizes, these results suggest that external tags with fishery-independent reporting capabilities are an available option for smaller tuna species.

Keywords Satellite tagging · Blackfin · Tuna · Gulf of Mexico · Habitat preferences

Introduction

Blackfin tuna, *Thunnus atlanticus* Lesson, 1831, is a relatively small species that frequently schools with skipjack tuna, *Katsuwonus pelamis* Kishinouye, 1915, yellowfin tuna, *Thunnus albacares* Bonnaterre, 1788, and little tunny, *Euthynnus alleteratus* Rafinesque, 1810 (Taquet et al. 2000), resulting in fisheries interactions throughout their Western Atlantic range. Blackfin, along with the other small tunas, are a main source of food and are highly important to many commercial and recreational fisheries in Cuba (Rawlings 1953), the French West Indies (Taquet et al. 2000), Bermuda (Luckhurst et al. 2001), and Brazil (Freire et al. 2005). The species is only of minor importance to U.S. commercial pelagic longline fisheries and catches are generally not retained due to their low market value, but

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blackfin is a common target species for the recreational rod-and-reel fishery.

The species also is the smallest of the eight tunas in its genus belonging to the family Scombridae (all-tackle gamefish record of 22.39 kg; IGFA 2012). Blackfin tuna is limited to waters above the 20 °C isotherm (Collette and Nauen 1983), resulting in a somewhat limited distribution to the tropical waters of the western Atlantic Ocean and Caribbean Sea, including all year within the Gulf of Mexico (Maghan and Rivas 1971; Richards and Bullis 1978). As an epipelagic species that is mostly neritic, blackfin are commonly found traveling in large schools with close proximity to shorelines.

Blackfin tuna are also an important ecological component throughout their range (Headley et al. 2009), feeding on epipelagic prey and being preyed upon by larger tunas, marlins, and sharks (Nishikawa and Kikawa 1983). Based on the physiological similarities between blackfin and its congeneric yellowfin tuna, one would expect their average temperature and depth profiles to be similar, especially those found in the same body of water. However, the habitat preferences of blackfin tuna are poorly known; the only study to date on blackfin habitat preference was conducted through the use of experimental fisheries catch data and associated oceanographic data (Bertrand et al. 2002).

Extensive work in the Eastern Pacific has used implantable electronic tagging technology on large thunnids (e.g., yellowfin tuna by Schaefer et al. 2007), although this method requires extensive outreach to the various fishing fleets in the region. In the absence of such outreach, fishery-independent reporting by small pop-off satellite archival tag (PSAT) technology has clear relevance. This study reports on the tagging of 10 blackfin tuna with PSATs to determine the habitat utilization by this species in the northern Gulf of Mexico.

Methods

The study site for this project was the north-central Gulf of Mexico near the Sackett Bank, located south of the Mississippi Delta and adjacent to the Mississippi Canyon, running diagonally from northwest to southeast. This location, known regionally as the “Midnight Lump,” is the site of an intensive winter recreational chum fishery that targets blackfin and yellowfin tunas during the late winter and early spring. The shelf-edge topographic features include sand, debris, rock ledges, and drowned coral reefs; depths range from 63–100 m (Rezak et al. 1985). All tag deployment locations were within a range of approximately two nautical miles (3.7 km) and are encircled in Fig. 1.

The ten blackfin tuna tagged in this study were captured in the Gulf of Mexico on April 11, 2012 on conventional hook-and-line gear common to the local recreational tuna fishery. Tunas were attracted with chum (Gulf menhaden, *Brevoortia patronus*, Goode, 1878) while drifting near the southern break of the bank and hooked on drifted chunk baits (little tunny, *Euthynnus alletteratus,* Rafinesque, 1810) using a non-offset 7/0 barbed circle hook (Mustad 39950BL). All fish were caught within 8 m of the surface.

The tag used in this study was the HR model X-Tag pop-up satellite archival tag (Microwave Telemetry, Inc.; Columbia, MD, USA). The tag has a length of 12 cm, width of 3.2 cm, a weight of 40 g, and resists pressures at depths up to 2500 m. The tag sensors collect individual data readings of temperature, pressure (converted to depth), and light levels of the surrounding environment every 90 s (n=2 tags, total deployment duration 9.5 days), 180 s (n=4, total duration 19 days), or 270 s (n=4, total duration 28.5 days) following capture and release. Programmed tag durations were intentionally staggered to allow determination of adequate attachment methods through different deployment dates; however, all tags were deployed on a single day. This tag model collected individual data points, allowing for a reconstruction of the vertical movement profiles of the tagged fish.

Tagging procedure

Fish were boarded with a large landing net, placed in a wetted beanbag chair, and ventilated with a hose connected a 500 gallon per hour raw seawater pump. The tag was inserted approximately one inch below the base of the second dorsal fin. Each tag had a 17.5 cm monofilament attachment leader with a hydroscopic nylon tag head modified to include small “wings” (see Lerner et al. 2013). A National Marine Fisheries Service (NMFS) streamer tag was attached to the dorsal section of five of the fish, helping to further identify the fish to anglers as a research subject (only five were tagged with streamer tags due to limited availability of tags). When the hook was easily accessible, it was removed; if unreachable, the leader was cut near the hook and the fish

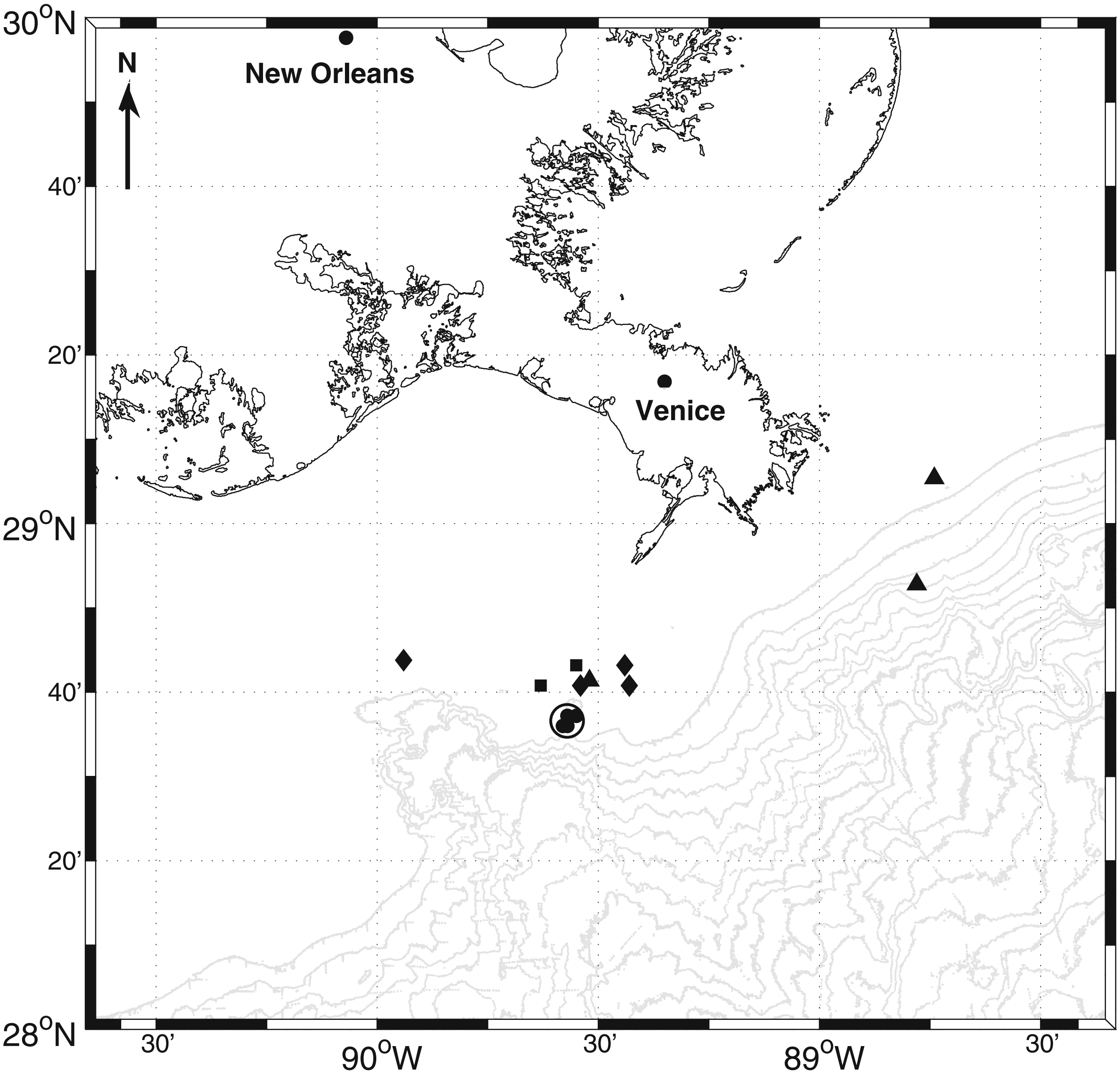


Fig. 1 All tagging locations (circled group) and tag pop-off locations for nine pop-up satellite archival tags deployed on blackfin tuna in the northern Gulf of Mexico on 11 April 2012. The square markers represent 9.5-day deployment period tags, the diamond markers represent 19-day tags, and the triangle markers represent 28.5-day tags. The gray lines are isobaths lines at 100-m intervals (data provided by NOAA National Ocean Service Hydrographic Survey Data, Received Aug 21, 2013, http://maps.ngdc.noaa.gov/viewers/bathymetry/). Coastal outline along the top is the southern coast of Louisiana; the inland cities of New Orleans, and Venice, Louisiana are shown for orientation. Seafloor depths of tagging and pop-off locations are in Table 1

was released with the hook still attached. Fig. 2 shows how the fish was restrained and the placement of the PSAT tag head and the streamer tag.

The tags were programmed to detach after a predetermined deployment duration, float to the surface, and transmit the archived data via the Argos satellite system. With each pass of the satellite, additional position, temperature, and pressure information was transferred and transmitted to a ground station and then to the investigator via the Internet. Data were transmitted early if premature detachment occurred or there was a lack of vertical movement (“constant depth”) for 24 h. A software-based release mechanism detached the tag if it approached a crush depth of 2500 m.

Fig. 2 Restraining procedure for a blackfin tuna tagged in the northern Gulf of Mexico on 11 April 2012 on a wetted beanbag within the landing net. Photo shows the deck hose in the mouth of the tuna, the tagging location along the dorsal musculature near the second dorsal fin, the electronic tag head on the applicator stick, and the applied conventional streamer tag in the musculature near the first dorsal fin. (Photo credit: Rachel Hickey.)

Fish lengths, estimated weights, hooking location, time of day, geographic location, and surface water temperature were also recorded. Individuals were also quickly evaluated for condition prior to tagging using six standard characteristics: activity, color, condition of the eyes, stomach eversion, general state of body musculature, and level of bleeding (similar to Kerstetter et al. 2003). This standardized evaluation method was implemented to specifically to minimize potential researcher biases.

Data analysis

Survival was inferred from three types of data: temperature changes, depth changes, and ambient light intensity per Kerstetter and Graves (2008). Net displacement distance, also referred to as straight-line distance traveled, was defined as the distance between the release location and the location of the first good transmission to the Argos satellite system (Horodysky et al. 2007). Transmissions were labeled with a location accuracy code; “good” locations are those with an accuracy code of 1, 2, or 3. In cases where a good accuracy code was not initially achieved, the first location code of 1, 2, or 3 within the first 3 h was used (Collecte Localisation Satellites 2010). Straight-line distances were calculated using Google Earth software (Google Inc. 2013).

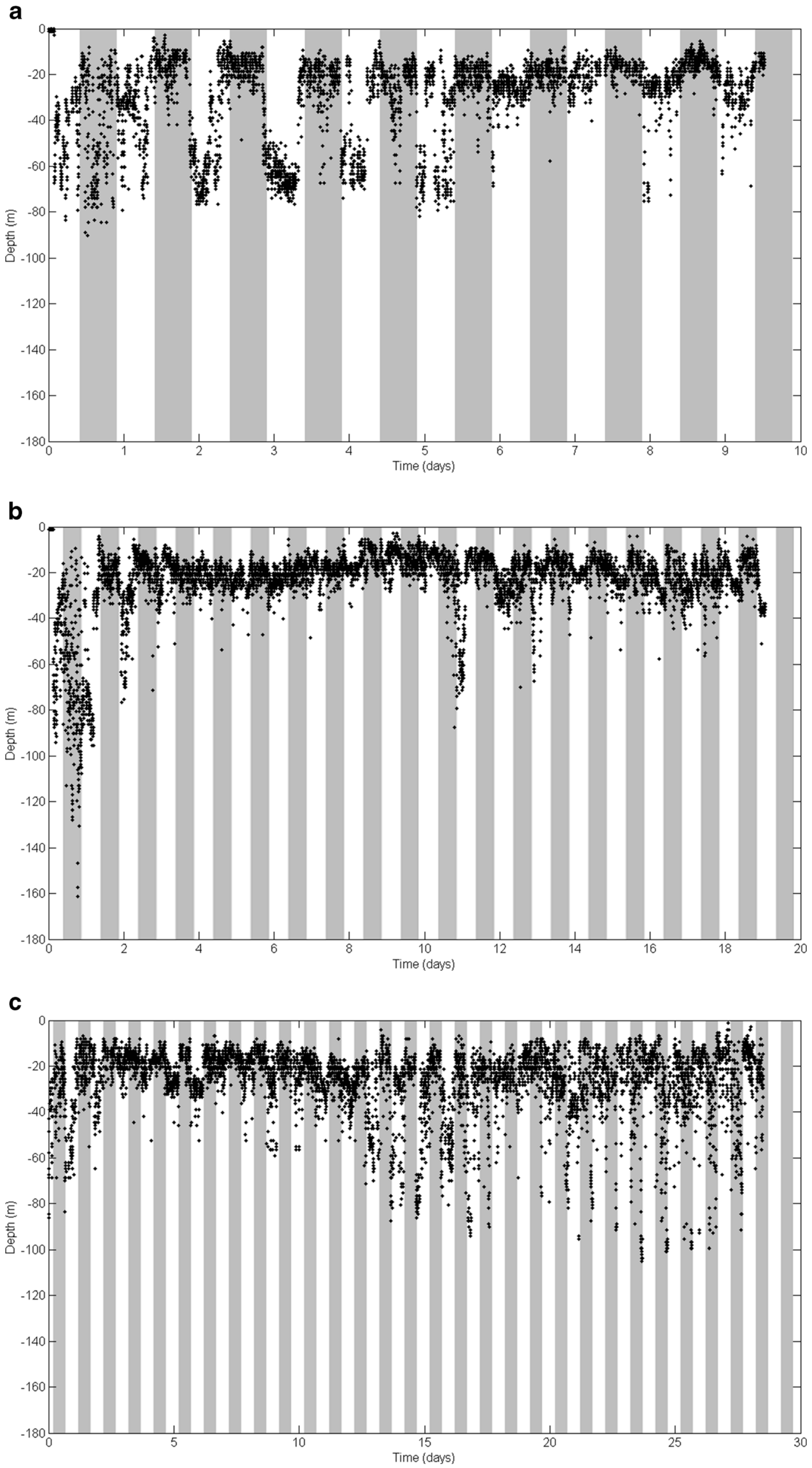
Depth-over-time data were plotted for one fish representing each deployment length, with approximate nighttime bins (as determined by sunset and sunrise times) outlined in gray (Fig. 3). Mean depth and temperature were evaluated against individual fish size to determine correlation. Day and night depth and temperature data were plotted in box-and-whisker plots to determine distribution (Fig. 4). The change in depth was analyzed to determine the magnitude and frequency of the depth changes for all records combined. A Welch’s *t*-test was used to test for differences in the depth or temperature data between day and night periods within individual tags or among deployment lengths (MATLAB 2012, function *ttest2*).

Results

The results of the Welch’s *t*-test showed that in all but two of the cases the null hypothesis was rejected, meaning that the data being compared came from independent random samples from normal distributions with equal means and variances. The two tests where the null hypothesis was accepted were 1) comparing the day vs. night temperature differences in tag Blk-02 (Fig. 4c, 4d) and 2) comparing the depth differences in the 19-day vs. 28.5-day deployments.

Fish sizes ranged from 69.9–86.4 cm FL. Eight of the fish were jaw hooked, one was gut-hooked, and one was hooked in the snout; all hooks were removed except for the swallowed hook. Table 1 presents data on the tagging details for all tags deployed. Nine out of 10 blackfin tuna tagged survived their full deployment. One fish died approximately 5 h after being caught, tagged, and released; data from this tag was excluded from all subsequent behavioral analyses. Straight-line distance traveled ranged from 7.3–97.5 km. One fish moved in a northwest direction, traveling 38.0 km. Six of the fish stayed in approximately the same area, traveling between 7.3–16.9 km. Two of the fish moved in a northeast direction, traveling 84.2 km and 97.5 km.

Fig. 3 **a-c** Depth-over-time data plotted for one fish representing ▶ each deployment length, with approximate nighttime bins (as determined by sunset and sunrise times) outlined in gray: **a**) Blk-01 (9.5-day deployment), **b**) Blk-02 (19-day deployment), and **c**) Blk-03 (28.5-day deployment)


a
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Depth (m)
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b
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-80
-100
-120
-140
-160
-180
Depth (m)
0 2 4 6 8 10 12 14 16 18 20
Time (days)
c
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Depth (m)
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Time (days)

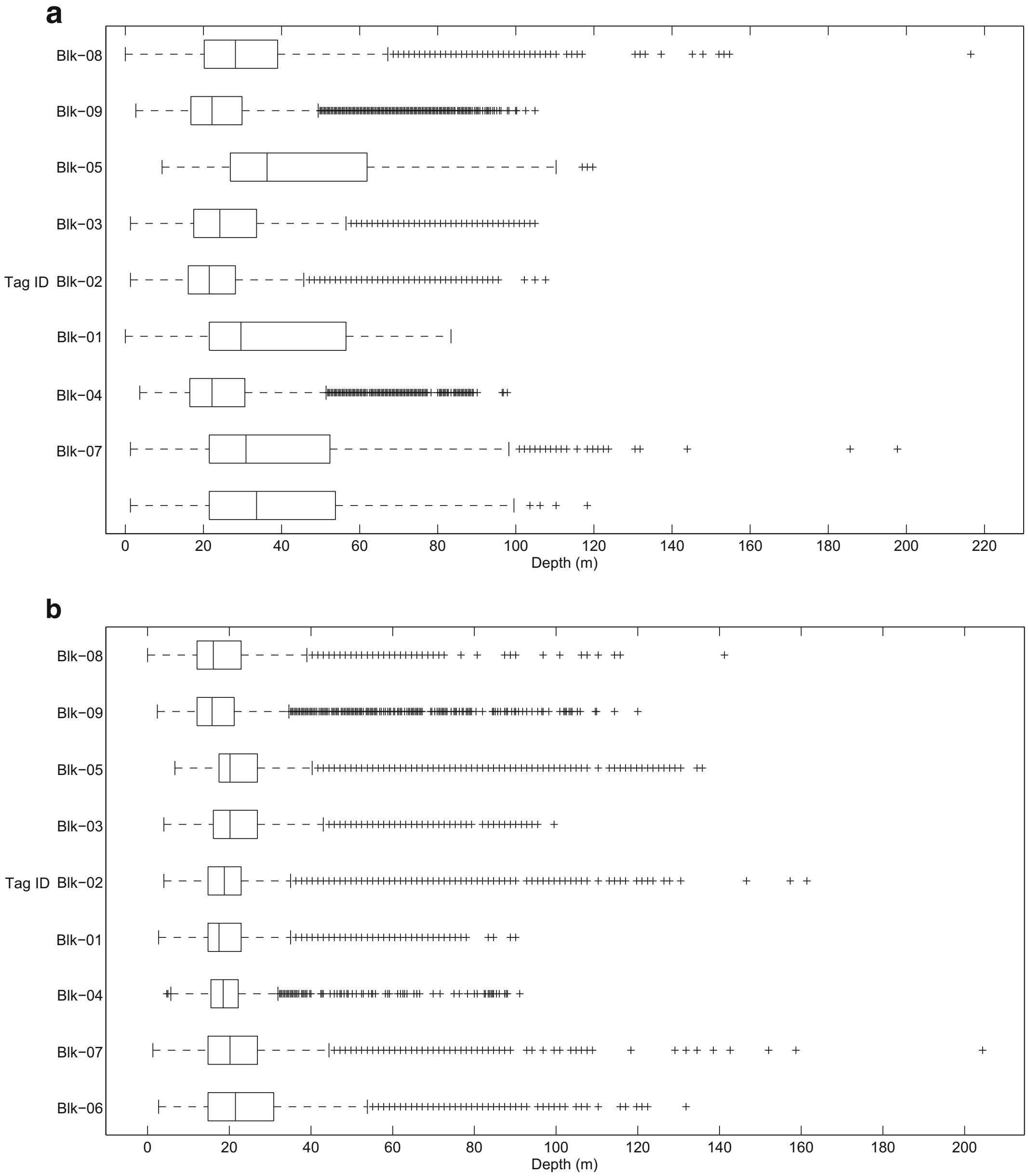

Fig. 4 Box and whisker plots of (**a**) depth distributions during the day, (**b**) depth distributions at night, (**c**) temperature distributions during the day, and (**d**) temperature distributions at night for nine pop-up satellite archival tags deployed on blackfin tuna *Thunnus atlanticus* in the northern Gulf of Mexico on 11 April 2012. Day versus night data were categorized using local sunset and sunrise times from astronomical charts. The records are plotted in vertical order by individual tuna size from smallest (*top*) to largest (*bottom*)

Depths ranged from 0–217 m with a mean of 28 m (*SD*=8.38 m) for all nine PSAT records, while temperatures ranged from 13.9–32.9 °C with a mean of 23.8 °C (*SD*=1.3 °C). The fish spent 90 % of their time in depths from 0–57 m (Fig. 3, 4) and 89 % of their time in temperatures from 21.9–26.6 °C (Fig. 3, 4). Individual ranges and means can be found in Table 1. The data also show two linear correlations: the mean depth reached increased as fish size increased (R^2=0.07472) and the mean temperature encountered decreased as fish size increased (R^2=0.26153). Over 87 % of the vertical movements in the water column were less than 12 m in distance, as evidenced by the distribution of the change in depth data.

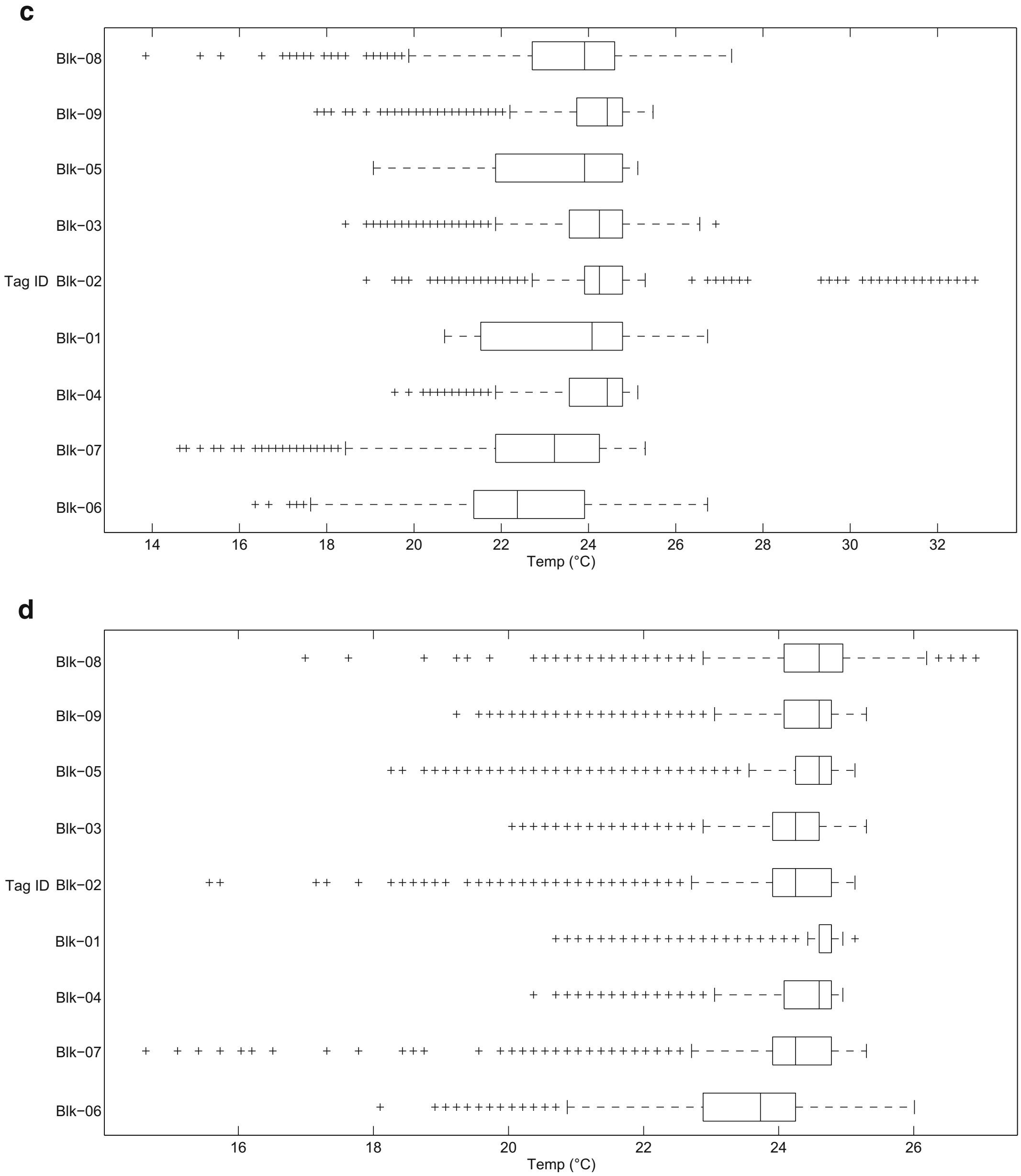

Fig. 4 (continued)

Discussion

Blackfin habitat utilization in the Gulf

The results of this study show that the tagged blackfin tuna are remaining deeper in the water column during daytime hours and ascending to shallower depths during nighttime hours with some overlap during both time periods (Fig. 4). Blackfin tuna appear to be limited by water temperature in the maximum depths they can reach. This observation is supported by the mean depth and temperature trends with individual body size seen in Fig. 3 and 4, as well as the very infrequent abrupt movements to depth.

Tags from six of the fish popped off within a 20 km radius of the tagging location. This result could be an indication of two scenarios: the fish left the area and came back prior to tag detachment, or the fish stayed in

Table 1 Deployment and reporting details for 10 pop-up satellite archival tags deployed on blackfin tuna in the north-central Gulf of Mexico during 2012. Fish “Blk-10” did not survive for the full term of the tag deployment, so behavioral data are omitted from this table

Tag ID Number	Tag Duration	Tagging Date	Tagging Location	Seafloor Depth	Pop-Off Date	Pop-Off Location	Seafloor Depth
Blk-01	10 days	04/11/12	28.62 N 89.55 W	113 m	04/12/12	28.68 N 89.63 W	99 m
Blk-02	19 days	04/11/12	28.62 N 89.57 W	110 m	04/30/12	28.72 N 89.44 W	113 m
Blk-03	28.5 days	04/11/12	28.62 N 89.57 W	110 m	05/10/12	28.69 N 89.52 W	112 m
Blk-04	10 days	04/11/12	28.62 N 89.57 W	110 m	04/21/12	28.72 N 89.55 W	100 m
Blk-05	19 days	04/11/12	28.62 N 89.57 W	110 m	05/01/12	28.68 N 89.54 W	112 m
Blk-06	28.5 days	04/11/12	28.60 N 89.57 W	132 m	05/10/12	29.09 N 88.74 W	96 m
Blk-07	19 days	04/11/12	28.60 N 89.58 W	129 m	05/01/12	28.73 N 89.94 W	54 m
Blk-08	28.5 days	04/11/12	28.60 N 89.58 W	129 m	05/10/12	28.88 N 88.78 W	485 m
Blk-09	19 days	04/11/12	28.60 N 89.58 W	129 m	05/01/12	28.68 N 89.43 W	125 m
Blk-10	28.5 days	04/11/12	28.62 N 89.57 W	110 m	–	–	–

Tag ID Number	Distance Traveled	Length (cm FL)	Hook Location	Hook Status	Full-term Survival?	Depth Range	Mean Depth	Temp Range	Mean Temp
Blk-01	10.3 km	81.3	Jaw	Removed	Yes	0–90	30	20.7–26.7	23.9
Blk-02	16.4 km	81.3	Jaw	Removed	Yes	1–161	23	15.6–32.9	24.2
Blk-03	8.8 km	80.0	Jaw	Removed	Yes	1–105	27	18.4–26.9	24.0
Blk-04	11.1 km	81.9	Jaw	Removed	Yes	4–98	23	19.6–25.1	24.2
Blk-05	7.3 km	78.7	Jaw	Removed	Yes	7–136	36	18.3–25.1	23.8
Blk-06	97.5 km	86.4	Gut	Left in	Yes	1–132	33	16.4–26.7	22.9
Blk-07	38.0 km	83.8	Jaw	Removed	Yes	1–204	32	14.6–25.3	23.5
Blk-08	84.2 km	71.1	Jaw	Removed	Yes	0–217	26	13.9–27.3	23.9
Blk-09	16.9 km	78.7	Snout	Removed	Yes	2–120	23	17.8–25.5	24.2
Blk-10	–	69.9	Jaw	Removed	No	–	–	–	–

the area for the full tag deployment. Deployment duration varied among these six tags; two were 10-day tags, three were 19-day tags and one was a 28-day tag. The staggered appearance of these fish near the tagging location is a possible indication of some site fidelity, especially given the presence of several oil rigs in the vicinity. However, the other three surviving fish traveled between 38.0–97.5 km. While the reason for the distances travelled are unknown, possible explanations include predatory evasion or pursuit of a food source.

Unfortunately, the resolution of the light-level data from this model of PSAT does not allow the recreation of actual tracks using light-based geolocation methods. However, the straight-line distance traveled was calculated for each fish as a proxy for total horizontal displacement. This is a very rough estimate of the distance a fish might have covered during the tag deployment, as it is highly unlikely that these fish only moved in a straight line. Using this size PSAT in a different software configuration could provide additional information on horizontal displacement rates and movements in association with varying isobaths.

Blackfin interactions with other tuna species

The tagged blackfin tuna showed a preference for the surface mixed layer, they spent 90 % of their time in the upper 57 m of the water column, undertook periodic brief deep dives to depths in excess of 200 m, demonstrated a shallower nighttime distribution, and spent 89 % of their time in waters warmer than 21.9 °C. Comparatively, yellowfin in the Gulf of Mexico prefer the upper 50 m of the water column, exhibit periodic brief deep dives through the thermocline to depths in excess of 1000 m, have a shallower nighttime distribution, and spend a very limited amount of time in waters cooler than 20 °C (Carey and Olson 1982; Block et al. 1997; Josse et al. 1998; Dagorn et al. 2006; Weng et al. 2009). Atlantic bluefin tuna in the Gulf spend a majority of time in the upper 30 m of the water column, frequently dive to depths in excess of 1000 m, exhibit a shallower nighttime distribution, and spend a very limited amount of time in waters cooler than 14 °C (Lutcavage et al. 2000; Block et al. 2001; Brill et al. 2002; Stokesbury et al. 2004; Wilson et al. 2005; Teo et al. 2007).

The discrepancies between the described vertical niches of these tuna species have been attributed to varying physiological thermoregulative capabilities, mostly due to differences in their countercurrent heat exchange systems, or *retia mirabilia* (Dickson and Graham 2004; Katz 2002). This vascular arrangement conserves heat and ultimately slows the rate of cooling during dives below the thermocline (Brill 1994). Morphologists have established two subgenera for true tunas, partially based on these circulatory variations. The subgenus *Neothunnus* consists of the yellowfin, blackfin, and longtail tunas usually found in warm waters, whereas the subgenus *Thunnus* are usually found in cooler waters and include the Atlantic northern bluefin, southern bluefin, Pacific bluefin, bigeye, and albacore tunas. Although the sample size for this study was small ($n=9$), the water column preferences of the tagged blackfin did coincide with the expected distribution based on tuna physiology.

Methodological challenges

Studying movement characteristics of small tuna species can be challenging due to difficulties associated with manipulating and tagging the species; any tag-related study should minimize adverse impacts (see Wilson 2011). Among PSAT types, the tag model used in this study was comparatively small to the fish tagged. The usual threshold for behavioral changes due to tags is if they incur a cost of more than 10 % of the total fish bioenergetic output (Grusha and Patterson 2005). A minimum length of 56 cm fork length (FL) was needed here; *a posteriori* calculations following Grusha and Patterson (2005) indicated that all the tuna tagged in this study exceeded said bioenergetics threshold. It is unclear why the one fish (Blk-10) died following release. Although it was the smallest tagged individual by a small margin, it was hooked externally (in the jaw) and did not show any behavioral differences at release.

Longer-duration tags would have provided additional data, but the untested nature of the attachment on small tunas warranted a more conservative deployment strategy using stages of progressively longer durations. While all electronic tagging technologies should be used with caution, especially with species undergoing rapid movements to depth (e.g., Atlantic bluefin tuna in Galuardi and Lutcavage 2012), the success with short-duration PSATs seen in this study suggests that similar studies on small tunas should be explored, including deployments of longer durations.

Future management and protection

Blackfin tuna are a major source of food to many countries and have been becoming increasingly popular in both the commercial and recreational fisheries of the United States. The basis for understanding a marine organism is knowledge of its biology and how it interacts with its habitat (Brill and Lutcavage 2001), which in turn can be used for standardizing catches for stock assessment purposes. The description of habitat utilization, including temperature and depth profiles, for blackfin tuna will ultimately lead to a greater knowledge of pelagic species interactions, especially with other tunas, and subsequently a better managed stock.

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