PAPER

Comparative Performance of Current-generation Geolocating Archival Tags

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ABSTRACT

The performances of the current-generation Lotek Wireless LTD2310 and the Wildlife Computers Mk9 geolocating archival tags were compared. The depth, temperature, and light level sensors of 15 LTD2310 and 15 Mk9 archival tags were evaluated through hydrocasts of these, along with a calibrated Sea-Bird SBE39 temperature and depth probe, to nearly 500 m. Three experiments were conducted; each included five archival tags of each type simultaneously deployed in hydrocasts, along with the SBE39 probe. In all three experiments, the average differences between depth sensors on the Mk9 archival tags and the SBE39 were significantly greater than those between the LTD2310 archival tags and the probe depths for the hydrocast stops at about 500 m, 300 m, and 200 m. The standard errors about the average depth values for those hydrocast stops in Experiments 1 and 2, were greater for the LTD2310 tags, but for Experiment 3 the standard errors were greater for the Mk9 tags. The average differences between the LTD2310 and Mk9 archival tag temperatures measured by their stalk sensors and the SBE39 probe temperatures were similar in all three experiments over a temperature range of from about 9° to 27° C. The standard errors about the average temperature values were similar in all three experiments. The temperatures recorded by the Mk9 archival tag body temperature sensors lagged significantly, while those of the LTD2310 sensors were close to the temperatures recorded by the SBE39 probe during descents and ascents. The standard errors about the average tag body temperature values in all three experiments are greater for the Mk9 tags. Following the stabilization of light sensors at maximum depths (about 500 m) and darkness, during the three hydrocast ascents the 15 LTD2310 and 15 Mk9 archival tag light sensors indicated an average sensitivity to light at 440 m and 380 m, respectively. Two separate experiments conducted with archival tags implanted in the peritoneal cavity of tunas provided estimates of the accuracy and precision of geolocation based on ambient light level data. The computed distances between the average estimated geolocations, from three LTD2310 and three Mk9 archival tags recovered from captive yellowfin tuna *Thunnus albacares*, to the tank location (7°25'N-80°10'W) were 43.7 nm and 32.1 nm, respectively. The computed distances between the average estimated geolocations, from 13 LTD2310 and 15 Mk9 archival tags from bigeye tuna *Thunnus obesus*, released and recovered in association with a moored buoy, to the actual buoy location (1°59'S-95°11'W) were 118.5 nm (1.975 dd) and 162.8 nm (2.713 dd), respectively.

Introduction

Understanding the movements, behavior and habitat of commercially important or protected marine animals is paramount for appropriate management of such resources. Current-generation archival tags (electronic data storage devices) are capable of simultaneously sampling, at relatively high frequencies, four or more parameters of the physical oceanographic environment experienced by large marine animals and storing several years of such data in memory. These tags record depth, temperature, and light intensity with relatively high levels of accuracy and precision. When animals previously tagged and released with archival tags are recaptured, the data can then be downloaded from the recovered tags. From the daily light level data collected by these tags it is possible to estimate an animal's daily geolocation (Hill and Braun, 2001; Ekstrom, 2004). In recent years these tags, externally attached or implanted in the peritoneal cavity, have been used to elucidate movements, behavior, and habitat of various large marine animals over relatively long periods of time (Arnold and Dewar, 2001: Block et al., 2001; Gunn and Block, 2001; West and Stevens, 2001; Block et al., 2003; Schaefer and Fuller, 2002). Archival tags deployed with large marine animals have also been proposed as efficient autonomous samplers of physical oceanographic data (Boehlert et al., 2001; Charrassin, et al., 2002; Lyderson et al., 2002; Fedak, 2004).

Considering the importance for inclusion of these archival tag data sets into various resource assessments and oceanographic data libraries, evaluations of the accuracy and precision of the data collected by tags, along with the associated estimates of geolocations are crucial. The potential to obtain additional physical oceanographic data sets from large marine animals carrying archival tags in time/area strata, which may otherwise be unavailable or inadequately sampled, and incorporate those into database libraries for applications including verification of other data sources, monitoring of physical oceanographic features, or climate predictions, should be carefully evaluated.

Previous studies (Gunn et al., 1994; Welch and Eveson, 1999, 2001; Musyl et al., 2001; Schaefer and Fuller, 2002; Teo et al., 2004) have evaluated the accuracy of estimates of geolocation, based on ambient light levels recorded by archival tags and

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found that estimates of longitude are significantly more accurate and less variable than those for latitude. Previous generations of archival tags, which were inferior to those available today, were utilized in those studies. The previous evaluations of Welch and Eveson (1999) and Musyl et al. (2001) included comparisons of geolocation estimates from two earlier-generation archival tags, but did not include any comparative evaluations of sensor performance.

Similarities that exist between the current generation of Lotek Wireless LTD2310 and Wildlife Computers Mk9 geolocating archival tags include: 1) size, weight, and pressure ratings, 2) batteries, memory availability, and non-volatile flash memory, 3) maximum depth sensing, and 4) external sensor stalks for ambient temperature and light measurements. Some fundamental differences that exist between these archival tags include: 1) casing composition, 2) pressure sensors, 3) external stalks, 4) light sensors, 5) connections for PC-based communications, 6) PC-based software for downloading and analysis of data, 7) onboard processing of geolocation estimates provided in a day log for the LTD2310, 8) user-specified processing of light level data to obtain geolocation estimates from software provided with the Mk9.

Since 2002, we have conducted experiments with both captive and wild tropical tunas, employing archival tags manufactured by Lotek Wireless and Wildlife Computers. Their tags, based on different architectures, have evolved over this period, and it is important to evaluate the comparative performances of these current-generation archival tags. The objectives of this study are to evaluate the accuracy and precision of sensors in and geolocation estimates from LTD2310 and Mk9 archival tags.

Methods

The depth, temperature, and light level sensors of fifteen LTD2310 and fifteen Mk9 archival tags were evaluated through hydrocasts to nearly 500 m, along with a calibrated Sea-Bird SBE39 time/temperature/depth probe (Sea-Bird Electronics, 2005). The Sea-Bird probe was used as the reference source, as it is a highly accurate scientific oceanographic instrument. These experiments were conducted in the equatorial eastern Pacific Ocean (EEPO), aboard the chartered fishing vessel *Her Grace*, a 17.7-m, 99 gross-t, live-bait pole-and-line vessel, during an Inter-American Tropical Tuna Commission (IATTC) tuna tagging cruise. Three experiments were conducted each with five archival tags from each manufacturer simultaneously deployed in hydrocasts along with an SBE39 probe. The first experiment was conducted on April 8, 2004, at 1°47.7'N-95°19.6'W from approximately 12:12 h to 12:52 h (standard local time), with about 80% cloud overcast, utilizing recycled archival tags recovered from previous deployments with bigeye tuna *Thunnus obesus* (Table 1). The second experiment was conducted on April 15, 2005, at 1°56.9'S-95°10.8'W from approximately 11:33 h to12:29 h, with about 50% cloud overcast, using new tags (Table 1). The third experiment was conducted on April 15, 2005, at 1°56.9'S-95°10.8'W from 12:43 h to 13:38 h, with about 70% cloud overcast, using new tags (Tables begin on page 10).

Specifications and available configurations for current-generation LTD2310 archival tags (Lotek Wireless, Inc., 2005) and Mk9 archival tags (Wildlife Computers, Inc., 2005) are available at their respective Web sites. The LTD 2310 and Mk9 tags used in each of the three trials had similar manufacturing and programmed configurations, regardless of the manufacturing dates (Table 1). All of the five tags used in Experiment 1 had been sent back to the respective manufacturer for evaluations and verification of sensor calibrations previous to their use in that experiment.

The experimental design followed for each of these three experiments included selection of an overcast day at around noon (standard local time), while in offshore, relatively clear blue water of the EEPO in about 3000 m depth, to conduct the hydrocasts. The descent rate was fairly constant, until reaching a depth of 400 to 500 m, at which the SBE39 probe, and archival tags, were held for 15 minutes. During the ascent, stops were made for 5-minute intervals in steps of approximately 100 m, with the final stop at about 5 m below the surface.

The SBE39 probe was secured inside a nylon mesh bag connected alongside another nylon mesh bag containing the 10 tags (5 of each type). With the tag bodies secured inside the mesh bag, the stalks from the tags were fastened so as to protrude entirely outside the bag. The SBE39 probe recorded depth and temperature measurements in memory every 1.5 seconds. The LTD2310 and Mk9 archival tags were programmed to sample and store the depth, temperatures from stalk and tag body sensors, and light level in memory every 4 seconds. After retrieval, the data were downloaded from the SBE39 probe and each tag.

Sensor performances of the LTD2310 and Mk9 tags were evaluated in comparison to the data collected simultaneously by the SBE39 probe, within each of the three experiments. The accuracy of the sensors are reported as the calculated average differences between the data from the tags and those from the probe. Statistical comparisons of the average differences for the two tag types were conducted utilizing the Wilcoxon paired-sample test (Wilcoxon, 1945) to evaluate the closeness of the tag sensor estimates to those considered the "true values" from the probe. The precision of the sensors are reported as the standard errors of the calculated average values for the tag sensors and the dispersion of the data about the average values is also illustrated.

Yellowfin tuna, *Thunnus albacares*, with LTD2310 and Mk9 archival tags surgically implanted in their peritoneal cavities using techniques described in Schaefer and Fuller (2002), were maintained in a 8.5-m diameter, 3-m depth, 170-m^3 capacity land-based tank located at 7°24.88'N-80°10.37'W, at the IATTC Achotines Laboratory in the Republic of Panama (Wexler et al., 2003). This experiment began on January 16, 2002, when LTD2310 tags were implanted into the peritoneal cavities of five yellowfin and Mk9 tags were implanted into the peritoneal cavities of five other yellowfin. As of April 22, 2003, there were three LTD2310 and three Mk9 tags recovered from deceased yellowfin (Table 1). Only partial data sets were obtained from these tags, because each tag malfunctioned during the experiment. Comparisons between the daily geolocation estimates, based on ambient light levels, using the tag-specific algorithms, to the actual position of the tank, were conducted for the six tags during the 16-day period from January 16, 2002, to February 1, 2002.

LTD2310 and Mk9 archival tags were implanted into bigeye tuna from March 26 to April 8, 2003, and released adjacent to a Tropical Atmospheric and Oceanographic (TAO) Buoy moored at 1°58.8'S-95°11.4'W, following procedures similar to those described by Schaefer and Fuller (2002). At this same location on April 19, 2003, thirteen bigeye with LTD2310 tags and fifteen bigeye with Mk9 tags (Table 1), were recaptured by a purse-seine vessel. Complete data sets for times at liberty were downloaded from each of the archival tags. Evaluations of the depth records for each fish indicated that they remained associated with the TAO buoy throughout the period at liberty, based on the criteria for associative behavior with floating objects reported by Schaefer and Fuller (2002). Comparisons between the daily geolocation estimates, based on ambient light levels, using the tag-associated algorithms, to the position of the moored buoy were conducted for the 28 tags recovered from recaptured bigeye tuna.

Results

Performance Evaluations of Sensors

The hydrocast profiles of the five LTD2310, five Mk9 tags, and the SBE39 probe from Experiment 3 are shown in Figure 1.

The recorded depths of the Mk9 tags are significantly greater than the recorded depths of the LTD2310 tags and the SBE39 probe at the bottom of the hydrocast (484.6 m) and the stops at 307.6 m and 211 m. There is also a greater dispersion of the recorded depths of the Mk9 tags to those of the LTD2310 tags at those three depths (Figure 1). The recorded depths of both the Mk9 and LTD2310 tags are close to those of the SBE39 probe at 107.3 m and 5.9 m. Comparisons of the average depth records from the five LTD2310 and five Mk9 tags to SBE39 probe depths at specific times from the bottom of the hydrocasts to near the surface, from each of the three experiments, are given in Table 2. The average differences between the Mk9 tags and the SBE39 probe depths are significantly greater than those between the LTD2310 tags and the SBE39 probe for the stops at about 500 m (about 20 m), 300 m (about 10 m), and 200 m (about 7 m) in all three experiments (Table 2). The standard errors about the average values in Experiments 1 and 2, at each of those depths, are greater for the LTD2310 tags, but in Experiment 3 the standard errors are greater for the Mk9 tags (Table 2). The average differences between the Mk9 tags and the SBE39 probe depths are similar to those of the LTD2310 tags for the stops at about 100 m and 5 m in all three experiments, except for the 5-m stops in Experiments 2 and 3 where the LTD2310 archival tags are significantly greater by about 2 m (Table 2).

FIGURE 1

Depth comparisons from Experiment 3 (Table 1) of five LTD2310 (green [gray]) and five MK9 (blue [dashed]) archival tags with Sea-Bird SBE39 (black [solid]) probe.

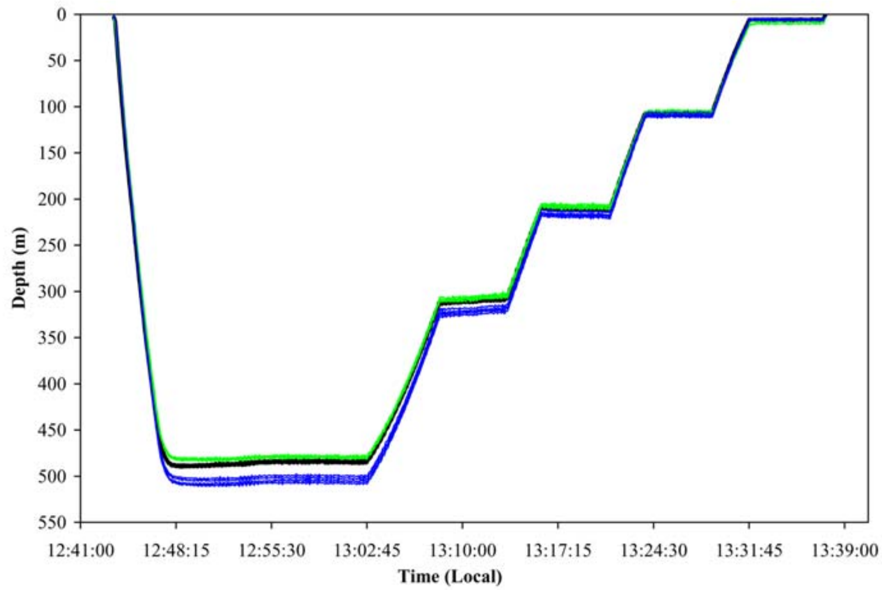


FIGURE 2

Stalk temperature comparisons from Experiment 3 (Table 1) of five LTD2310 (green [gray]) and five Mk9 (blue [dashed]) archival tags against Sea-Bird SBE39 (black [solid]) probe.

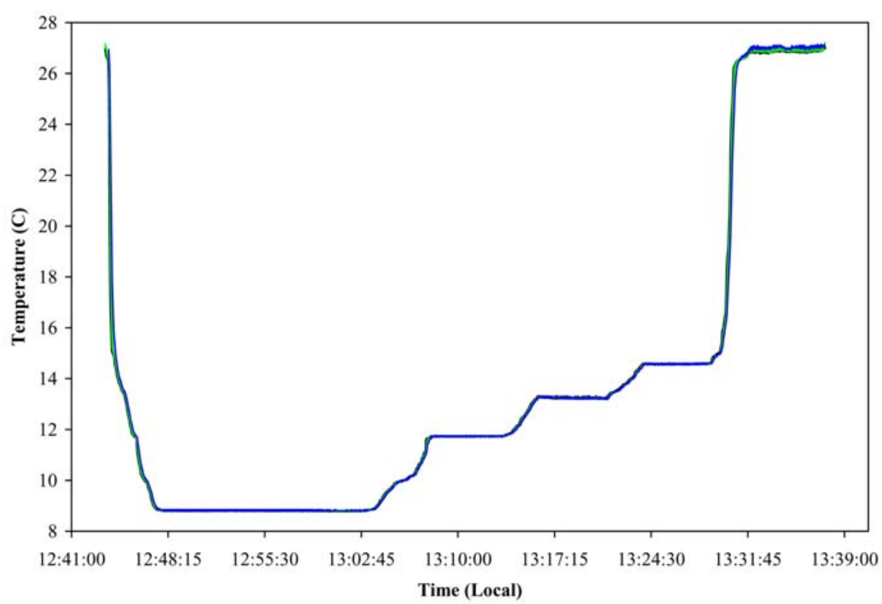
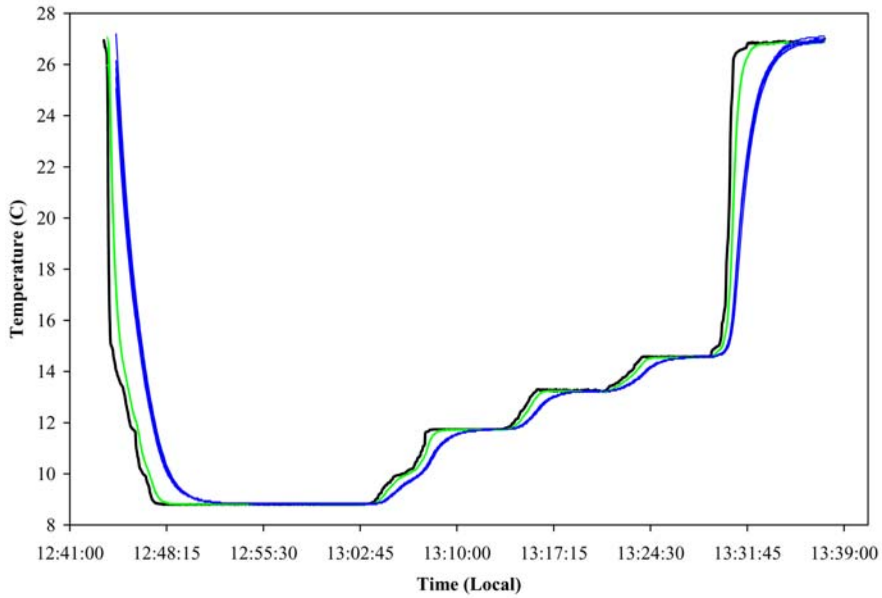


FIGURE 3

Tag body temperature comparisons from Experiment 3 (Table 1) of five LTD2310 (green [gray]) and five Mk9 (blue [dashed]) archival tags against Sea-Bird SBE39 (black [solid]) probe.



Ambient temperature (tag stalk)

The hydrocast profiles from Experiment 3, showing the temperatures recorded by the stalk sensors of the five LTD2310 tags, the five Mk9 tags, and the SBE39 probe temperatures are shown in Figure 2.

The recorded temperatures of the LTD2310 and Mk9 tags appear close to those temperatures recorded by the SBE39 probe throughout the hydrocast, and the dispersion of the recorded temperatures for the two tags appears similar. Comparisons of the average stalk temperature records from the five LTD2310 and five Mk9 tags, to SBE39 probe temperatures at specific times from the bottom of the hydrocasts to near the surface, from each of the three experiments, are given in Table 3. The average differences between the LTD2310 and Mk9 tag temperatures measured by the stalk sensors and the SBE39 probe temperatures are similar in all three experiments over a range of temperatures from about 9° to 27° C (Table 3). The standard errors about the average values are similar in all three experiments (Table 3).

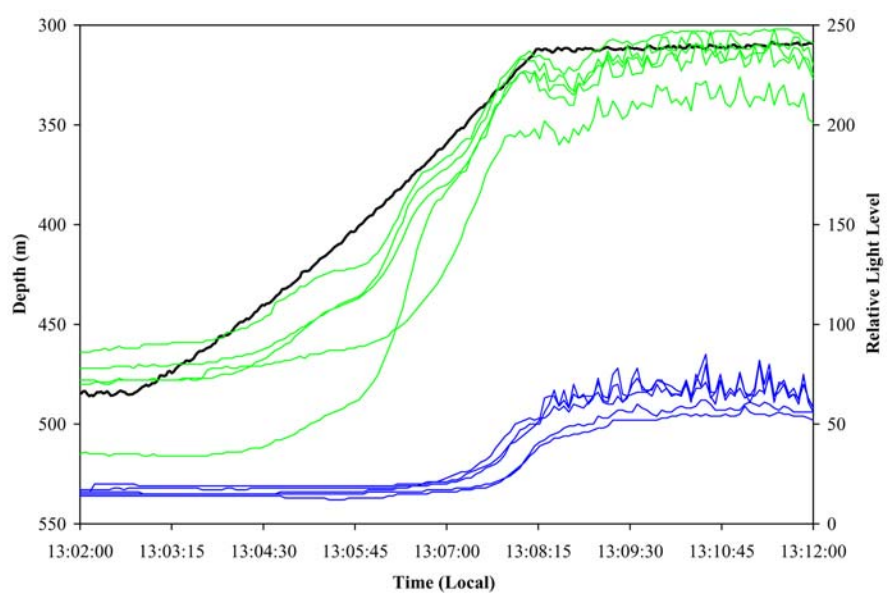
Body temperature (tag body)

The hydrocast profiles from Experiment 3, showing the temperatures, recorded by the tag body sensors of the five LTD2310 tags, the five Mk9 tags, and the SBE39 probe temperatures, are shown in Figure 3.

The recorded temperatures of the Mk9 tag body temperature sensors lagged significantly behind the recorded temperatures of the LTD2310 tag body temperature sensors, which are close to those temperatures recorded by the SBE39 probe, during the descent and the ascents of the hydrocast. The recorded temperatures from the Mk9 archival tag body temperature sensors reached equilibrium temperatures comparable to those from the SBE39 probe after a few minutes during each stop. There is a greater dispersion of the recorded temperatures of the Mk9 tag body temperature sensors to those of the LTD2310 tags (Figure 3). Comparisons of the average temperature records from the five LTD2310 and five Mk9 tag body sensors, compared to the SBE39 probe temperatures at specific times from the bottom of the hydrocasts to near the surface, from each of the three experiments (Table 1), are given in Table 4. The average differences between the Mk9 tag body temperature sensors and the SBE39 probe temperatures are significantly greater than those of the LTD2310 tag body temperature sensors at the end of the descent and significantly less throughout the ascents in all three experiments (Table 4). At the end of the descent the average differences in temperatures recorded by the Mk9 and LTD2310 tag body sensors relative to the SBE39 probe temperatures in Experiment 1 were 2.8° C and 0.6° C, in Experiment 2 were 1.6° C and 0.1° C, and in Experiment 3 were 1.7° C and 0.1° C, respectively (Table 4). The standard errors about the average tag body temperature values in all three experiments are greater for the Mk9 tags (Table 4).

FIGURE 4

Light sensor sensitivity comparison from Experiment 3 (Table 1) of five LTD2310 (green [gray]) and five MK9 (blue [dashed]) archival tags, based on depth from a Sea-Bird SBE39 (black [solid]) probe.



Light

The segment of the hydrocast profile from Experiment 3, showing the comparative sensitivity of light level sensors of the five LTD2310 and five Mk9 tags, relative to that of the SBE39 probe depths, is shown in Figure 4.

The LTD2310 sensor has 32 counts/decade, whereas the Mk9 has 16 counts/decade, which creates the differences in resolution and shapes of the light response curves. Following the 15-minute stop at the bottom of the hydrocast, and stabilization of the light sensors, during the ascent the five LTD2310 and five Mk9 tag sensors indicated average light sensitivities at 455 and 364 m, respectively.

In Experiment 1, following the 15-minute stop at the bottom of the hydrocast, during the ascent the five LTD2310 and five Mk9 tag sensors indicated average light sensitivities at 412 and 356 m, respectively. In Experiment 2, following the 15-minute stop at the bottom of the hydrocast, during the ascent the five LTD2310 and five Mk9 tag sensors indicated average light sensitivities at 453 and 419 m, respectively. For all three hydrocast ascents the 15 LTD2310 and 15 Mk9 tag sensors indicated average light sensitivities at 440 and 380 m, respectively.

Geolocation Estimates

Captive tuna at the Achotines Laboratory in Panama

The average and range of estimated latitudes and longitudes from three LTD2310 and three Mk9 tags, recovered from yellowfin tuna maintained in captivity at the Achotines Laboratory of the Inter-American Tropical Tuna Commission in Panama (Table 1) are given in Table 5.

Estimates of longitude from all tags are considerably less variable than those for latitude. The average and range in longitude estimates for the LTD2310 tags were 80.24°W (79.60°-81.20°W) and for the Mk9 tags were 80.14°W (79.50°-80.98°W) (Table 5). The average and range in latitude estimates for the LTD2310 tags were 8.14°N (5.80°-10.00°N) and for the Mk9 tags were 6.88°N (3.00°-11.00°N) (Table 5). The calculated distances for the average estimated latitude and longitude from the three LTD2310 and three Mk9 tags to the exact location of Tank 2 at the Achotines laboratory are 43.7 nm and 32.1 nm, respectively (Table 5).

Tuna associated with a moored buoy in the EEPO

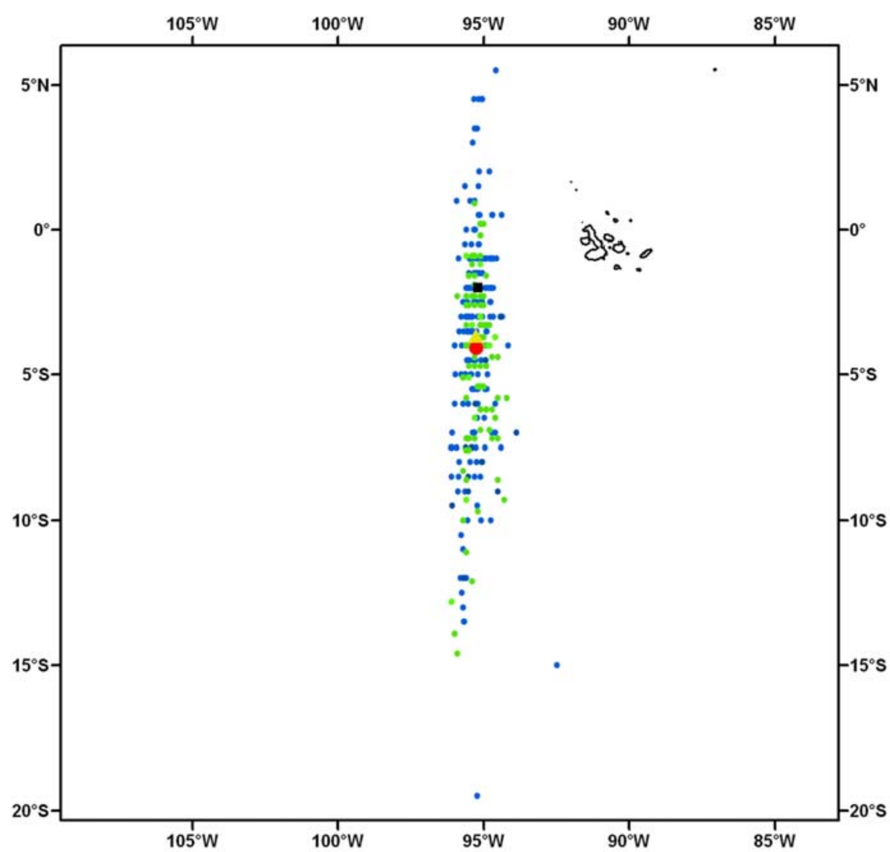
The average and range of estimated latitudes and longitudes for thirteen LTD2310 and fifteen Mk9 tags, recovered from bigeye tuna associated with a moored buoy in the EEPO are given in Table 6.

Estimates of longitude from all tags are considerably less variable than those for latitude. The average and range of longitude estimates for the LTD2310 tags were 95.23°W (94.20°-96.10°W) and for the Mk9 tags were 95.27°W (94.27°-96.13°W) (Table 5). The average and range of latitude estimates for the LTD2310 tags were 3.95°S (0.90°N-14.60°S) and for the Mk9 tags were 3.66°S (4.5°N-19.50°S) (Table 5). The distances of the average estimated latitude and longitude from the thirteen LTD2310 and fifteen Mk9 tags to the exact location of the moored buoy are 118.5 nm and 149.1 nm, respectively (Table 6).

All estimated daily geolocations for the thirteen LTD2310 and fifteen Mk9 archival tags, recovered from recaptured bigeye tunas in Table 6, are plotted in Figure 5, along with the location of the moored buoy with which they remained associated while at liberty. Both distributions illustrate significantly less variation in estimates of longitude compared to those for latitude. The overlap of the distributions and their respective centroids for all daily estimates of geolocation from the LTD2310 and MK9 archival tags, shown in Figure 5, illustrate the similarities in these two distributions.

FIGURE 5

Geolocation estimates based on ambient light levels from 13 LTD2310 (green dots [circles]) and 15 Mk9 (blue dots [diamonds]) tags and their associated algorithms, for bigeye tuna in Table 6. The solid yellow triangle is the centroid for the Mk9 tags and the solid red circle is the centroid for the LTD2310 tags. The solid black square is the location of the moored TAO buoy.



Discussion

Performance Evaluations of Sensors

The average differences in depths estimated by the tags and the SBE39 probe depths were significantly greater for the Mk9 tags for the hydrocast stops at about 500 m, 300 m, and 200 m in all three experiments. The depth sensor in the LTD2310 tag is a silicon piezoresistive chip protected from salt water by oil and coupled to a thin stainless steel diaphragm. The pressure sensor in the Mk9 tag is a silicon piezoresistive chip protected from water by a thick plug of elastomeric material.

The temperatures recorded by the LTD2310 and Mk9 tag stalk sensors, relative to the SBE39 probe temperatures, during the three hydrocasts, are comparable. The sensors used on the stalks of these archival tags are similar thermistors. The temperatures measured by the LTD2310 and Mk9 tag body sensors, relative to the SBE39 probe temperatures, during the three hydrocasts, show some significant differences. The Mk9 tag body sensor temperatures lag significantly behind those of the SBE39 probe temperatures and those recorded by the LTD2310 tag body sensor temperatures during the hydrocast descents and ascents in all three experiments. The casings of these two tags are constructed of different materials, which may be responsible for the relatively slow thermal response of the Mk9 tag body temperature sensor. Apparently the tag body thermistor of the Mk9 is more deeply encased in the epoxy, and provides a greater thermal inertia, which explains the slower response time to changes in temperature. Although both the LTD2310 and Mk9 tags have a reported resolution in temperature of 0.05°C, for both the stalk sensor and tag body sensor, the accuracy of temperatures recorded by the LTD2310 tags are reportedly 0.1°C whereas the accuracies recorded by the Mk9 tags are 0.2°C (Lotek Wireless, Inc., 2005; Wildlife Computers, Inc., 2005). The increased accuracy and response times of the LTD2310 tag body temperature sensors can be important for numerous reasons, including detection of small changes in internal temperatures of large pelagic fish with archival tags, such as in studies of physiology including feeding energetics of wild and captive tunas (Gunn et al., 2001).

The sensitivity of the light sensor in the LTD2310 tag is greater than that of the Mk9 tag, based on results of the three experiments. For the three hydrocast ascents the LTD2310 archival tag sensors indicated an average light sensitivity at 440 m, which was 60 m greater depth than that of the Mk9 tag. For the LTD2310 tag, the optical sensor is of fluorescent conversion type that employs a plastic optical fiber doped with a fluorescent dye to collect from all directions around the measurement stalk, concentrate, and filter blue light, then conduct the proportional green fluorescence into the body of the tag where a small-area silicon photodiode and preamplifier are located. The excitation spectrum of the fluorescent dye determines the optical acceptance passband, which has a peak near 470 nm and a steep red-side edge near 500 nm. For the Mk9 tag the light detector is a silicon photodiode covered by a conventional flat optical filter to define the optical passband. Photodiode and preamplifier are located at the end of the sensor stalk. Although both of these tags are capable of detecting changes in light at depths in excess of 300 m near midday, during dawn and dusk events, when the azimuth of the sun is minimal and animal diving behavior common, the recorded light levels may be externally attenuated, which will degrade the accuracy of geolocation estimates (Hill and Braun, 2001).

Geolocation Estimates

The two experiments conducted with captive and wild tunas provide a comparative evaluation of the LTD2310 and Mk9 tag estimates of geolocation in lower latitudes, based on ambient light levels, from tag-associated algorithms. In the experiment with the implanted archival tags in captive yellowfin tunas, the estimates for longitude from both tag types were nearly identical and reasonably close to the actual longitude. The estimates for average latitudes from the LTD2310 tags were only slightly north and those for the Mk9 tags only slightly south of the actual latitude. The distances from the average estimated latitudes and longitudes for the LTD2310 and Mk9 archival tags to the actual location of the tank were quite close, and similar during the period of this experiment.

In the experiment with the implanted archival tags in bigeye tuna released adjacent to a moored buoy in the EEPO, the estimates for longitude from both tag types were again nearly identical and very close to the actual longitude. However, the estimates for average latitudes from the LTD2310 and the Mk9 tags were both significantly south of the actual latitude by about 2° and 2.5°, respectively. The distance from the average estimated latitudes and longitudes to the actual location of the moored buoy was slightly less for the LTD2310 tags than for the Mk9 tags.

Estimates of the expected accuracy in daily geolocation of marine animals carrying archival tags are realistically obtained only from the current generation of tags implanted or externally attached to the animal being investigated and within the specific oceanographic region of interest. This is because of continued changes and improvements in tag architecture and software, the unique behavior of different species which can adversely affect such estimates, and the potential differences in behavior under different physical oceanographic conditions. In the present study with implanted archival tags in bigeye tuna, the accuracy in geolocation estimates is estimated to be just less than 2 degrees in latitude and 0.25 degrees in longitude. An earlier study in the EEPO with previous-generation Wildlife Computers Mk7 archival tags implanted in bigeye tuna (Schaefer and Fuller, 2002) demonstrated the accuracy in geolocation estimates to be about 2 degrees in latitude and 0.5 degrees in longitude. For Atlantic bluefin tuna *Thunnus thynnus*, the accuracy in geolocation estimates from earlier generation Mk7 and NMT v1.1 (Northwest Marine Technology and Lotek Wireless) archival tags, is reported to be an average of 2.05 degrees in latitude and 0.58 degrees in longitude (Teo et al., 2004).

Previous studies on accuracy of light-based geolocation estimates, obtained from earlier-generation archival tags, have been conducted with captive fish and tags attached to ships and moored buoys (Gunn et al., 1994; Welch and Eveson, 1999, 2001; Musyl et al., 2001). Gunn et al. (1994) implanted archival tags in captive southern bluefin tuna, *Thunnus maccoyii,* at mid-latitudes and estimated accuracy in latitude to be 1.52 degrees and longitude to be 0.54 degrees. Welch and Eveson (2001), based on archival tags attached to moored buoys at high latitudes estimated accuracy in latitude to be 0.76 degrees and in longitude to be 0.41 degrees. Musyl et al. (2001), based on archival tags attached to a moored buoy at low latitudes, estimated accuracy in latitude to be 1.49 to 4.36 degrees and longitude to be 0.15 to 0.29 degrees.

The estimates for accuracy of light-based geolocation estimates from archival tags in the present study are approximations for marine animals at low latitudes that remain in the shallow mixed layer and are not diving near dawn or dusk. Diving behavior by marine animals during these times can significantly degrade the accuracy of light-based geolocation estimates (Gunn and Block, 2001). Tunas are commonly diving during dawn and dusk events, and in the study by Schaefer and Fuller (2002), with free-swimming bigeye tuna, there was a high percentage of days for which geolocation estimates obtained from light level data were unrealistic. Estimates for longitude based on ambient light level data are normally still quite accurate with tunas diving at dawn and dusk, and estimates of latitude can be significantly improved by use of additional information such as matching sea-surface temperatures recorded by archival tags with those derived from remote sensing data, along longitudinal gradients (Teo et al., 2004; Domeier et al., 2004). This approach is also useful for estimating latitude near the spring and autumn equinox, when there is very little variation in day length, and latitude estimation from light level data is impossible (Hill and Braun, 2001). The average light-based geolocation estimates for latitude in the present study, obtained from archival tags implanted in bigeye tuna (Tables 1 and 6), are unexpectedly good, considering that these estimates are derived just a couple of weeks after the spring equinox.

The current-generation geolocating archival tags available from Lotek Wireless (LTD2310) and Wildlife Computers (Mk9) have been shown in this study to provide comparable estimates of geolocation at low latitudes and appear suitable for studies of horizontal and vertical movements of large pelagic marine species within areas of about 1 degree of longitude and 2 to 4 degrees of latitude.

Tables

TABLE 1

Information on five experiments comparing LTD2310 and Mk9 tags: 1) sensor performances from recovered tags 2) sensor performances from new tags 3) sensor performances from new tags 4) estimates of geographical position from light-levels 5) estimates of geographical position from light-levels.

Tag type	Tag #	Build Date	Experiment	Deploy Date	Recovery Date	Duration (days)
LTD2310	A1100	February 2003	1	April 8, 2004	April 8, 2004	0.035
LTD2310	A1104	February 2003	1	April 8, 2004	April 8, 2004	0.035
LTD2310	A1106	February 2003	1	April 8, 2004	April 8, 2004	0.035
LTD2310	A1111	February 2003	1	April 8, 2004	April 8, 2004	0.035
LTD2310	A1115	February 2003	1	April 8, 2004	April 8, 2004	0.035
Mk9	0390045	January 2003	1	April 8, 2004	April 8, 2004	0.035
Mk9	0390052	January 2003	1	April 8, 2004	April 8, 2004	0.035
Mk9	0390054	January 2003	1	April 8, 2004	April 8, 2004	0.035
Mk9	0390075	January 2003	1	April 8, 2004	April 8, 2004	0.035
Mk9	0390080	January 2003	1	April 8, 2004	April 8, 2004	0.035
LTD2310	B3994	November 2004	2	April 15, 2005	April 15, 2005	0.039
LTD2310	B4009	November 2004	2	April 15, 2005	April 15, 2005	0.039
LTD2310	B4023	November 2004	2	April 15, 2005	April 15, 2005	0.039
LTD2310	B4026	November 2004	2	April 15, 2005	April 15, 2005	0.039
LTD2310	B4035	November 2004	2	April 15, 2005	April 15, 2005	0.039
Mk9	0490915	October 2004	2	April 15, 2005	April 15, 2005	0.039
Mk9	0490925	October 2004	2	April 15, 2005	April 15, 2005	0.039
Mk9	0490926	October 2004	2	April 15, 2005	April 15, 2005	0.039
Mk9	0590049	January 2005	2	April 15, 2005	April 15, 2005	0.039
Mk9	0590054	January 2005	2	April 15, 2005	April 15, 2005	0.039
LTD2310	B4012	November 2004	3	April 15, 2005	April 15, 2005	0.038
LTD2310	B4016	November 2004	3	April 15, 2005	April 15, 2005	0.038

TABLE 1, *continued*

Tag type	Tag #	Build Date	Experiment	Deploy Date	Recovery Date	Duration (days)
LTD2310	B4036	November 2004	3	April 15, 2005	April 15, 2005	0.038
LTD2310	B4038	November 2004	3	April 15, 2005	April 15, 2005	0.038
LTD2310	B4052	December 2004	3	April 15, 2005	April 15, 2005	0.038
Mk9	0490911	October 2004	3	April 15, 2005	April 15, 2005	0.038
Mk9	0490916	October 2004	3	April 15, 2005	April 15, 2005	0.038
Mk9	0590050	January 2005	3	April 15, 2005	April 15, 2005	0.038
Mk9	0590051	January 2005	3	April 15, 2005	April 15, 2005	0.038
Mk9	0590053	January 2005	3	April 15, 2005	April 15, 2005	0.038
LTD2310	A0006	January 2002	4	January 16, 2002	April 22, 2003	16
LTD2310	A0031	January 2002	4	January 16, 2002	June 6, 2002	32
LTD2310	A0034	January 2002	4	January 16, 2002	June 11, 2002	21
Mk9	0190020	November 2001	4	January 16, 2002	Nov. 27, 2002	26
Mk9	0190021	November 2001	4	January 16, 2002	June 29, 2002	25
Mk9	0190028	November 2001	4	January 16, 2002	Nov. 27, 2002	25
LTD2310	A1082	February 2003	5	April 4, 2003	April 19, 2003	14
LTD2310	A1084	February 2003	5	April 4, 2003	April 19, 2003	14
LTD2310	A1098	February 2003	5	April 7, 2003	April 19, 2003	11
LTD2310	A1100	February 2003	5	April 8, 2003	April 19, 2003	10
LTD2310	A1101	February 2003	5	April 4, 2003	April 19, 2003	14
LTD2310	A1103	February 2003	5	April 8, 2003	April 19, 2003	10
LTD2310	A1100	February 2003	1	April 8, 2004	April 8, 2004	0.035
LTD2310	A1104	February 2003	5	April 7, 2003	April 19, 2003	11
LTD2310	A1106	February 2003	5	April 8, 2003	April 19, 2003	10
LTD2310	A1108	February 2003	5	April 4, 2003	April 19, 2003	14
LTD2310	A1111	February 2003	5	April 4, 2003	April 19, 2003	14
LTD2310	A1115	February 2003	5	April 8, 2003	April 19, 2003	10
LTD2310	A1117	February 2003	5	April 7, 2003	April 19, 2003	11
LTD2310	A1122	February 2003	5	April 8, 2003	April 19, 2003	10
Mk9	0390045	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390047	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390048	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390053	January 2003	5	April 6, 2003	April 19, 2003	12
Mk9	0390054	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390055	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390059	January 2003	5	March 26, 2003	April 19, 2003	23
Mk9	0390063	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390067	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390070	January 2003	5	April 6, 2003	April 19, 2003	12
Mk9	0390075	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390077	January 2003	5	March 26, 2003	April 19, 2003	23
Mk9	0390081	January 2003	5	April 4, 2003	April 19, 2003	14
Mk9	0390098	January 2003	5	April 5, 2003	April 19, 2003	13
Mk9	0390100	January 2003	5	April 4, 2003	April 19, 2003	14

TABLE 2

Average depths for five LTD2310 and five Mk9 tags in each of three experiments (Table 1), compared to Sea-Bird SBE39 probe depths at specific times. The *Z* (critical value) from the Wilcoxon paired-sample test (Wilcoxon, 1945) is given for the comparisons of the differences between the archival tags and the probe.

Tag type	Experiment	Time (Local)	Average(m) ± (SE)	SBE39 (m)	Average difference (m)	*Z*
LTD2310	1	12:16:28	394.6 (1.400)	402.1	7.5	2.02*
Mk9	1	12:16:28	413.8 (1.168)	402.1	11.7	
LTD2310	1	12:22:00	449.6 (1.470)	452.9	3.3	2.03*
Mk9	1	12:22:00	475.8 (1.158)	452.9	22.9	
LTD2310	1	12:29:00	373.2 (1.530)	377.5	4.3	2.03*
Mk9	1	12:29:00	393.6 (1.099)	377.5	16.1	
LTD2310	1	12:37:00	263.8 (1.497)	267.0	3.2	2.03*
Mk9	1	12:37:00	276.9 (0.914)	266.0	10.9	
LTD2310	1	12:44:20	162.0 (1.303)	163.4	1.4	2.02*
Mk9	1	12:44:20	169.9 (0.714)	163.4	6.5	
LTD2310	1	12:51:00	3.6 (0.927)	4.4	0.8	0.27
Mk9	1	12:51:00	3.8 (0.903)	4.4	0.6	
LTD2310	2	11:36:00	367.6 (1.120)	378.9	11.3	-2.03*
Mk9	2	11:36:00	384.2 (0.340)	378.9	5.3	
LTD2310	2	11:53:00	484.4 (1.360)	487.2	2.8	2.06*
Mk9	2	11:53:00	507.5 (0.320)	487.2	20.3	
LTD2310	2	12:05:00	310.2 (1.160)	312.5	2.3	-2.02*
Mk9	2	12:05:00	322.9 (0.430)	312.5	10.4	
LTD2310	2	12:12:00	212.2 (0.860)	212.0	0.2	-2.02*
Mk9	2	12:12:00	219.4 (0.190)	212.0	7.4	
LTD2310	2	12:20:00	105.8 (0.970)	106.7	0.9	-1.91
Mk9	2	12:20:00	108.5 (0.420)	106.7	1.8	
LTD2310	2	12:28:00	7.6 (0.930)	5.0	2.6	2.02*
Mk9	2	12:28:00	3.9 (0.250)	5.0	1.1	
LTD2310	3	12:47:00	450.4 (0.810)	461.7	11.3	-2.02*
Mk9	3	12:47:00	470.5 (1.100)	461.7	8.8	
LTD2310	3	13:02:00	480.0 (0.320)	484.6	4.6	-2.02*
Mk9	3	13:02:00	505.1 (1.440)	484.6	20.5	
LTD2310	3	13:13:00	304.6 (0.930)	307.6	3.0	-2.02*
Mk9	3	13:13:00	319.3 (1.310)	307.6	11.7	
LTD2310	3	13:21:00	208.4 (0.750)	211.0	2.6	-2.03*
Mk9	3	13:21:00	217.7 (1.080)	211.0	6.7	
LTD2310	3	13:28:00	106.0 (0.550)	107.3	1.3	-1.91
Mk9	3	13:28:00	108.8 (0.750)	107.3	1.5	
LTD2310	3	13:37:00	7.6 (0.810)	5.9	1.7	2.03*
Mk9	3	13:37:00	5.6 (0.250)	5.9	0.3	

*$P<0.05$

TABLE 3

Average stalk temperatures for five LTD2310 and five Mk9 tags, in each of three experiments (Table 1), compared to Sea-Bird SBE39 probe temperatures at specific times. The *Z* (critical value) from the Wilcoxon paired-sample test (Wilcoxon, 1945) is given for the comparisons of the differences between the archival tags and the probe.

Tag type	Experiment	Time (Local)	Average(°C) ± (SE)	SBE39 (°C)	Average difference (°C)	*Z*
LTD2310	1	12:16:28	9.70 (0.013)	9.60	0.105	-2.02*
Mk9	1	12:16:28	9.80 (0.022)	9.60	0.201	
LTD2310	1	12:22:00	8.75 (0.025)	8.71	0.050	-2.02*
Mk9	1	12:22:00	8.72 (0.020)	8.71	0.039	
LTD2310	1	12:29:00	10.01 (0.023)	9.98	0.037	-2.02*
Mk9	1	12:29:00	10.01 (0.025)	9.98	0.053	
LTD2310	1	12:37:00	12.13 (0.022)	12.10	0.032	0.27
Mk9	1	12:37:00	12.12 (0.020)	12.10	0.042	
LTD2310	1	12:44:20	13.85 (0.023)	13.83	0.037	0.81
Mk9	1	12:44:20	13.84 (0.019)	13.83	0.035	
LTD2310	1	12:51:00	27.22 (0.019)	27.14	0.075	1.76
Mk9	1	12:51:00	27.16 (0.019)	27.14	0.036	
LTD2310	2	11:36:00	10.24 (0.010)	10.18	0.057	-2.02*
Mk9	2	11:36:00	10.58 (0.019)	10.18	0.397	
LTD2310	2	11:53:00	8.82 (0.005)	8.81	0.011	-2.03*
Mk9	2	11:53:00	8.92 (0.070)	8.81	0.109	
LTD2310	2	12:05:00	11.72 (0.009)	11.72	0.016	-2.02*
Mk9	2	12:05:00	11.84 (0.090)	11.72	0.118	
LTD2310	2	12:12:00	13.40 (0.008)	13.40	0.012	-0.57
Mk9	2	12:12:00	13.51 (0.110)	13.40	0.110	
LTD2310	2	12:20:00	14.81 (0.010)	14.83	0.024	-1.63
Mk9	2	12:20:00	14.92 (0.080)	14.83	0.104	
LTD2310	2	12:28:00	26.82 (0.010)	26.76	0.062	-2.02*
Mk9	2	12:28:00	26.90 (0.020)	26.76	0.144	
LTD2310	3	12:47:00	9.40 (0.020)	9.26	0.135	-2.03*
Mk9	3	12:47:00	9.53 (0.010)	9.26	0.269	
LTD2310	3	13:02:00	8.81 (0.003)	8.80	0.013	0.55
Mk9	3	13:02:00	8.81 (0.010)	8.80	0.013	
LTD2310	3	13:13:00	11.73 (0.007)	11.74	0.015	-0.68
Mk9	3	13:13:00	11.74 (0.010)	11.74	0.018	
LTD2310	3	13:21:00	13.22 (0.008)	13.23	0.018	-1.39
Mk9	3	13:21:00	13.24 (0.010)	13.23	0.020	
LTD2310	3	13:28:00	14.58 (0.004)	14.59	0.010	0.00
Mk9	3	13:28:00	14.58 (0.012)	14.59	0.022	
LTD2310	3	13:37:00	26.98 (0.019)	26.89	0.091	-1.75
Mk9	3	13:37:00	27.07 (0.025)	26.89	0.177	

* $P<0.05$

TABLE 4
Average tag body temperatures for five LTD2310 and five Mk9 tags, in each of three experiments (Table 1), compared to Sea-Bird SBE39 probe temperatures at specific times. The *Z* (critical value) from the Wilcoxon paired-sample test (Wilcoxon, 1945) is given for the comparisons of the differences between the archival tags and the probe.

Tag type	Experiment	Time (Local)	Average(°C) ± (SE)	SBE39 (°C)	Average difference (°C)	*Z*
LTD2310	1	12:16:28	9.70 (0.013)	9.60	0.105	-2.02*
LTD2310	1	12:16:28	10.23 (0.026)	9.60	0.631	-2.02*
Mk9	1	12:16:28	12.44 (0.083)	9.60	2..841	
LTD2310	1	12:20:00	8.57 (0.007)	8.61	0.042	-2.02*
Mk9	1	12:20:00	8.94 (0.018)	8.61	0.328	
LTD2310	1	12:22:00	8.65 (0.002)	8.71	0.058	-2.03*
Mk9	1	12:22:00	8.80 (0.016)	8.71	0.094	
LTD2310	1	12:29:00	9.94 (0.010)	9.98	0.047	-2.02*
Mk9	1	12:29:00	10.03 (0.012)	9.98	0.047	
LTD2310	1	12:33:00	12.10 (0.007)	12.17	0.067	2.02*
Mk9	1	12:33:00	11.74 (0.019)	12.17	0.427	
LTD2310	1	12:37:00	12.08 (0.007)	12.10	0.020	-2.02*
Mk9	1	12:37:00	12.22 (0.020)	12.10	0.124	
LTD2310	1	12:40:00	13.76 (0.008)	13.84	0.072	2.03*
Mk9	1	12:40:00	13.47 (0.012)	13.84	0.366	
LTD2310	1	12:44:20	13.77 (0.007)	13.83	0.055	-2.02*
Mk9	1	12:44:20	13.89 (0.019)	13.83	0.063	
LTD2310	1	12:51:00	27.07 (0.004)	27.14	0.071	2.03*
Mk9	1	12:51:00	26.72 (0.020)	27.14	0.427	
LTD2310	1	12:52:40	27.06 (0.005)	27.06	0.008	-1.22
Mk9	1	12:52:40	27.10 (0.027)	27.06	0.062	
LTD2310	2	11:37:40	8.92 (0.009)	8.81	0.115	-2.03*
Mk9	2	11:37:40	10.44 (0.040)	8.81	1.635	
LTD2310	2	11:53:00	8.81 (0.008)	8.81	0.014	-2.03*
Mk9	2	11:53:00	8.84 (0.010)	8.81	0.034	
LTD2310	2	11:59:28	11.59 (0.005)	11.71	0.116	2.02*
Mk9	2	11:59:28	10.92 (0.025)	11.71	0.790	
LTD2310	2	12:05:00	11.71 (0.004)	11.72	0.011	0.55
Mk9	2	12:05:00	11.71 (0.010)	11.72	0.024	
LTD2310	2	12:08:20	13.34 (0.007)	13.43	0.090	2.02*
Mk9	2	12:08:20	12.83 (0.020)	13.43	0.604	
LTD2310	2	12:12:00	13.39 (0.007)	13.40	0.018	-1.37
Mk9	2	12:12:00	13.40 (0.000)	13.40	0.004	
LTD2310	2	12:16:00	14.63 (0.012)	14.83	0.202	-2.02*
Mk9	2	12:16:00	14.16 (0.010)	14.83	0.668	
LTD2310	2	12:20:00	14.81 (0.005)	14.83	0.018	0.96
Mk9	2	12:20:00	14.80 (0.000)	14.83	0.026	
LTD2310	2	12:24:00	26.48 (0.012)	26.72	0.237	2.02*
Mk9	2	12:24:00	22.99 (0.019)	26.72	3.727	
LTD2310	2	12:28:00	26.70 (0.009)	26.76	0.056	0.41
Mk9	2	12:28:00	26.69 (0.019)	26.76	0.066	
LTD2310	3	12:48:00	8.90 (0.006)	8.81	0.097	-2.02*

TABLE 4, *continued*

Tag type	Experiment	Time (Local)	Average(°C) ± (SE)	SBE39 (°C)	Average difference (°C)	*Z*
Mk9	3	12:48:00	10.54 (0.060)	8.81	1.735	
LTD2310	3	13:02:00	8.80 (0.008)	8.80	0.013	-1.91
Mk9	3	13:02:00	8.82 (0.012)	8.80	0.023	
LTD2310	3	13:08:28	11.62 (0.004)	11.73	0.109	2.03*
Mk9	3	13:08:28	10.91 (0.025)	11.73	0.823	
LTD2310	3	13:13:00	11.72 (0.005)	11.74	0.017	-2.06*
Mk9	3	13:13:00	11.75 (0.000)	11.74	0.013	
LTD2310	3	13:16:24	13.19 (0.008)	13.26	0.073	-2.02*
Mk9	3	13:16:24	12.70 (0.022)	13.26	0.563	
LTD2310	3	13:21:00	13.22 (0.005)	13.23	0.017	-1.48
Mk9	3	13:21:00	13.24 (0.010)	13.23	0.020	
LTD2310	3	13:24:16	14.48 (0.004)	14.58	0.103	2.02*
Mk9	3	13:24:16	14.06 (0.024)	14.58	0.521	
LTD2310	3	13:28:00	14.55 (0.005)	14.59	0.041	-0.85
Mk9	3	13:28:00	14.56 (0.010)	14.59	0.033	
LTD2310	3	13:32:00	26.54 (0.010)	26.85	0.311	2.02*
Mk9	3	13:32:00	23.09 (0.129)	26.85	3.759	

TABLE 5

Average and range in estimated latitudes and longitudes, based on ambient light-levels, from three Lotek Wireless LTD2310 and three Wildlife Computer Mk9 archival tags, and their associated algorithms, recovered from yellowfin tuna maintained in captivity. Calculated distances from average estimated latitudes and longitudes to actual location of the tank are given.

Tag type	Average Latitude	Range in Latitude	Average Longitude	Range in Longitude	Distance from Actual (nm)
LTD2310	7.61 N	5.80 N – 9.70 N	80.45 W	80.00 W – 81.20 W	20.2
LTD2310	8.47 N	7.20 N – 10.00 N	80.17 W	79.80 W – 80.50 W	63.3
LTD2310	8.09 N	6.50 N – 9.70 N	80.13 W	79.60 W – 80.80 W	40.6
All Tags	8.14 N	5.80 N – 10.00 N	80.24 W	79.60 W – 81.20 W	43.7
Mk9	6.90 N	4.50 N – 10.50 N	80.18 W	79.50 W – 80.98 W	30.9
Mk9	8.50 N	6.00 N – 10.00 N	80.06 W	79.65 W – 80.65 W	65.5
Mk9	5.26 N	3.00 N – 11.00 N	80.18 W	79.78 W – 80.67 W	129.3
All Tags	6.88 N	3.00 N – 11.00 N	80.14 W	79.50 W – 80.98 W	32.1

TABLE 6

Average and range in estimated latitudes and longitudes, based on ambient light-levels, from 13 LTD2310 and 15 Mk9 tags, and their associated algorithms, recovered from bigeye tuna associated with a moored buoy.

Tag type	Average Latitude	Range in Latitude	Average Longitude	Range in Longitude	Distance from Actual (nm)
LTD2310	6.23 S	0.20 N – 13.90 S	95.27 W	94.20 W – 96.00 W	255.1
LTD2310	4.08 S	3.00 S – 13.90 S	95.17 W	94.30 W – 96.00 W	126.2
LTD2310	4.86 S	2.30 S – 12.10 S	95.26 W	94.60 W – 95.60 W	173.1
LTD2310	4.20 S	3.00 S – 6.50 S	95.19 W	94.60 W – 95.60 W	133.0
LTD2310	5.11 S	0.20 N – 14.60 S	95.28 W	94.50 W – 95.90 W	187.9
LTD2310	2.10 S	0.90 N – 4.00 S	95.22 W	94.60 W – 95.60 W	7.3
LTD2310	2.61 S	0.20 N – 8.30 S	95.26 W	94.70 W – 95.70 W	38.2
LTD2310	2.77 S	0.20 N – 5.80 S	95.20 W	94.50 W – 95.90 W	47.3
LTD2310	5.80 S	0.90 S – 12.8 S	95.28 W	94.50 W – 96.10 W	229.5
LTD2310	3.94 S	0.90 S – 12.8 S	95.30 W	94.60 W – 96.10 W	115.6
LTD2310	3.52 S	0.90 S – 7.20 S	95.21 W	94.70 W – 95.60 W	92.6
LTD2310	4.00 S	2.30 S – 11.10 S	95.22 W	94.70 W – 95.60 W	121.0
LTD2310	2.20 S	0.20 S – 4.40 S	95.15 W	94.50 W – 95.60 W	13.2
All	3.95 S	0.90 N – 14.60 S	95.23 W	94.20 W – 96.10 W	118.5
Mk9	3.10 S	0.50 S – 6.00 S	95.32 W	94.66 W – 95.98 W	67.5
Mk9	4.96 S	2.00 S – 12.00 S	95.31 W	94.89 W – 96.07 W	179.0
Mk9	1.43 S	2.00 N – 4.00 S	95.36 W	95.03 W – 95.69 W	34.5
Mk9	2.36 N	5.50 N – 1.00 S	95.27 W	94.58 W – 95.92 W	260.7
Mk9	1.62 S	4.50 N – 6.00 S	95.32 W	94.60 W – 95.86 W	23.2
Mk9	1.25 S	4.50 N – 8.00 S	95.26 W	94.76 W – 95.84 W	44.0
Mk9	7.34 S	1.00 S – 19.50 S	95.33 W	94.73 W – 96.13 W	321.8
Mk9	4.50 S	1.00 S – 13.00 S	95.23 W	94.56 W – 95.87 W	151.2
Mk9	4.50 S	0.50 N – 11.00 S	95.37 W	94.70 W – 95.00 W	151.6
Mk9	5.33 S	2.00 S – 13.50 S	95.38 W	94.86 W – 95.92 W	201.5
Mk9	4.11 S	2.00 N – 12.50 S	95.22 W	94.40 W – 96.10 W	127.6
Mk9	4.02 S	1.00 N – 15.00 S	95.20 W	92.47 W – 95.56 W	122.9
Mk9	7.14 S	2.00 S – 12.00 S	95.17 W	93.87 W – 96.08 W	309.8
Mk9	4.69 S	1.00 S – 13.50 S	95.23 W	94.59 W – 95.86 W	162.8
Mk9	3.29 S	0.50 N – 10.50 S	95.11 W	94.16 W – 96.07 W	78.5
All	3.66 S	4.50 N – 19.50 S	95.27 W	92.47 W – 96.13 W	149.1

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