Marine Mammal Science

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MARINE MAMMAL SCIENCE, 25(1): 199–205 (January 2009)

DOI: 10.1111/j.1748-7692.2008.00227.x

Field validation of an inexpensive time-depth recorder

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Time-depth recorders (TDRs) have proven to be an essential tool in studying the at-sea behavior of marine and aquatic animals (Kooyman 2004, Shaffer and Costa 2006). While their use is often limited by the difficulty of capturing and tagging the animal, in many cases the cost of the tag is the limiting factor (Wilson *et al.* 1989, Ropert-Coudert and Wilson 2004). Reduced instrument costs could benefit research on diving vertebrates by affording increased sample sizes, extending the scope of research objectives within and among species, and opening this technology to a larger segment of the research community.

One reason that the currently available TDRs are expensive is that they are developed explicitly for the animal tagging research market. Relatively small demand coupled with large investments in research, development, and quality control has led to increased precision, accuracy, and reliability. One way of reducing the cost of TDRs is to take advantage of products designed for a high-volume market, such as the dive computers used for recreation sport divers. While these have been bulky and limited to a few dives over a period of hours, new devices are available that can provide an inexpensive alternative to existing animal tags (approximately one-tenth of the price). With the exception of maximum readable depth, the Sensus Ultra TDR (ReefNet Inc., Mississauga, Ontario, Canada) has pressure and temperature sensor specifications similar or superior to most other commercially available electronic TDRs (Table 1). Memory capacity, depth rating, and additional sensor options are limited by comparison, but the Sensus Ultra TDR remains compatible with the diving behavior of many species. Here, we conduct an in-field comparison of the Sensus Ultra TDR against a purpose-built marine animal TDR (Wildlife Computers,

Table 1. Physical description and sampling regime of the two time-depth recorders. Specifications were provided by the respective tag manufacturers.

	Sensus Ultra	WC TDR
Depth (m, resolution ± accuracy)	0.01 ± 0.30	0.5 ± 1%
Maximum readable depth (m)	285	2,000
Temperature (°C, resolution ± accuracy)	0.01 ± 0.8	0.05 ± 0.1
Mass (g)	46	40
Dimensions (cm)	2.5 × 4.5 × 3.3	1.7 × 1.8 × 7.4
Memory (mb)	2	16
Sensors	Depth Internal temperature	Depth Internal temperature Fast-response temperature Light level Wet/dry
Cost per tag[a]	US$125	US$1,200

[a] Price as of 13 September 2007.

Redmond, WA; referred to hereafter as WC TDR) to investigate its utility and comparability for animal-borne deployments.

We deployed five sets of instruments on Galapagos sea lions (*Zalophus wollebaeki*) for two weeks beginning in August 2006 on Caamaño Islet, Galapagos, Ecuador. We simultaneously attached two TDRs: a Sensus Ultra TDR and a WC TDR (MK9 or MK10 model). We also attached VHF radio tags and satellite tags, but the resulting data were not used in this study. The Galapagos sea lion is particularly well suited for this comparison because they experience temperature extremes, make relatively deep dives (most animals routinely dive deeper than 100 m), haul out on sandy and rocky beaches, and are physically rough on tags (S. Villegas-Amtmann, personal observation).

Sensus Ultra and WC TDR specifications are compared in Table 1. We programmed the Sensus Ultra TDRs to record depth and temperature every 2 s after initiation of a 2-m depth change and to stop recording after 5 h of inactivity to conserve tag memory. We programmed the WC TDRs to record depth, internal tag temperature (slow-response), and external tag temperature (fast-response) every 2 s upon immersion in saltwater. The WC TDRs recorded data continuously after sampling was initiated. We attached all instruments using 5-min epoxy (Loctite, Henkel Corp.), mesh netting, and cable ties. The shape of the Sensus Ultra and positioning of the sensors made attachment more difficult than with the WC TDR, so we attached the Sensus Ultra TDRs label down.

Although WC TDRs are tested and calibrated by their manufacturer, we independently estimated the depth accuracy of the WC TDR *via* comparison with an oceanographic quality conductivity-temperature-depth (CTD) unit. We attached five WC TDRs to a Seabird CTD (model SBE-19) and compared the maximum depth readings for a total of 15 unique experimental dives at a mean depth of 244 m. WC TDRs overestimated depth by an average of 4.78 ± 0.91% compared to the CTD unit (S. Simmons and Y. Tremblay, unpublished data). We explicitly assume a linear depth offset, thus all WC TDR depth measurements were subsequently adjusted using this correction factor. All TDR records were analyzed using a purpose-built diving and tracking toolbox written in MatLab (IKNOS, Y. Tremblay, unpublished). Due to differences in sampling resolution and temporal offsets, some dives were only present in one of the two TDR records (either the Sensus Ultra or the WC TDR); these dives were always shallow and of short duration, so they were excluded from further analysis. Comparisons were made between maximum depth and temperature at the bottom of each dive (IKNOS outputs) to ensure appropriate time-synchronization of readings.

Of the five sets of instruments deployed, three were successfully recovered; two instruments were lost because the study animals were not recaptured. The three sets of recovered instruments all collected usable data for a minimum of two weeks at sea. One Sensus Ultra TDR contained less than a complete dataset because the memory was filled and it began overwriting the oldest data (364 of 1,874 dives). Another animal dived beyond the maximum recording depth of the Sensus Ultra (285 m) to depths up to 387 m, as measured by the WC TDR. For these three dives, the Sensus Ultra simply failed to record data below this depth, but was otherwise unaffected by the higher pressure. Specifically, there was no shift in the discrepancy of the depth readings after the deep dives or over the course of the deployment.

The Sensus Ultra TDRs were recovered with slight scratching of the external casing, but the integrity of the tags was not compromised. Although some sand became wedged in the ports of the metal plate covering the depth sensor, this did not appear to influence the resulting data. There was no noticeable corrosion on the communication contacts.

Temperature readings from the Sensus Ultra TDRs were qualitatively similar to the internal temperature readings from the WC TDRs. The Sensus Ultra TDRs overestimated temperature by an average of 0.91 ± 1.10 °C, relative to the fast-response temperature probe of the WC TDR. Although changes in temperature could be recorded, a correction algorithm would need to be applied to obtain accurate measurements of the ambient environment (Daunt *et al.* 2003).

The Sensus Ultra TDRs underestimated depth by an average of 3.39 ± 1.84 m, relative to the WC TDRs. This difference was depth dependent and variable between tags (Fig. 1). Excluding the three dives beyond the maximum recordable depth of the Sensus Ultra TDR, the mean depth values were almost always within 4 m of the value measured by the WC TDRs (Fig. 1). Six of the seven calculated mean dive statistics were within 5% of the value as estimated by the WC TDR and moderate variability between tags was observed (Table 2). Additionally, the Sensus Ultra TDR had a greater depth precision, making it possible to distinguish transit from rest by evaluating the variability in depth measurements while the animal was near the surface.

The clock drift in the Sensus Ultra TDRs was greater than other TDRs: -5.50 ± 0.91 s d^{-1} (Table 2). However, the drift was linear, which would allow for easy

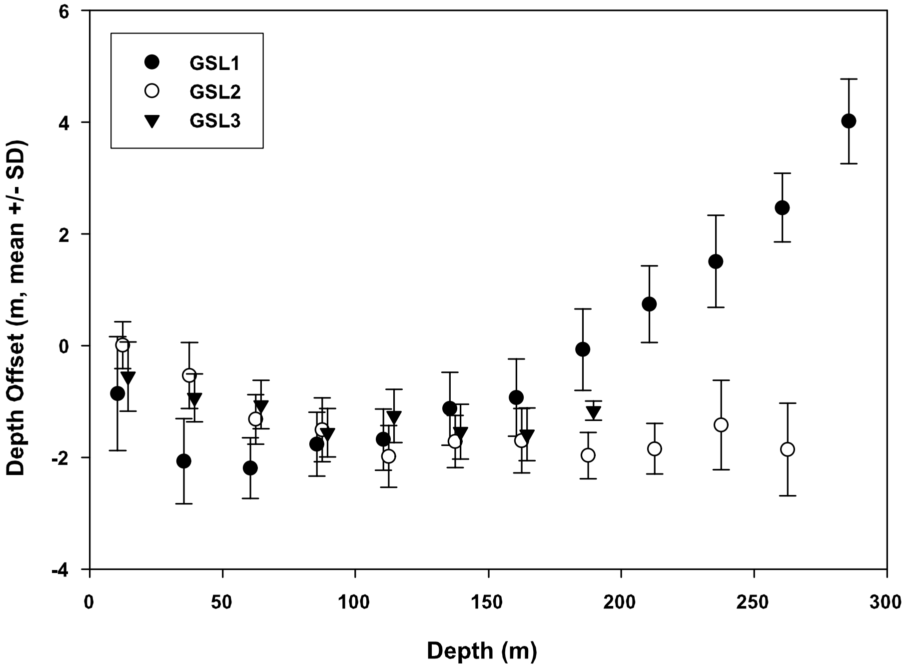

Figure 1. Difference between corrected WC TDR depth readings and Sensus Ultra TDR depth readings as a function of depth. Only measurements within the readable range of the Sensus Ultra are included (<285 m).

correction. The Sensus Ultra TDRs did not show any directional temperature drift over the course of the deployment. However, the temperature data were noisy given the large thermal inertia of the tag and the short amount of time spent at any temperature (the tag never had time to equilibrate). This observation is consistent with other slow-response temperature sensors (McCafferty *et al.* 1999). When compared to the WC TDRs, none of the tags showed a directional drift in the depth difference through time.

Field tests demonstrated the capability of the Sensus Ultra TDR to record dive data for short-duration studies on shallow diving animals. The comparison between the Sensus Ultra and WC TDRs revealed four limitations compared to purpose-built animal TDRs: (1) limited memory precluded high sampling rates over extended study periods, (2) a maximum measurable depth of 285 m is only suitable for relatively shallow-diving species, (3) greater between-tag variability of the depth sensor may require predeployment calibration, and (4) greater clock drift ($\sim$5 s d^{-1}) requires correction for long deployments. A depth offset was also observed in the Sensus Ultra TDR, but this was similar in magnitude to the offset observed in the WC TDR and CTD unit comparison. The Sensus Ultra TDR is not equipped with a light-level sensor that could be used for geolocation position estimates, but deployment with inexpensive light-level geolocation tags (Afanasyev 2004) could enable study of the

Table 2. Differences between mean dive parameters measured from two TDRs on each of the three study animals (Sensus Ultra TDR and WC TDR). Instrument clock drift is also included. "Difference" and "Mean percent difference" columns were calculated using absolute values.

	Sensus Ultra–WC TDR				
	GSL 1	GSL 2	GSL 3	Difference (mean ± SD)	Mean percent difference
Maximum dive depth (m)	−5.28	−1.61	−3.27	3.39 ± 1.84	3.77
Dive duration (s)	5.84	−0.79	2.75	3.13 ± 2.55	1.00
Bottom time (s)	−2.13	−2.45	−1.53	2.03 ± 0.47	1.91
Descent time (s)	4.93	0.22	3.92	3.03 ± 2.48	3.99
Descent rate (m s^{-1})	−0.08	−0.04	−0.10	0.07 ± 0.03	6.32
Ascent time (s)	3.04	1.43	0.35	1.61 ± 1.35	2.51
Ascent rate (m s^{-1})	−0.07	−0.05	−0.04	0.06 ± 0.01	4.86
Surface temperature (°C)	−1.90	−0.92	−2.57	1.79 ± 0.83	7.63
Bottom temperature (°C)	0.82	0.71	1.23	0.92 ± 0.27	5.45
Time drift (s d^{-1})	−5.40	−6.46	−4.64	5.50 ± 0.91	0.01

two basic components of at-sea animal behavior, diving and tracking, at a reasonable price.

The short duration and small sample size of this study precludes definitive comment on the performance of the Sensus Ultra TDR over extended deployment periods; however, the three recovered Sensus Ultra TDRs used in this study were subsequently deployed on juvenile Antarctic fur seals, allowing a qualitative assessment of longer duration deployments (up to 50 d). The instruments recorded usable data and there was no evidence of sensor degradation over the course of the deployment.[1] However, a more rigorous validation of the Sensus Ultra TDR using a larger sample size is recommended before large-scale deployments are conducted.

Despite the limitations outlined above, the Sensus Ultra TDR remains an economical choice for short-term deployment on a variety of species including whales, sea lions, fur seals, shallow-diving seals, penguins, turtles, large fish, and freshwater mammals; although, not all species within these groups are amenable to such studies. Time-depth records from deployments on these animals can provide a wealth of inferential information. Simple TDRs have been used to characterize feeding behavior (Croll *et al.* 2001, Simeone and Wilson 2003), activity budgets and activity bouts (Bowen *et al.* 1999), benthic or pelagic diving (Costa and Gales 2003), foraging success via change in buoyancy (Crocker *et al.* 1997, Biuw *et al.* 2003, Page *et al.* 2005), provide insight into diving physiology and energetics (Acevedo-Gutierrez *et al.* 2002, Costa *et al.* 2004), and help characterize the conservation needs of threatened species (Polovina *et al.* 2003).

Careful consideration of instrument limitations and project goals will be necessary to prevent false economy, but inexpensive TDRs, such as the Sensus Ultra, may provide accurate records of animal diving behavior and could facilitate a new suite of

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[1] Personal communication from G. McDonald, University of California, Santa Cruz, Long Marine Laboratory, 100 Shaffer Road, Santa Cruz, CA 95060, 1 June 2007.

research questions based on statistically relevant sample sizes and population-level assessments.

ACKNOWLEDGMENTS

We wish to thank the Charles Darwin Foundation and the Galapagos National Park. We also thank D. Casper, L. Huckstadt, C. Kuhn, V. Michuy, M. Rutishauser, F. Trillmich, M. Zavanelli, and the Darwin Station volunteers for fieldwork assistance and S. Maxwell for helpful insights and comments. This work was supported in part by the Dr. Earl H. Myers and Ethel M. Myers Oceanographic and Marine Biology Trust, the Friends of Long Marine Lab, and UC Mexus. This research was conducted as part of the Tagging of Pacific Pelagics (TOPP) program, funded by the National Ocean Partnership Program (N00014-02-1-1012), the Office of Naval Research (N00014-00-1-0880 & N00014-03-1-0651), and the Moore, Packard, and Sloan Foundations. All procedures used were approved by the UCSC CARC (IACUC) committee and permitted under NMFS marine mammal permits #786–1463 and #87–143.

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Received: 21 February 2008
Accepted: 27 May 2008