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Know Your Instruments: Ensuring Depth and Temperature Data from Pop-Up Satellite Archival Tags Are Reported Correctly

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Abstract

Pop-up satellite archival tags (PSATs) are electronic devices attached externally to aquatic animals that collect data such as light-level, pressure and temperature. After the PSAT has popped off and floats to the sea surface, archived data are transmitted via the Argos satellite system to the user, eventually providing insight into the spatial ecology of the study animals. Raw data received via the Argos satellite system are either processed directly by the manufacturer of the tag, or the tag manufacturer provides the user with custom-made analysis software, both resulting in data conditioned in files that can then be used for further analysis. Here I argue that insufficient knowledge by users about how PSATs record, archive and transmit data can be problematic. I revisit a dataset previously published from adult bull sharks *Carcharhinus leucas* to give an example of how erroneous depth and temperature data can slip into the peer-reviewed literature. I encourage PSAT users to engage in personal communication with tag manufacturers in order to understand how PSATs record, archive, process and transmit data. I argue that scientists must accurately report what data from PSATs they included and/or excluded in the analysis in order to avoid the publication of incomplete data.

Keywords: Delta limitation; Maximum depth/temperature; Pop-up tag; PSAT; Satellite tagging; Bull shark; Minimum depth/temperature; Microwave Telemetry

Introduction

Modern science is heavily reliant upon new technologies for helping make possible novel insights and advancing the pace of discovery through provision of ever increasing volumes of high quality data. Many scientific questions clearly could not be explored without such innovations. However, with the increasing complexity and availability of technological devices and supporting software, much of it automated, there is the burgeoning issue of researchers using tools inappropriately because they have not been trained properly in the details of how such equipment works [1]. Equally, it is possible that the procedures for using the tools are not sufficiently well detailed or clear such that scientists at different career stages do not understand the devices' workings or appreciate its limitations. As a recent Comment article in the journal Nature suggested [1], there is a need to understand how techniques work before we start using them. All too often though, we press a button on a 'black box' to get an output without knowing the details of its operation. This can potentially lead to problems.

Every year, many hundreds of pop-up satellite archival tags (PSATs) are attached externally to a diverse array of free-ranging aquatic animals, from invertebrates such as squid to vertebrates including turtles, bony and cartilaginous fishes [2-6]. First introduced as single-point, pop-up satellite tags with limited temperature data collection capability [7], PSAT technology and performance have greatly advanced over the years. Today, a variety of PSAT models are available from different manufacturers with tag models and software being constantly developed by the tag manufacturers, providing scientists with unprecedented insight into the behavior of aquatic animals of different sizes and at different temporal and spatial resolutions [8,9].

The basic principle of a PSAT is that after recording data while externally attached to the study animal, the tag floats to the surface from where position estimates and summarized archived data are transmitted to the Argos satellite system (www.argos-system.org) for a period of days to weeks until battery exhaustion. Due to its limited bandwidth, Argos is constrained on the amount of data that can be transmitted through the system, and consequently, manufacturers of PSATs have developed data compression techniques [10-12]. Once received, raw Argos data files are first processed using proprietary algorithms and software either by the manufacturer of the PSAT directly (e.g. Microwave Telemetry Inc., Columbia, Maryland, USA; http://microwavetelemetry.com), or the tag manufacturer provides the user with analysis software to process the Argos data files (e.g. Wildlife Computers, Redmond, Washington, USA; http://www.wildlifecomputers.com). In both cases, the user receives a data report in tag manufacturer-specific formats.

It is reasonable to assume that from the point of view of the user, data included in the reports from PSATs constitute raw data. However, these values are not true raw data, but data that was already processed with algorithms and software developed by the PSAT manufacturers [13]. The details on how PSATs record, archive, process and transmit data as well as the manufacturers' algorithms and software specifications used to process them are generally not publicly available. Whereas I accept that PSATs are commercial products, and hence manufacturers must adopt a 'commercial in confidence' stance to their products, I argue that if crucial raw data collection and processing aspects are unknown to PSAT users, this can lead to the publication of erroneous and incomplete data.

The goal of this article is to present an example of how incorrect and incomplete depth and temperature data can slip into the peer-reviewed literature. Through direct interaction and personal communication with the tag manufacturer I became aware that a dataset I published

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from bull sharks *Carcharhinus leucas* [14] contained some erroneous depth and temperature values, and did not include accurate daily minimum/maximum depths and temperatures. I furthermore review the peer-reviewed literature reporting depth and temperature data collected with the same PSAT model to estimate how widespread erroneous and incomplete datasets may be. By doing so, I highlight the need more generally to engage in personal communication with PSAT manufacturers in order to understand how PSATs record, archive, process and transmit data.

Delta Limited Values

Microwave Telemetry introduced the world's first PSAT for tracking fish in 1997 and since then has continually developed its pop-up tags. Currently, this manufacturer offers two PSAT models, PTT-100 and X-Tag, both of which are available as either standard or high rate versions. I strongly recommend the reader to visit Microwave Telemetry's website at http://microwavetelemetry.com/fish/ for detailed descriptions of tag models and specifications, data recording, compression and transmission techniques, and examples of data measurements and delta calculations.

In the following, I briefly describe how Microwave Telemetry's standard rate PSAT records, archives and transmits data. When the PSAT is in data collection mode, it reads the light, temperature and pressure sensors every ~2 minutes [12] to check if sunrise or sunset is occurring and to update the minimum/maximum light, pressure and temperature readings if necessary. However, these 2 minute readings are only recorded into memory as actual values, apart from the daily minimum/maximum pressure and temperature values, if they fall on the hours 00:00, 06:00, 12:00 and 18:00 or the 15 minute readings on those hours (e.g. 00:15, 06:30 and 12:45; Figure 1a; [15]). Depth and temperature data recorded at any other time are not actual values, but, due to the limited bandwidth of the Argos system, transmitted as the difference between the measurement at that time and the measurement taken 60 minutes earlier. The transmission of differences is done because it takes less capacity to send the change in depth/temperature than to send the actual value via the limited bandwidth of the Argos system [12]. The benefit of this data compression method is that a single Argos message can hold 24 pressure or temperature readings, a day's worth of archived data at hourly intervals (e.g. 0:15, 01:15, 02:15, …, 23:15; [15]). The downside, however, is that because the space in the Argos message allocated for the difference in the raw data is limited, there is a hard limit to the maximum range the tag can transmit from one pressure or temperature reading to the next reading an hour later, i.e. 166.8 m for descents and 172.2 m for ascents [15]. Such values are referred to by Microwave Telemetry as delta limited descents/ascents and increase/decrease in temperature [12].

Similar to PSAT models and software, data reports are constantly being developed and expanded by manufacturers. For example, Microwave Telemetry has made two important amendments to its data reports from standard rate PSATs in 2011. First, the manufacturer highlights delta limited depth and temperature values. Secondly, and not related to delta limited values, data reports from standard rate PSATs now also include, aside from archived depth and temperature readings made at a temporal resolution of 15 minute to hourly readings [12], daily minimum/maximum temperature and pressure values recorded at 2 minute intervals (see previous paragraph, and Supplementary File 1 for examples of former and current data reports).

To the best of my knowledge, both these amendments are highlighted in reports from standard rate PSATs by default only since

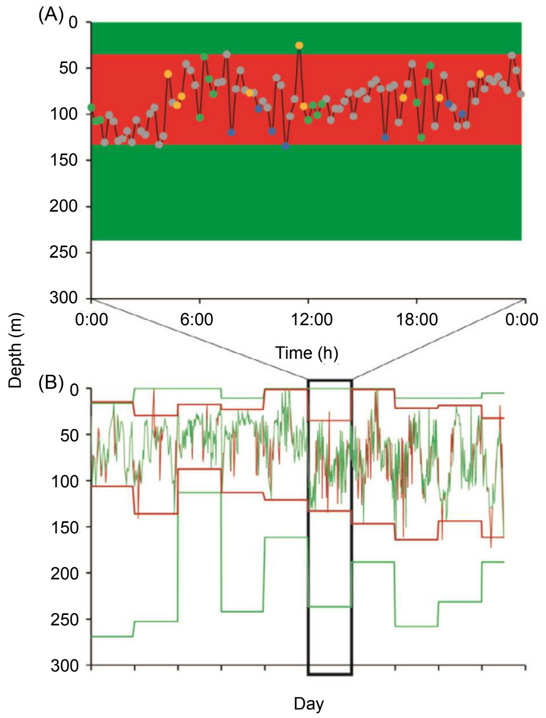

Figure 1: (a) Time-depth series of 12 February 2009 recorded with a standard rate X-Tag attached to a bull shark in Fiji (F14 in [14]). Each dot (96 in total corresponding to four Argos messages each containing 24 pressure readings = the full dataset for that day) indicates a depth value at 15 minute intervals. Green dots denote actual pressure readings whereas all other colours denote values transmitted as the difference between that time and the measurement made 60 minutes before. Blue dots denote delta limited descents (meaning that the bull shark likely was deeper), and yellow dots denote delta limited ascents (meaning that the bull shark likely was less deep). Excluding delta limited values, the red shaded area denotes the vertical niche calculated from archived data; the green shaded area denotes the vertical niche calculated using minimum/maximum depth values recorded at 2 minute intervals. The entire time-depth series of tag F14 (7 -16 February 2009) is shown in (b); red lines denote the time-depth series including delta limited values and daily minimum/maximum depths calculated from archived data; green lines denote the time-depth series excluding delta limited values and daily minimum/maximum depths calculated from 2 minute sensor readings.

2011. This, in my view, is an important potential gap in knowledge because it is likely that researchers that did not engage in personal communication with the manufacturer prior to 2011 may have regarded all depth and temperature data points as actual values, and identified daily minimum/maximum depths and temperatures from archived 15 minute readings. Thus, published datasets may contain erroneous and incomplete depth and temperature data. This, as a consequence, may have implications for the description and interpretation of the vertical behavior of the species studied.

Expanded Vertical Niche of the Bull Shark

Similar to using up-to-date techniques [16], updated PSAT data reports including previously unavailable information, enable users to revisit datasets and where applicable, amend published information b(for an example see [15] which corrects [17]).. In the following I do just that and re-examine a dataset previously published from adult bull sharks that contains erroneous and incomplete depth and temperature values [14]. For each animal tagged with a standard rate PSAT and included in the previous analysis (13 bull sharks; see [14], the percentage of delta limited depth and temperature values was calculated from

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updated data reports provided by Microwave Telemetry, and the depth and temperature ranges calculated using daily minimum/maximum values recorded at 2 minute intervals were compared with previously published values [14].

The reports from four bull sharks (30.8%) included delta limited depth and temperature values. Three reports contained ≤ 1% delta limited depth and temperature values and the report from bull shark F14 [14] contained 20.2% of delta limited depth and 1% of delta limited temperature values. Most notably, this shows that delta limited values can be a distinct variable not only in data reports of oceanic species known to dive to considerable depths and showing large vertical displacements [12,15,18-21], but also species that are mostly found in shallow coastal waters such as bull sharks [22].

Using daily minimum/maximum depth and temperature values recorded at 2 minute intervals resulted in broader vertical niches overall and, as a consequence, the thermal niches for the majority of the animals were also broader (Table 1). All bull sharks had broader daily vertical niches on the majority of days when using actual minimum/maximum depth readings instead of identifying the values from archived 15 minute readings (Figure 1b and Supplementary Figure S1).

The issue of delta limitation in combination with using daily minimum/maximum depths recorded at lower temporal resolution can be illustrated clearly. For example, in the previous paper, the deepest depth reported for any bull shark was 204.4 m (F11 in [14]). This archived datum was actually a delta limited descent meaning that the fish likely to have been deeper [12]. Taking maximum depth readings from updated data reports, three bull sharks (F9, F11 and F14 in [14]) were recorded deeper, with the deepest depth being 349.7 m (Table 1). This expands the vertical niche of this species to within the mesopelagic (200-1000 m) realm.

Evidence for Erroneous and Incomplete Data in the Literature

To estimate the potential issue of erroneous and incorrect depth and temperature data in the peer-reviewed literature, I ran a search in Web of Science and Google Scholar (February 2014). Excluding my own papers [14,15,17], I found 32 papers that report depth and temperature data collected with Microwave Telemetry's standard rate PSATs (Supplementary Table S1). I checked in each paper whether or not it was mentioned that certain depth and temperature variations could not be detected by the tag (=delta limited values), and if values recorded at 2 minute intervals were used to determine daily minimum/maximum depths and temperatures. Six papers (= 21.9%), most of them recently published (i.e. after 2011 when Microwave Telemetry made the two amendments to its data reports, and the concept of delta limitation was explained to the user on the manufacturer's website), refer to the concept of delta limitation [12,18-21,23,24]. However, it is notable that only one of these papers [12] mentions that also certain temperature variations could not be detected by the PSATs used. Further, none indicates unequivocally that values recorded at 2 minute intervals were used to determine daily minimum/maximum depths and temperatures (Supplementary Table S1).

Conclusion

As stated above, the details on how PSATs record, archive, process and transmit data as well as the manufacturers' algorithms and software specifications that are used to process them are generally not publicly available. It is therefore of utmost importance that users are trained properly in the details of how such equipment works by collaborating and entering into a dialogue with the tag manufacturers [10]. This would ensure that the procedures for using the technological tools are sufficiently well detailed and clear so that scientists at different levels can understand the devices' workings and appreciate its limitations. This is even more important as PSAT models and software frequently change and are constantly developed by the tag manufacturers.

Hence, of similar importance is that standards of reporting of the different PSAT models used and the parameters they record be defined and employed for all publications reporting such data (Supplementary Table S1). For example, now that the issue of delta limitation is becoming known among users of Microwave Telemetry's standard rate PSATs, and the manufacturer amends its data reports accordingly, it should become standard that researchers report in publications whether or not datasets contained delta limited depth and/or temperature values. Further, these values should be quantified and it should be clearly indicated if and how such data points were included in analysis [12,15,18-20,24]. This would ensure that not only readers but also reviewers are as much as possible aware of the hardware and software specifications, filters applied and any potential biases in the data, and can take this into account when interpreting the results and checking them for accuracy.

Tag number	Depth range archived	Depth range 2 minute	Δ depth range	Temperature range archived	Temperature range 2 minute	Δ temperature range
B1	0–139.9	0–172.1	+32.2	24.25–26.92	22.20–27.10	+2.23
B2	0–91.5	0–156	+64.5	20.21–26.92	14.63–26.92	+5.58
B3	0–91.5	0–139.9	+48.4	25.13–26.19	25.13–26.55	+0.36
B4	0–16.1	0–26.9	+10.8	23.05–27.10	23.22–27.10	-0.17
F4	0–96.8	0–118.3	+21.5	24.25–26.01	23.22–26.01	+1.03
F5	5.4–07.6	0–107.6	+5.4	24.78–26.37	24.43–26.37	+0.35
F6	0–102.2	0–129.1	+26.9	24.60–26.37	24.08–26.73	+0.88
F7	5.4–96.8	0–96.8	+5.4	24.60–27.28	24.60–27.46	+0.18
F8	10.8–02.2	0–129.1	+37.7	25.48–26.37	24.25–26.37	+1.23
F9	0–161.4	0–290.5	+129.1	21.70–27.46	21.70–29.52	+2.06
F10	21.5–43.0	0–53.8	+32.3	26.19–26.19	26.01–26.37	+0.36
F11	0–172.1	0–349.7	+177.6	21.53–28.39	20.21–28.39	+1.32
F14	1.3–164.1	0–269.0	+106.2	21.37–29.33	18.91–29.52	+2.65

Table 1: Vertical and thermal niches of bull sharks. Depth and temperature ranges calculated using minimum/maximum values recorded from archived data and from 2 minute sensor readings (see text for details). Δ was calculated by subtracting the depth/temperature range from archived data from the respective range from 2 minute intervals so that + indicates a broader and - a less broad vertical/thermal niche. Note that 5.4 m and 0.18°C are the respective resolutions (± errors; for PSAT specifications see Brunnschweiler et al. [14]).

In summary, and if we are to avoid using tracking tools as 'black boxes' in aquatic animal telemetry studies, I feel that, apart from introducing standards of reporting, the dialogue between users and tag manufacturers should become the norm. Personal communication with PSAT manufacturers will become increasingly necessary as the sophistication of devices and analysis techniques develop further. And last but not least, building on the experience with bull shark datasets revisited in this article and with a similar dataset from a whale shark [15,17], I encourage other users of Microwave Telemetry's standard rate PSATs to ask the manufacturer for updated data reports and re-examine their published datasets. Given the fact that these biologging devices are relatively expensive and data transmission is limited, it seems appropriate to extract as much information as possible from every single PSAT.

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