Post-release mortality and behavior of sharks in shore-based recreational fisheries using citizen scientists and low-cost tags

John A. Mohan , R.J. David Wells, Marcus Drymon, Gregory Stunz, and Matthew Streich

SEDAR77-DW07

Received: 11/29/2021

Revised: 12/16/2021

This information is distributed solely for the purpose of pre-dissemination peer review. It does not represent and should not be construed to represent any agency determination or policy.

Please cite this document as:

Mohan, John A., R.J. David Wells, Marcus Drymon, Gregory Stunz, and Matthew Streich. 2021. Post-release mortality and behavior of sharks in shore-based recreational fisheries using citizen scientists and low-cost tags. SEDAR77-DW07. SEDAR, North Charleston, SC. 66 pp.

Post-release mortality and behavior of sharks in shore-based recreational fisheries using citizen scientists and low-cost tags

NOAA Cooperative Research Program (NOAA Federal Award Number: NA19NMF4540065)

Principle Investigators: John A. Mohan[1], R.J. David Wells[1], Marcus Drymon[2], Gregory Stunz[3], and Matthew Streich[3]

[1]Texas A&M University at Galveston, Galveston, TX; [2]Mississippi State University, Coastal Research and Extension Center, Biloxi, MS; [3]Harte Research Institute for Gulf of Mexico Studies, Texas A&M University–Corpus Christi, Corpus Christi, TX

II. Executive Summary: Recreational shark fishing has become increasingly popular in recent decades, especially shore-based fishing that has provided access to a broad demographic of anglers. Catch and release shark fishing has become best practice to limit deleterious effects on overall stocks, but species-specific stress levels and post-release mortality in shore-based fisheries is unclear. Advances in electronic tagging technology, including acceleration data loggers (ADLs) and pop-up satellite archival transmitting (PSAT) tags, now provide unprecedented insight into fine scale (e.g. seconds to minutes with ADLs) and long term (e.g. daily to monthly with PSAT) behavior of sharks post-release. Using electronic tags, research has demonstrated that the physical injury and physiological stress inflicted upon sharks caught and released contributes directly to post-release mortality (PRM), which can occur immediately or as a result of cumulative sub-lethal effects causing fitness losses over time. Currently, PRM estimates from boat-based shark fisheries are primarily used to inform management strategies and research into the contribution of shore-based shark fishing to overall PRM rates is lacking. This project cooperatively engaged recreational shore-based shark anglers to deploy ADLs and PSATs on blacktip, bull, tiger and hammerhead sharks (*Sphyrna spp.*) to estimate post-release behavior and mortality rates. These species vary in physiological sensitivity to capture from highly sensitive (hammerhead species) to less sensitive (tiger) and the tagging approach ensured increased tag deployment rates in unpredictable but diverse catches to explore species specific mortality rates. The objectives of the study were: 1) Characterize both fine and broad-scale post-release behavior and mortality of beach-caught sharks in Texas using ADLs and PSATs deployed by experienced recreational fishermen; 2) Compare behavioral capture responses among diverse shark species with variable capture-sensitivities (blacktip, bull, tiger, hammerhead species) and seasonal environmental variables; 3) Host both pre- and post-tagging shark angler workshops to train anglers in shark identification, disseminate tagging results and discuss how results can be applied to shark conservation efforts. Sharks were captured by recreational shore-based anglers from August 2018 to October 2021. For each captured shark, fight time, handling time, and biological metrics including length and sex were recorded, and release condition was scored as good, fair, poor, or dead.

Of the 21 PSATs deployed, 8 PSAT tags were recovered and provided high-resolution archived data for temperature, light level, and depth measurements every few seconds to confidently determine shark outcomes. Six sharks survived and 2 sharks experienced mortality 10 minutes to 1.25 hours after release. Seven tags transmitted limited data, but the data was sufficient to

determine shark status based on high-resolution depth data for the final 5 days of deployment and daily summaries for minimum and maximum depths, temperature, and light levels: 7 sharks survived, and 1 shark experienced mortality immediately after release. 1 tag on a shark that experienced mortality less than 10 min after release returned light level, depth, and temperature data that was sufficient to determine the shark was ingested by a predator. Six tags did not transmit any data after deployment and thus we cannot determine the post-release fate of those sharks. The PRM rate across all the PSAT tags was therefore found to be 20% (3/15) (Table 1; Appendix 1).

Of the 22 ADLs deployed, 4 were not recovered or programming/battery/user error provided no data. 18 ADLs were recovered for analysis: 13 sharks survived, and 5 sharks experienced mortality within seconds up to 5 hours post release. The PRM rate across all the ADL tags was therefore found to be 27.8% (5/18) (Table 2; Appendix 2). Across both tag types a total of 20 bull sharks were caught and tagged: 1 shark experienced mortality, 13 sharks survived, and 6 tags had unknown fates due to tag malfunction. The post-release mortality rate for bull sharks was therefore estimated to be 7.1% (1/14). A total of 14 blacktip sharks were caught and tagged: 5 sharks experienced mortality, 5 sharks survived, and 4 tags did not transmit any data. The post-release mortality rate for blacktip sharks was therefore estimated to be 50% (5/10). A total of 5 tiger sharks were caught and tagged and all survived, suggesting 0% mortality. However, one tiger shark exhibited mortality 41 days after tagging that was categorized as a natural mortality and not due to capture stress**.** That said, the cumulative sub-lethal effects of tagging such as gear left in the body or infection at the tagging site could have significantly reduced fitness, resulting in a delayed post-release mortality. Although scalloped hammerheads were originally targeted, 2 great hammerheads were caught and tagged: 1 experienced immediate mortality and was ingested, and 1 survived up to 16 days following release. The mortality rate for great hammerheads was therefore estimated at 50%.

Understanding how fishing mortality rates may differ between shore-based and boat-based recreational fleets and across different species is essential for accurately assigning gear type and mortality estimates in stock assessment models. Angler outreach and education was achieved by PIs attending the *Sharkathon* shore-based fishing tournament in October 2021, reaching hundreds of participating anglers, even though 2020 survey ambitions were delayed due to COVID19. Follow-up angler surveys will occur in 2022 after finalizing/publishing results to generate reference data on angler attitude and response to research results. In summary, this collaborative project combined cooperative angler citizen scientists and advanced electronic tags to provide an empirically derived post-release mortality rate estimate across different species in a recreational shore-based fishery for use in management protocols.

A. Purpose

A.1. *Detailed description of problem or impediment of fishing industry that was addressed*: Many state agencies do provide guidelines on best-practices for handling fish that are not based on conclusive science, thus it is important to generate data on best handling practices, and for the public to understand the role science plays in fisheries management. Information from this work is particularly timely for managers, as the Florida Fish and Wildlife Conservation Commission is currently accepting public comment on potential new management measures for the Florida shore-based shark fishery. Additionally, current post-release mortality rate estimates used in stock assessment models are derived from boat-based shark fisheries, and do not incorporate the contribution of shore-based fisheries in overall mortality rate estimates. This project directly addresses the need of the CRP by using a well-established cooperative relationship between Texas shore-based fishermen and PIs to **provide estimates of post-release mortality of shark HMS across gear types that is directly applicable to resource management.** The information gained from this proposed project will provide usable and relevant information to aid fishery researchers, scientists, and managers to make informed management decisions that can be directly utilized for future assessments. In particular, the research-track hammerhead stock assessment is ongoing, and this project provides a very preliminary dataset for recreational PRM estimates for hammerheads caught from shore.

A.2. *Objectives of the project:* Specific objectives include: 1) Characterize both fine and broad-scale post-release behavior and mortality of beach-caught sharks in Texas using ADLs and PSATs deployed by experienced recreational fishermen; 2) Compare behavioral capture responses among diverse shark species with variable capture-sensitivities (blacktip, bull, tiger, scalloped hammerhead) and seasonal environmental variables; 3) Host both pre- and post-tagging shark angler workshops to train anglers in shark identification, disseminate tagging results and discuss how results can be applied to shark conservation efforts.

B. Approach

B.1. *Detailed description of the work that was performed:* Highly experienced shore-based anglers were recruited from the Galveston Bay area, Port Aransas, and Padre Island National Seashore (PINS) in Texas. Anglers were trained in shark identification, data collection, and tag deployment; however no further input was provided by investigators to ensure the preservation of normal techniques utilized by shore-based recreational fisherman (see Appendix 4). Fishing, data collection, and tag deployment was conducted from August 2018 to October 2021. Metrics for data collection included fight time, handling time, shark length and sex, and condition upon release. Fight time refers to the time from the hooking of the shark to the landing of the shark, while handling time refers to the time the shark is landed on the beach to its release back into the water. Release condition was determined using the vitality code from Manire et al. (2001) and the indices suggested by Braccini et al. (2012), and was described as either good, fair or poor. Species targeted included Scalloped Hammerheads, Bull Sharks, Tiger Sharks, and Blacktip Sharks, all commonly caught species in the Gulf of Mexico with known variations in susceptibility to PRM. Tags utilized in this study included pop-off satellite archival transmitting (PSAT) tags and acceleration data loggers (ADL), fitted with smart position and temperature SPOT) Argos trackers

The ADLs utilized in this study recorded triaxial movement at a frequency of 25 Hz, ambient ocean temperature at 1Hz, and depth at 0.033 Hz and were designed following the methodology presented in Whitmore et al. (2016) and Lear & Whitney (2016). Captured sharks were beached to allow anglers to mount tags to the dorsal fin of the shark by drilling two holes and securing the package with monofilament or plastic cable ties. The tag packages include an accelerometer and VHF antenna enclosed in a float for package relocation and recovery following release. Tags were labeled with PI contact information to facilitate recovery by the public. ADLs are programmed to release from the shark in response to a galvanic timed-release system that dissolves in seawater 12-72 hours following deployment. Tags were located using a hand-held VHF receiver, or via mail or pick-up when located by members of the public.

The PSATs utilized in this study recorded temperature, depth, and changes in light level over long-term deployments to analyze shark behavioral responses to capture and release on a broad time scale. Captured sharks were beached to drill a hole in the dorsal fin for PSAT attachment with a tether that consisted of monofilament or nylon coated stainless steel wire covered in Tygon tubing to reduce chaffing and crimped close to the dorsal fin. Three different types of PSAT style tags created by two different manufacturers were utilized. Traditional PSAT tags manufactured by Lotek (n=6) were pre-programmed to release after a 28-day deployment. Survivorship Pop-off Archival tags (sPATs) and miniPATs manufactured by Wildlife Computers were pre-programmed to release after 60 and 180 days, respectively (n=12, n=1, respectively). All tags were pre-programmed to release if constant depth was detected for 3-5 days, meeting the mortality clause for premature release. Following release, tags were located using an Argos goniometer or PTT antenna for recovery.

Data from both the ADLs and PSATs were obtained directly when tags were able to be physically recovered, or, for PSATs, via satellite transmission when recovery was not possible. When high-resolution data was available through the recovery of a tag, Igor Pro was used to create time-series analyses of changes in environmental conditions over the course of deployment. PSAT data obtained via satellite transmission provided data across larger time sampling units, however disruptions in satellite connectivity due to weather or physical obstructions did occur. This led to some instances where data transmission was prevented, effectively reducing data recovery. The data that was recovered via satellite was analyzed using both Igor Pro (high frequency recordings) and Prism (daily minimum and maximum values) to decode adequate data detail to determine the fate of the shark (see Appendix 1).

In all cases, temperature, depth, and changes in light level (or x-y-z axis) from each tag was plotted and examined to determine the status of each shark. Mortality events were identified by periods of constant depth, as the four species targeted are obligate ram-ventilators for whom constant motion, visualized by consistent depth changes (or z-axis), is necessary for survival. Ingestion events were determined by a period of constant depth (30 minutes or more), indicating a mortality occurred, followed by a return to depth variations, low light levels, and constant temperature. For tags that were hypothesized to have been ingested, it was found that these tags were recovered with their tethers intact, indicating the release mechanism was not triggered. This supports the hypothesis that the tagged shark experienced mortality and was preyed upon before the mortality clause could be met to trigger release. At a later time, the tag was regurgitated with its release mechanism still intact and floated to the surface to be recovered.

Sharks were determined to have survived if depth, light level, and temperature variations were consistent with normal shark movement and ambient ocean conditions over the course of the deployment, up to 15 days following release (see Appendices 1 and 2). Results were the compiled to determine overall mortality rates as well as species specific mortality rates.

B.2. *Project management: List individuals and/or organizations actually performing the work and how it was done:*

This project is highly collaborative involving recreational anglers, academic scientists including professors, research scientists, postdoctoral researchers and graduate students. Individuals working on the project include scientists: Dr. John Mohan, Dr. R.J. David Wells, Dr. Travis Richards, Dr. Marcus Drymon, Dr. Matthew Streich, Dr. Greg Stunz, Dr. Kesley Banks, Dr. Nick Whitney, Connor White, MS graduate student Addie Binstock; recreational anglers involved with electronic tagging: Eric Ozolins, John-Michael Kamel, Donnie Tidewell and several hundred recreational anglers that participate in the *Sharkathon* and Texas Shark Rodeo that will be providing angling data through the tournaments (see Appendix 4).

C. Findings

C.1. *Actual accomplishments and findings:*

A total of 21 PSATs and 22 ADLs were deployed on bull sharks (n=20), blacktip sharks (n=14), tiger sharks (n=6), and hammerhead sharks (n=2). Of the 39 sharks caught for which metadata was available, 74.4% (29/39) were released in good condition, 23.1% (9/39) in fair condition, and 5.1% (2/39) in poor condition. Of the 21 PSATs and 22 ADLs deployed, 28.6% (6/21) of PSATS and 18.2% (4/22) of ADLs did not have recoverable data after deployment and thus we were unable to determine post-release fate of those sharks. 81.8% (18/22) of ADLs were recovered, which provided high resolution measurements of depth, temperature and tri-axial movement sufficient to accurately determine post-release fate. 71.4% (15/21) of satellite tags provided definitive data on shark fate and 8 PSAT tags were recovered (38.1%), which provided high resolution archived measurements of depth, temperature, and light level. Results will be presented below in several sections related to project objectives.

C.1.a. Post-release mortality: PSAT Tags

Of the 21 sPATs, Mini-PATs, and PSATLIFE tags deployed over the course of the study, there were a total of 3 confirmed mortalities, 12 confirmed survivors, and 6 tags for which no data was transmitted. 15 tags provided definitive data on shark fate and 8 tags were recovered, which provided high resolution archived measurements of depth, temperature, and light level. Both the archived and transmitted data from the 15 reporting tags was used to determine post-release fate. (Table 1; Appendix 1).

C.1.b. Post-release mortality: ADL Tags

Of the 22 ADLs deployed over the course of the study, there were a total of 5 confirmed mortalities and 13 confirmed survivors, with 4 tags that did not have recoverable data (Table 2; Appendix 2).

Table 1: Results of 21 satellite tags deployed on blacktip sharks, bull sharks, tiger sharks, and great hammerheads in the Gulf of Mexico by shore-based recreational anglers. PTT tag IDs in bold were recovered, providing archived high-resolution datasets. PSATLIFE tags denoted with an * were pre-purchased and included in the dataset to increase sample size. Mini-PAT tags are italicized. FL= fork length; ND=no data. See Appendix 2 for plots of each tag.

Shark_ID	Status	Date Capture	Fight Time (min)	FL (cm)	condition	sex	PTT	data days	time to mortality
C_leu01_P	ND	3/25/20	22	213	good	F	180825	0	
C_leu02_P	ND	3/20/20	19	150	good	F	180826	0	
C_leu03_P	ND	3/25/20	28	185	good	M	195447	0	
C_leu04_P	survive	3/17/20	11	114	good	F	**195449**	10	
C_leu05_P	mortality	8/17/18					175046*	28	immediate
C_leu06_P	survive	8/7/18		140		M	**175048***	28	
C_leu07_P	survive	7/20/19	10	130	good	F	**175041***	28	
C_leu08_P	survive	7/20/19	10	153	good	F	175045*	28	
C_leu09_MP	survive	4/5/21	14	183	good	M	*205517*	47	
C_leu10_MP	ND	4/24/21	17	157	good	M	*182795*	0	
C_lim01_P	ND	12/5/19	10	135	good	F	180824	0	
C_lim02_P	mortality	8/15/18		144			**175047***	16	1.25hr
C_lim03_P	survive	5/12/19	10	145	good	F	**175043***	28	
C_lim04_P	ND	12/27/19	10	150	good	F	175044*	0	
G_cuv01_P	survive	8/20/20	49	231	good	M	195443	57	
G_cuv02_P	survive	8/22/20	58	287	good	F	195442	60	
G_cuv03_P	survive	6/14/21	17	203	good	M	**195445**	5	
G_cuv04_P	survive	7/3/21	23	226	good	F	195448	51	
G_cuv05_MP	survive	8/26/21	23	226	good	F	*205518*	57	
S_mok01_P[1]	mortality	10/21/20	18	175	fair	F	**195446**	8	45 min
S_mok02_P	survive	4/12/21	22	168	fair	F	**195444**	16	

[1]**S_mok01_P:** Shark was double tagged with ADL PTT ID 182622

Table 2: Results of 22 ADL tags deployed on blacktip sharks, bull sharks, tiger sharks, and great hammerheads in the Gulf of Mexico by shore-based recreational anglers. FL= fork length

Shark_ID	Status	Date Capture	Fight Time (min)	FL (cm)	condition	sex	PTT	data days	time to mortality
C_leu01_A	survive	5/13/20	8	129	fair	M	182632	1	
C_leu02_A	survive	7/10/20	7	130	poor	F	182620	1	
C_leu03_A	survive	10/17/20	23	147	good	F	182621	4	
C_leu04_A	survive	10/13/20	5	119	fair	M	182618	2	
C_leu05_A	survive	10/13/20	10	130	good	M	182632	5	
C_leu06_A	ND	10/13/20	7	135	good	M	182620	0	
C_leu07_A	survive	10/30/20	8	130	fair	F	182618	1	
C_leu08_A	survive	10/30/20	7	130	fair	F	182632	3	
C_leu09_A	survive	11/19/20	11	137	good	F	182618	1	
C_leu10_A[1]	ND	11/22/20	390	147	fair	F	182622	0	
C_lim01_A	survive	7/2/20	3	135	good	F	182618	1	
C_lim02_A	mortality	9/26/20	10	126	fair	F	182621	1	1hr
C_lim03_A	mortality	10/1/20	17	132	good	F	182622	2	5hr
C_lim04_A	survive	10/30/20	16	130	good	F	182621	3	
C_lim05_A	survive	11/1/20	11	137	good	F	182622	2	
C_lim06_A	ND	11/14/20	12	135	good	F	182621	0	
C_lim07_A	ND	5/20/21	11	127	good	F	182621	0	
C_lim08_A[2]	mortality	6/12/21	6	135	poor	F	182632	0	immediate
C_lim09_A	mortality	6/16/21	6	119	good	F	182632	1	1hr
C_lim10_A	survive	6/16/21	4	114	good	M	182620	3	
G_cuv01_A	survive	7/13/21	25	89	good	M	182621	1	
S_mok01_A[3]	mortality	10/21/20	18	175	fair	F	182622	5	45min

[1]**C_leu10_A:** shark picked up a bait and line drifted down the beach. Fish was hooked for hours. Swam off, but was fatigued. 20 minutes to reel the shark in; tag lost

[2]**C_lim08_A:** The shark was brought up on the beach and thrashed repeatedly, dislodging the tag multiple times resulting in a handling time of 8 minutes. The shark was initially released at 20:38 central but had trouble clearing the first sand bar. The angler grabbed the shark again at 20:40 central, moved it past the first sand bar, and spent a couple of minutes reviving the shark. Shark was released a second time at 20:42 central. At approximately 21:10 central, the shark was seen dead in the surf. The shark was brought ashore and the tag was removed and turned off.

[3]**S_mok01_A:** Shark was double tagged with sPAT PTT ID 195446

C.1.c. Post-release behaviors of survivors

Immediate post-release mortality occurred within minutes (N=2) or after 0.75 to 5 hours post-release (N=5). For sharks that experienced mortality (N=7), evidence of ingestion occurred for the hammerhead S_mok01 and the blacktip C_lim09. Analysis of combined accelerometer data (Appendix 2) for blacktip, bull and tiger sharks demonstrate that tail beat frequency slows down after about 24 hours for bull sharks, and continually decreases for blacktip sharks up to about 36 hours where is starts to plateau. Overall dynamic body acceleration was highly variable for bull sharks and displayed a decreasing trend up to about 24 hours for blacktip sharks. Histogram plots from PSAT tag data demonstrate high variability in temperature and depth preferences among individual sharks and species (Appendix 3).

C.2. *If significant problems development which resulted in less than satisfactory or negative results, they should be discussed.*

The primary issue encountered was premature release and non-reporting of tags. Of the 21 PSAT tags deployed, no transmission or data was received from 6 tags. Non-reporting is common in satellite tagging studies and cannot be avoided. ADLs require recovery for data acquisition, which proved difficult for the tags that washed ashore in Mexico. One ADL tags was lost and never recovered due to landing in Mexico. The COVID-19 pandemic also delayed some research progress, but efforts by the PI and participating anglers has allowed research to be conducted. Tags continued to be deployed as weather conditions and social distancing conditions allowed.

C.3. *Description of need, if any, for additional work:*

D. Evaluation

D.1. *Describe the extent to which the project goals and objectives were attained. This description should address the following:*

D.1.a. *Were the goals and objectives attained? How? If not, why?*

The data obtained is sufficient to meet the goals and objectives. From the reporting PSATs and recovered ADLs, species specific post-release fates were able to be determined over fine and long-term periods. From this information, comparisons of behavioral capture responses between blacktips, bulls, tigers, and hammerheads were able to be conducted. Shark recovery time as a factor of environmental, biological, and capture conditions will only be able to be determined for bull sharks due to small sample sizes for all other species.

D.1.b. *Were modifications made to the goals and objectives? If so, explain.*

The primary modification was tagging great hammerhead sharks as opposed to scalloped hammerheads, since no scalloped hammerheads were encountered. The COVID pandemic prohibited the planned pre-angler workshop that was part of the outreach component of the project. A post-angler survey is planned for the 2022 *Sharkathon* tournament to assess angler attitudes and perceptions of the PRM rate results and if the project affected their behavior in handling sharks caught from the shore.

D.2. *Dissemination of Project results. Explain, in detail, how the project's results have been, and will be disseminated.*

Shark tagging and tag recovery efforts have been disseminated on social media platforms. The general public that has assisted with tag recoveries have been sent Texas A&M Shark Biology and Fisheries Science Lab hats, coffee cups, and shirts and were informed of the project. Presentations by the PI were made to broaden outreach by communicating the progress of the project to the Fall 2020 Biology of Fishes class at the University of New England. An outreach 'Scientist-a-go' presentation entitled "*Tag your it! Exploring the secret lives of sharks*" to ~60 Maine middle school students was delivered on 3/2/2021 via Zoom, hosted by the Gulf of Maine Research Institute. Another outreach presentation was provided to the Texas A&M at Galveston Succeeding in Science class (~80 undergraduate students) on 3/23/2021 with a Zoom presentation "*Exploring the secret lives of sharks using biotelemetry and chemical tags*". Both presentations provided an overview of this tagging project and what we are learning from the preliminary results. The students had engaging question about the study and sharks in general and allowed public engagement despite COVID. ***Sharkathon*** shark tournament organizers have been accepting and willing to allow project researchers to engage them during the annual tournaments. The team foresees several collaborative manuscripts resulting from this project including: 1) Post-release mortality estimates of four common shark species captured in Texas shore-based fisheries; 2) Using acceleration data loggers (ADLs) and pop-up satellite archival transmitting (PSAT) tags to investigate fine and broad scale post release behaviors of beach caught sharks; 3) Shore based shark angler response to citizen science research. Additionally, the COVID pandemic prevented the original plan to attend the 2020 *Sharkathon* tournament to engage anglers. Instead, the 2021 *Sharkathon* was attended and a white board presentation to anglers was disseminated (https://www.youtube.com/watch?v=t_vdOBSskrA) in addition to a survey on angler attitudes. The 2022 *Sharkathon* tournament will also be attended to disseminate the final results of the project, once PRM results are published in peer-reviewed journals.

Literature cited:

Braccini M, Rijn J van, Frick L (2012) High post-capture survival for sharks, rays and chimaeras discarded in the main shark fishery of Australia? PLoS One 7

Lear KO, Whitney NM (2016) Bringing data to the surface: recovering data loggers for large sample sizes from marine vertebrates. Anim Biotelemetry 4:12

Manire C, Hueter R, Hull E, Spieler R (2001) Serological changes associated with the gill-net capture and restraint in three species of shark. Trans Am Fish Soc 130:1038–1048

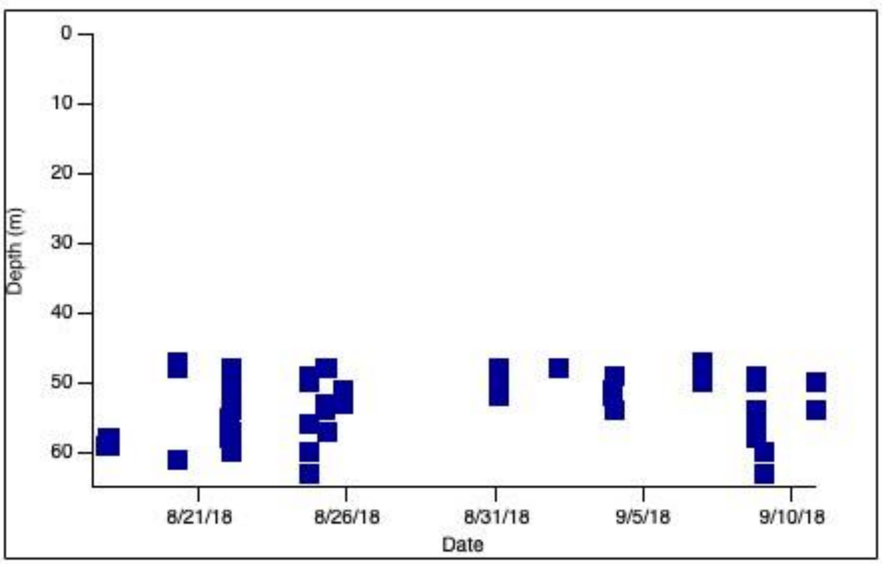
Whitmore BM, White CF, Gleiss AC, Whitney NM (2016) A float-release package for recovering data-loggers from wild sharks. J Exp Mar Bio Ecol 475:49–53

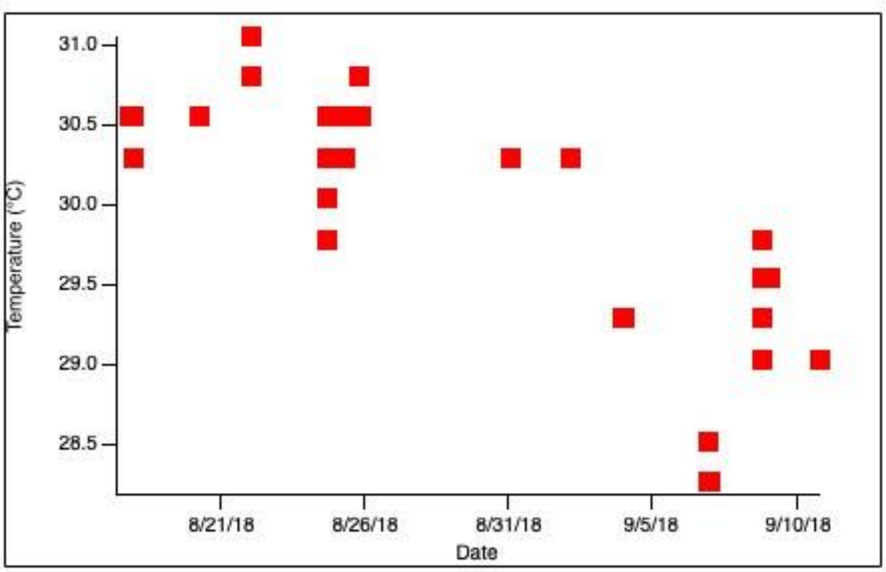
APPENDIX 1

PSAT tag time series data from confirmed MORTALITIES (N=3)

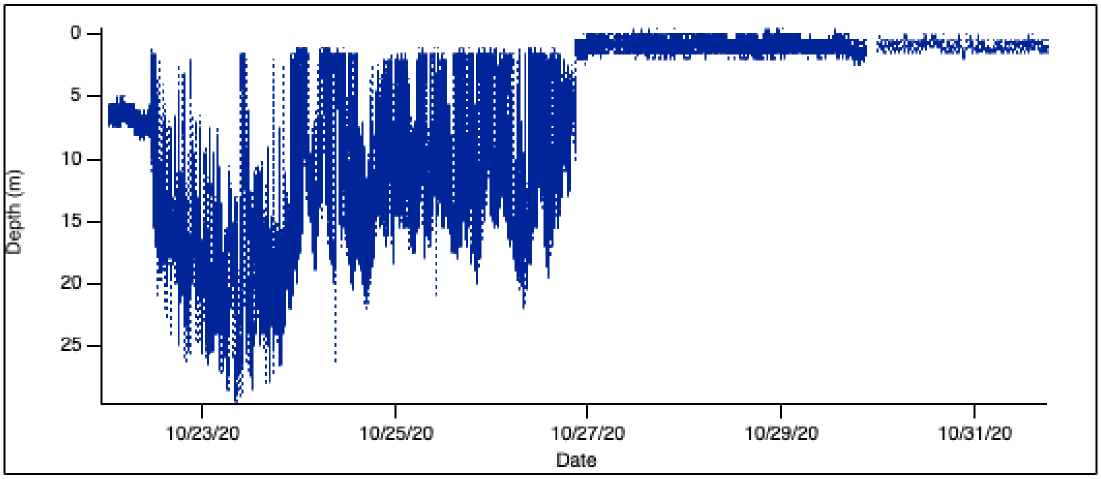
Temperature, depth, a light level plots of shark post-release mortalities. Mortalities confirmed by constant depth patterns and tag ingestion revealed by low light levels with changing depth.

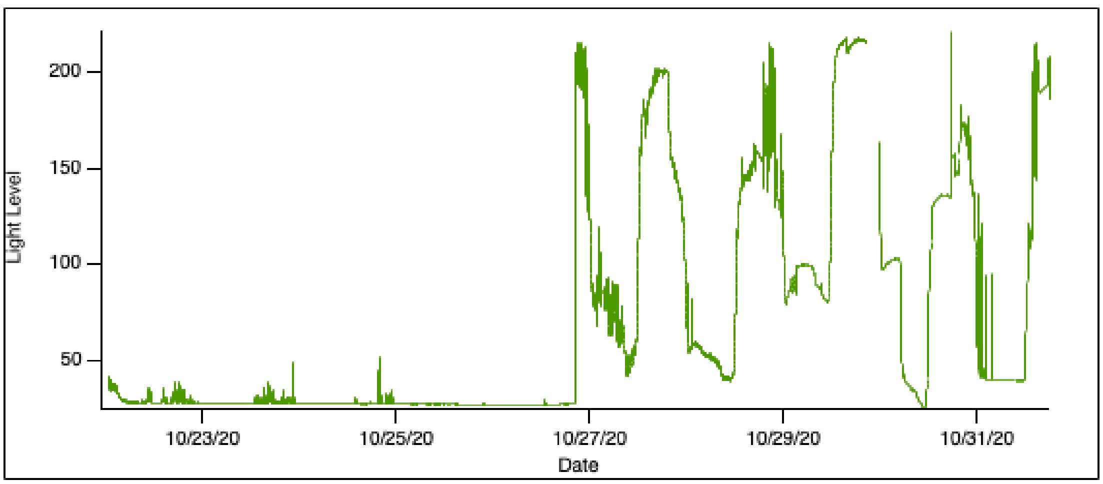
C_leu05_P: PSATLIFE tag with 28 days of transmitted data reveal the shark immediately went to 59m and remained at constant depth for 3.25 hours, indicating a **mortality.** The tag remained at near constant depth for the rest of the deployment, but minimal changes in depth (perhaps due to currents and tidal motion) prevented the release condition to release the tag. The tag released at programmed 28 days, but data transmission was not continuous and patchy with no light level data.

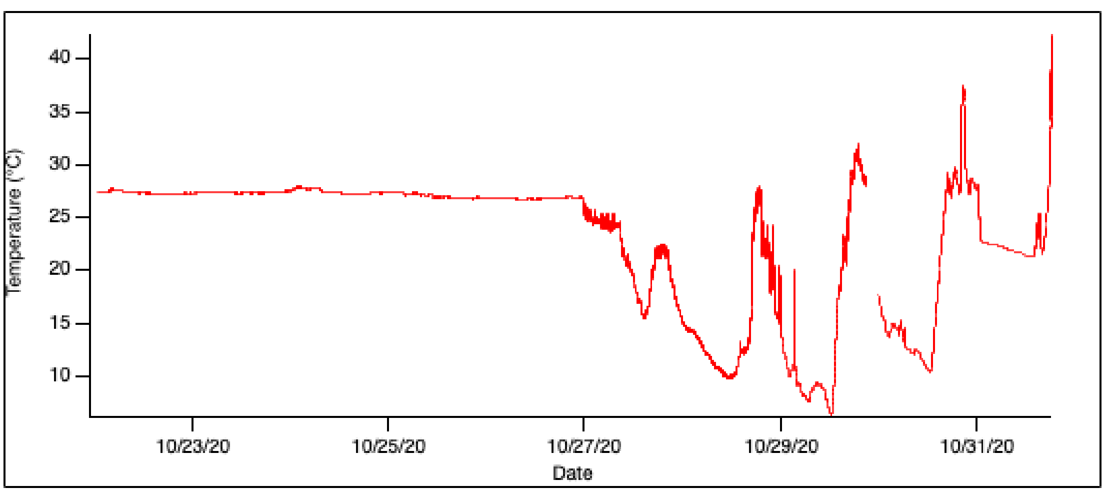




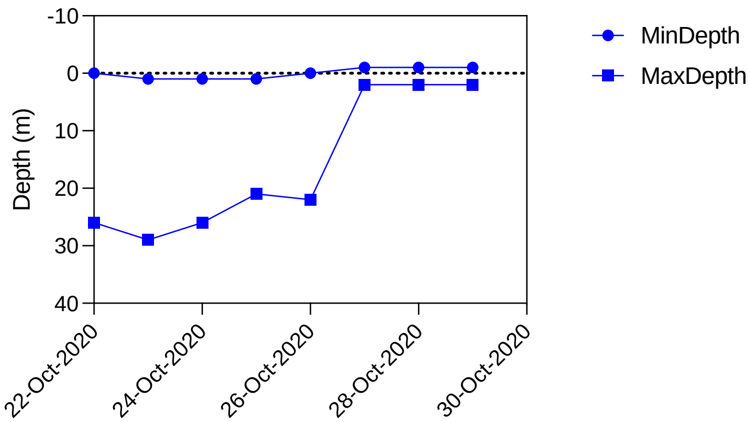
S_mok01_P: Immediately after being tagged, shark went to bottom in less than 10 minutes where it remained for 11 hours at constant depth, indicating **mortality.** The tag was then ingested, indicated by low light level and temperature variation for 5 consecutive days while depth changed. The tag was regurgitated on 26 October, indicated by large light and temperature changes with minimal depth variation around 0-1.5m, where it floated on the surface for the following 2 days

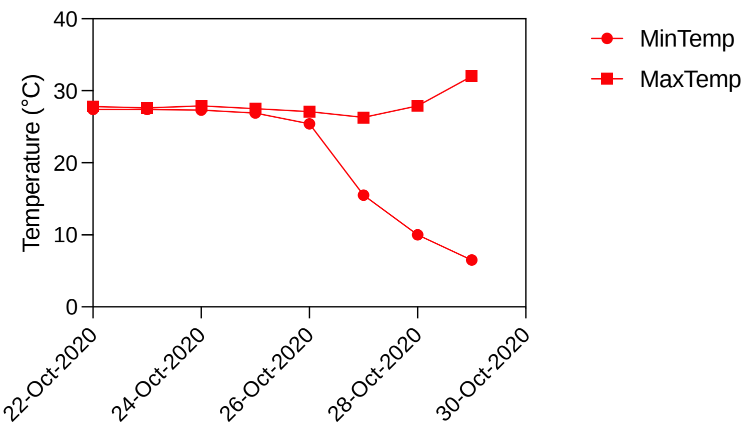


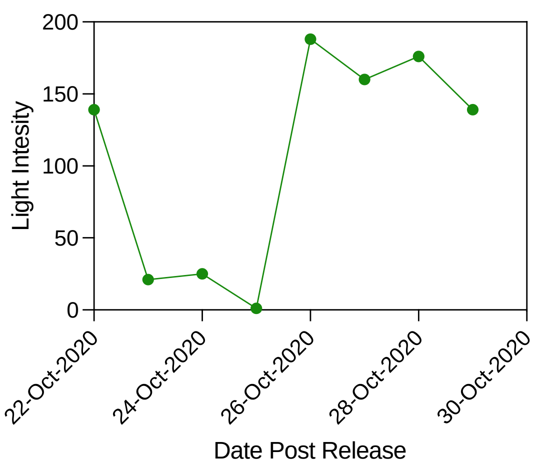




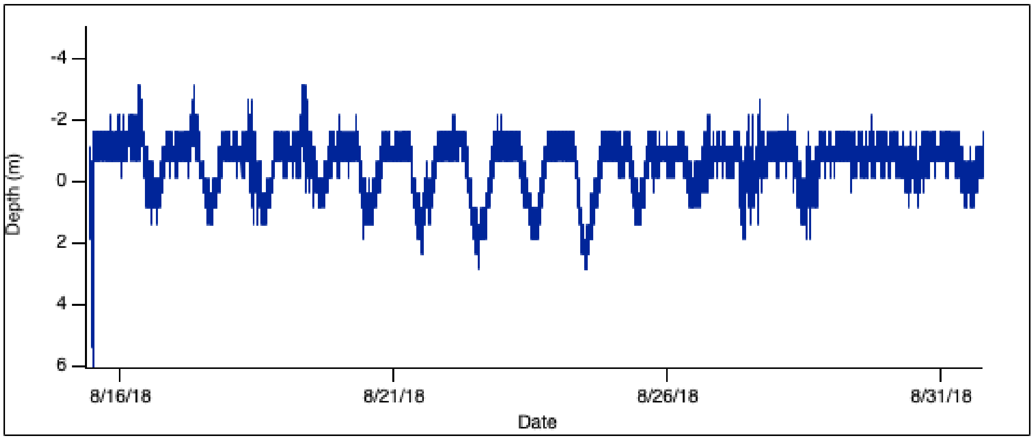
S_mok01_P con't: Transmitted data for sPAT tag showing high resolution depth data, daily changes in light intensity, and daily min and maximum temperatures and depth values for the full deployment. The constant depth (mortality) can be seen at far left of top graph.

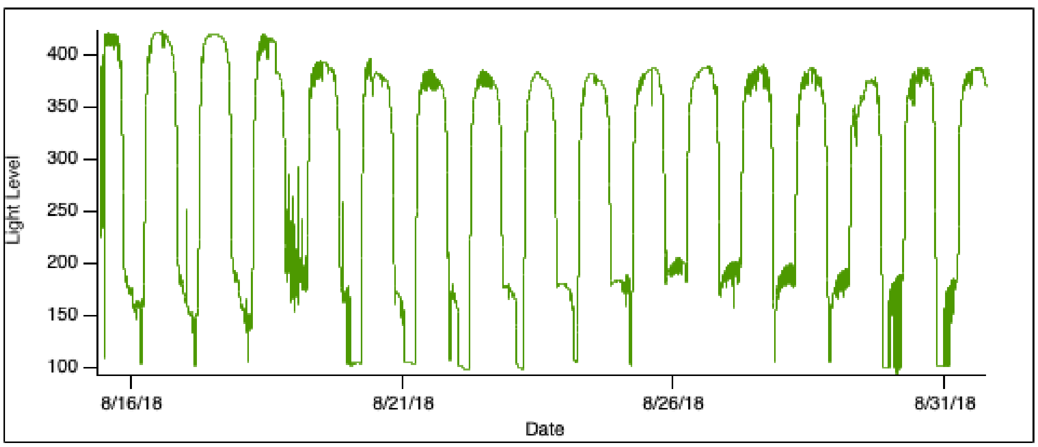


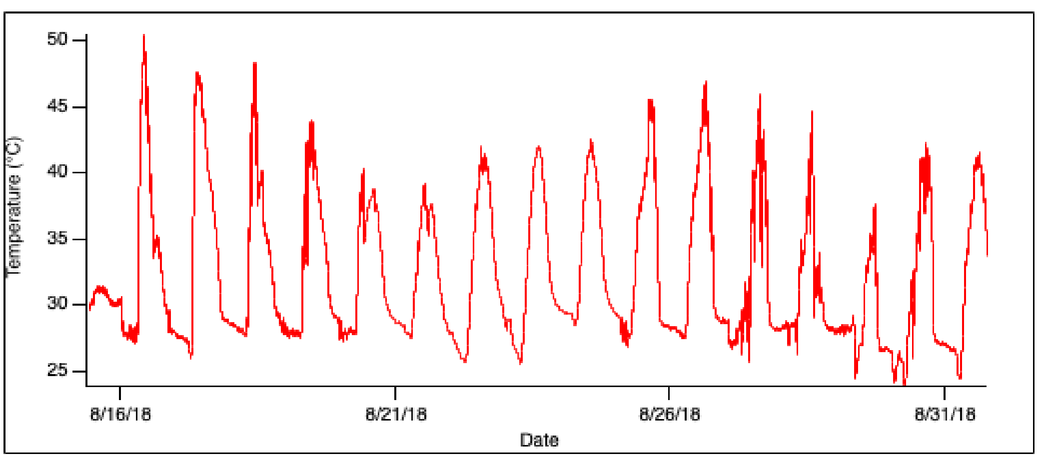




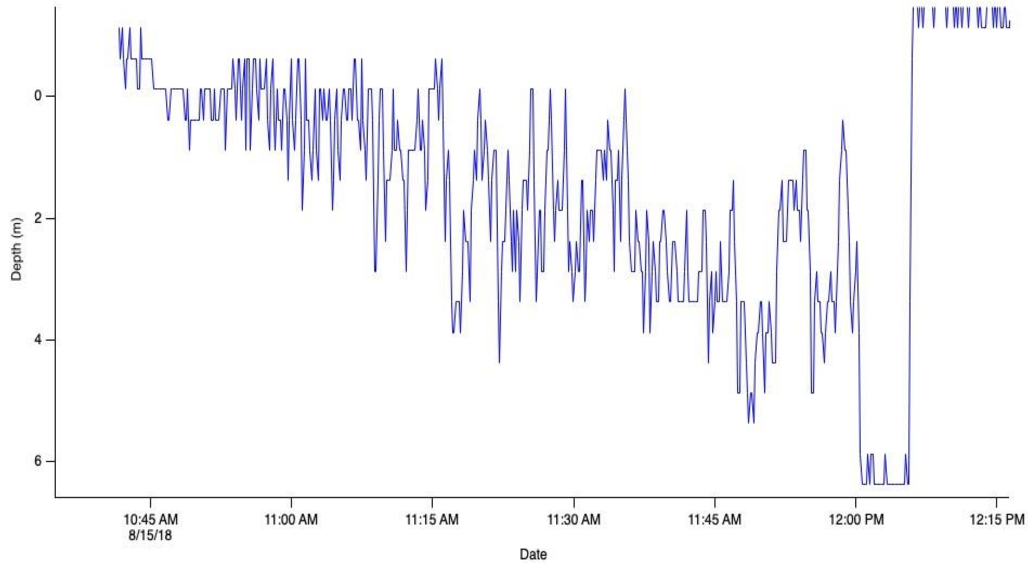
C_lim02_P: PSATLIFE tag recovered with 16 days of archived data reveal a post-release **mortality** 1.5 hours after tagging. The shark spent 75 minutes yo-yoing from the surface to ~4m before settling at 6m for 5 minutes. The tag then popped off the shark and floated to the surface, where it remained going in and out with the tides for 15 days before shutting off. This is indicated by large temperature and light level changes in conjunction with depth showing the tag 2m above sea level for the period following release from the shark.

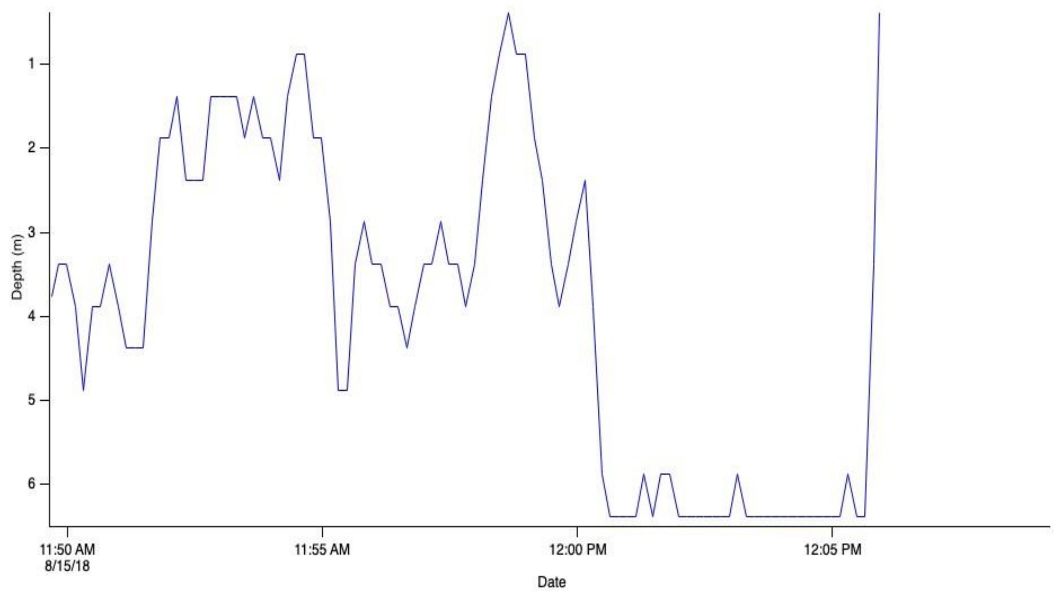






C_lim02_P con't: Zoomed in view of the first 1.5 hour of data recording. The shark spent 1.25 hours making its way to the bottom, where it settled at 6m for 5 minutes before the tag released. The length of time spent at depth for an obligate ram ventilating species suggests **mortality** occurred.

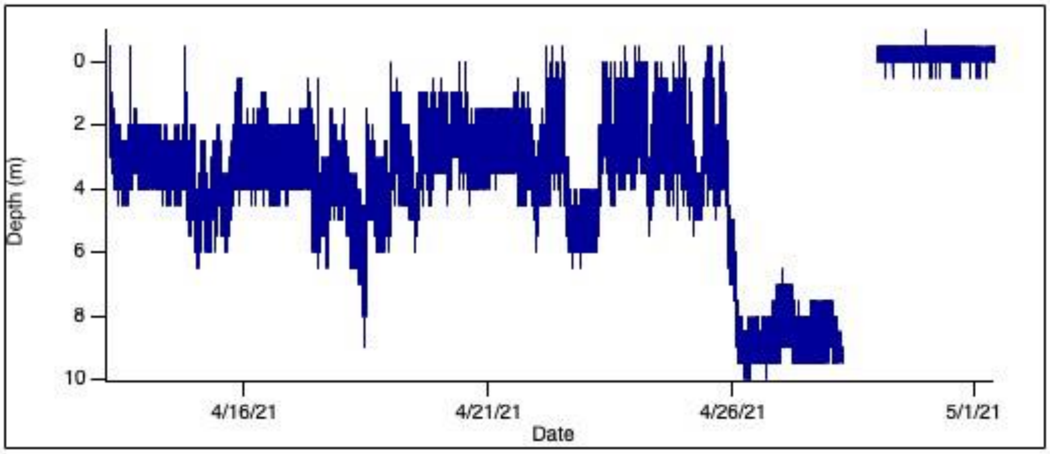


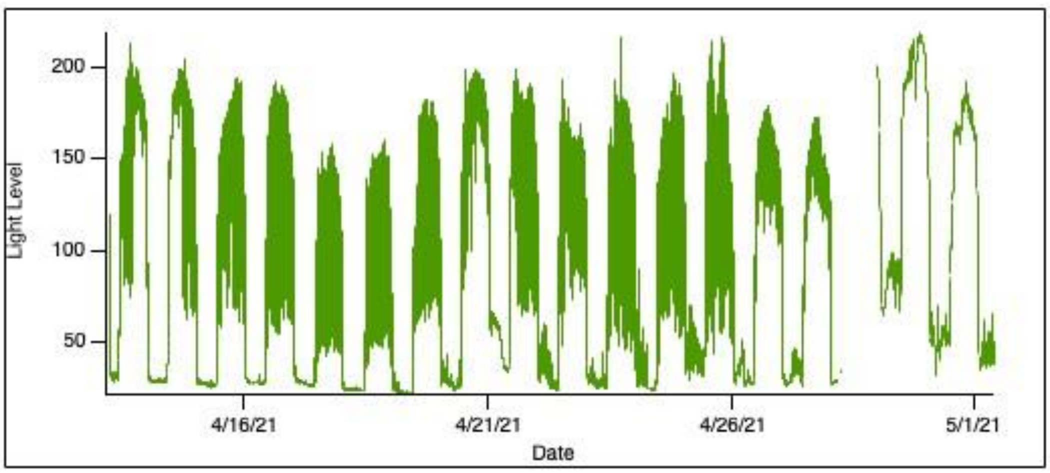


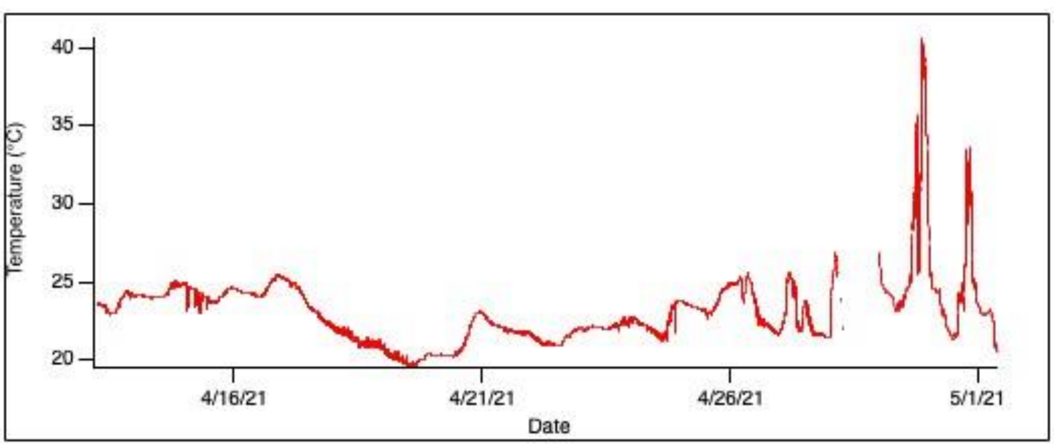
PSAT time series data from confirmed SURVIVORS (N=12)

Temperature, depth, a light level plots of shark post-release survivals. Survival confirmed with consistent changes in light level, depth and temperature, indicating free movement in water column.

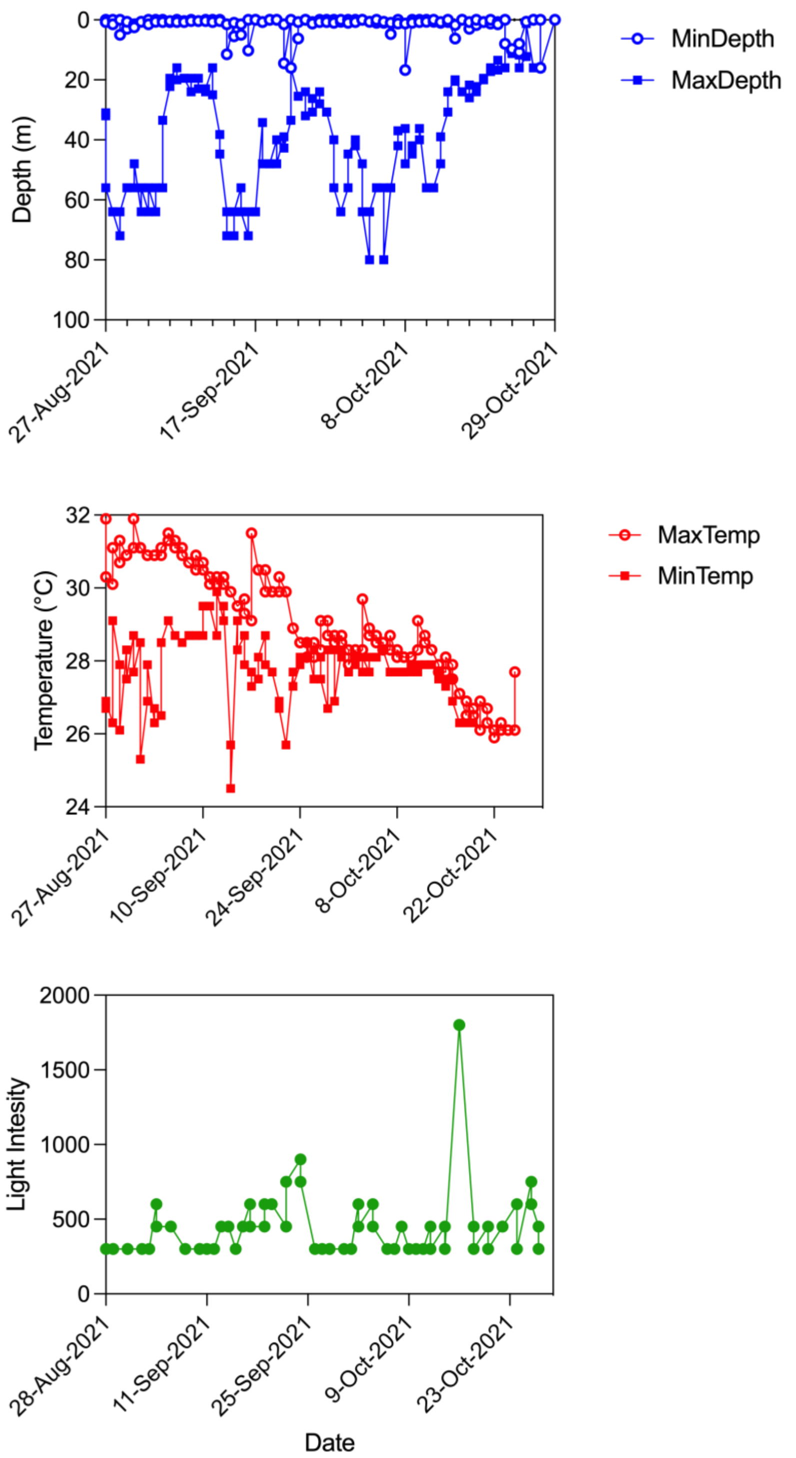
S_mok02_P: sPAT tag recovered with 16 days of archived data reveal consistent changes in depth, temperature, and light level, indicating **survival.** It is possible the last few days of reduced depth variation resulted in the tag release mechanism being enacted even though the shark was alive.



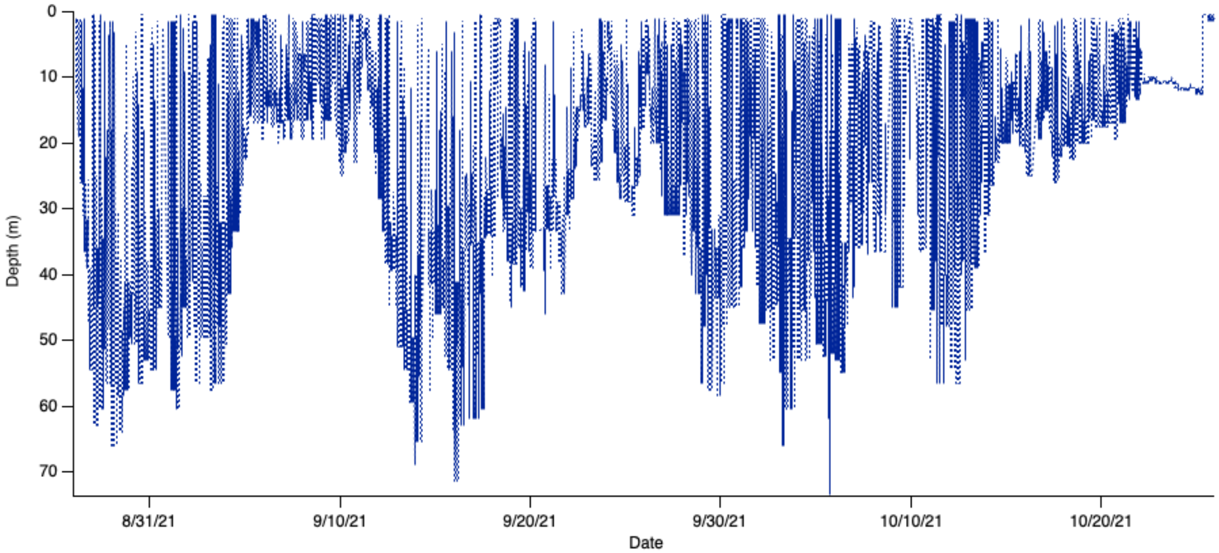




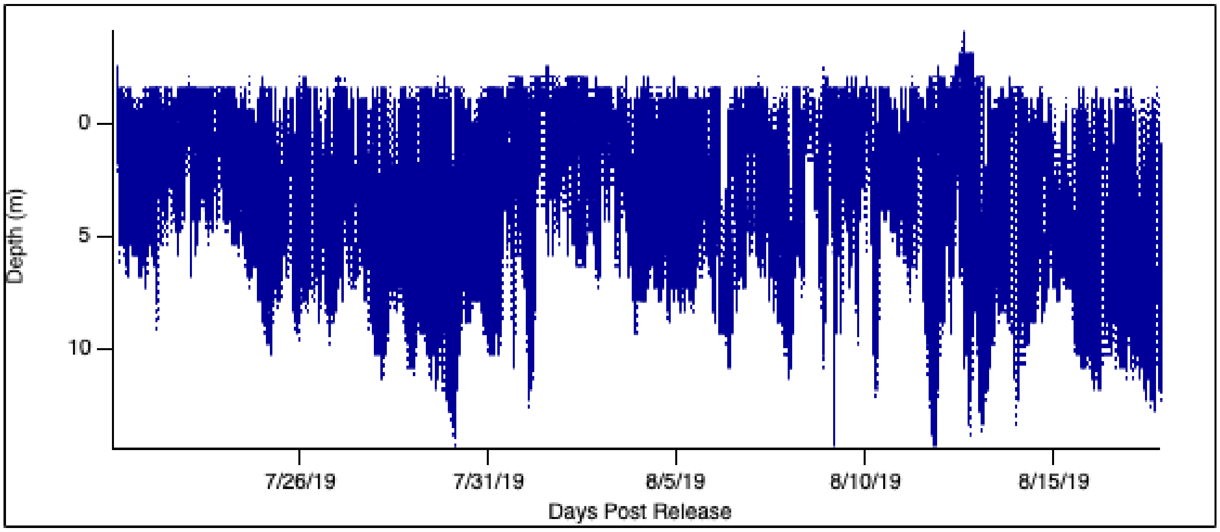
G_cuv05_MP: Mini-PAT tag with 57 days of transmitted data reveal consistent changes in depth, temperature, and light level, indicating **survival.** The data indicates a mortality event occurred on 10/22 where depth remains constant for 3 days, initiating the tag release to the surface. Given almost 2 months of normal movement post-release, this was considered a natural mortality.

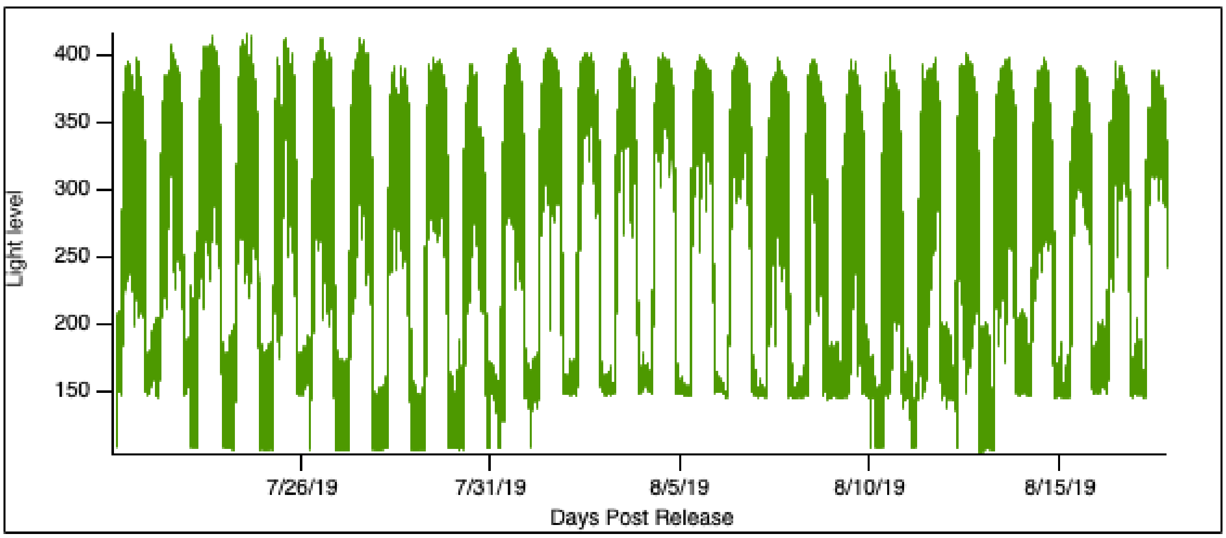


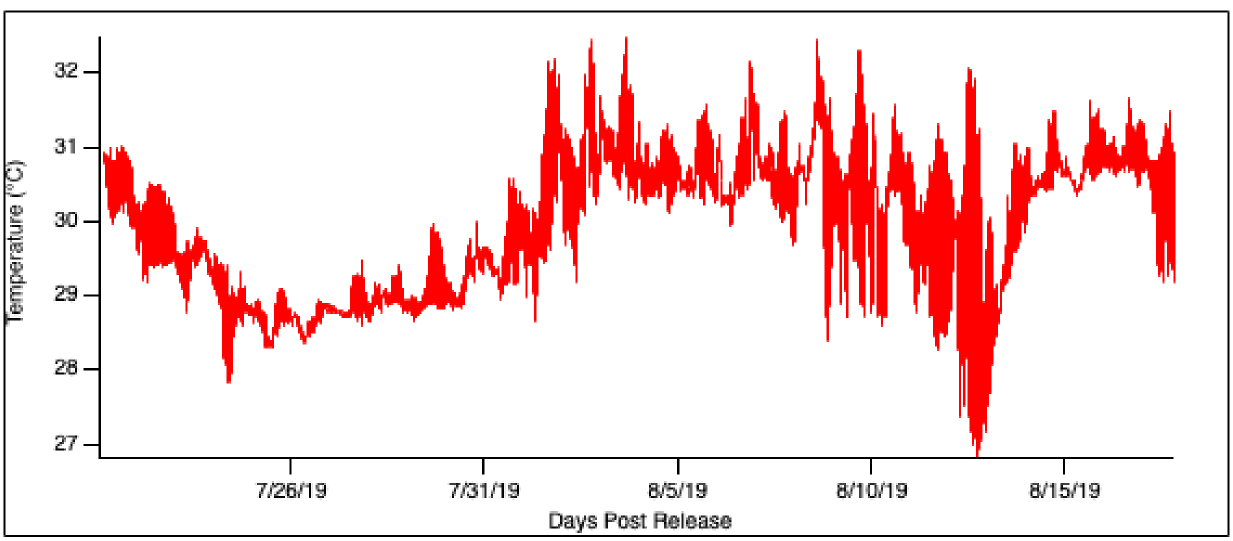
G_cuv05_MP: The data indicates a mortality event occurred on 10/22 where depth remains constant for 3 days, initiating the tag release to the surface. Given almost 2 months of normal movement post-release, this was considered a natural mortality



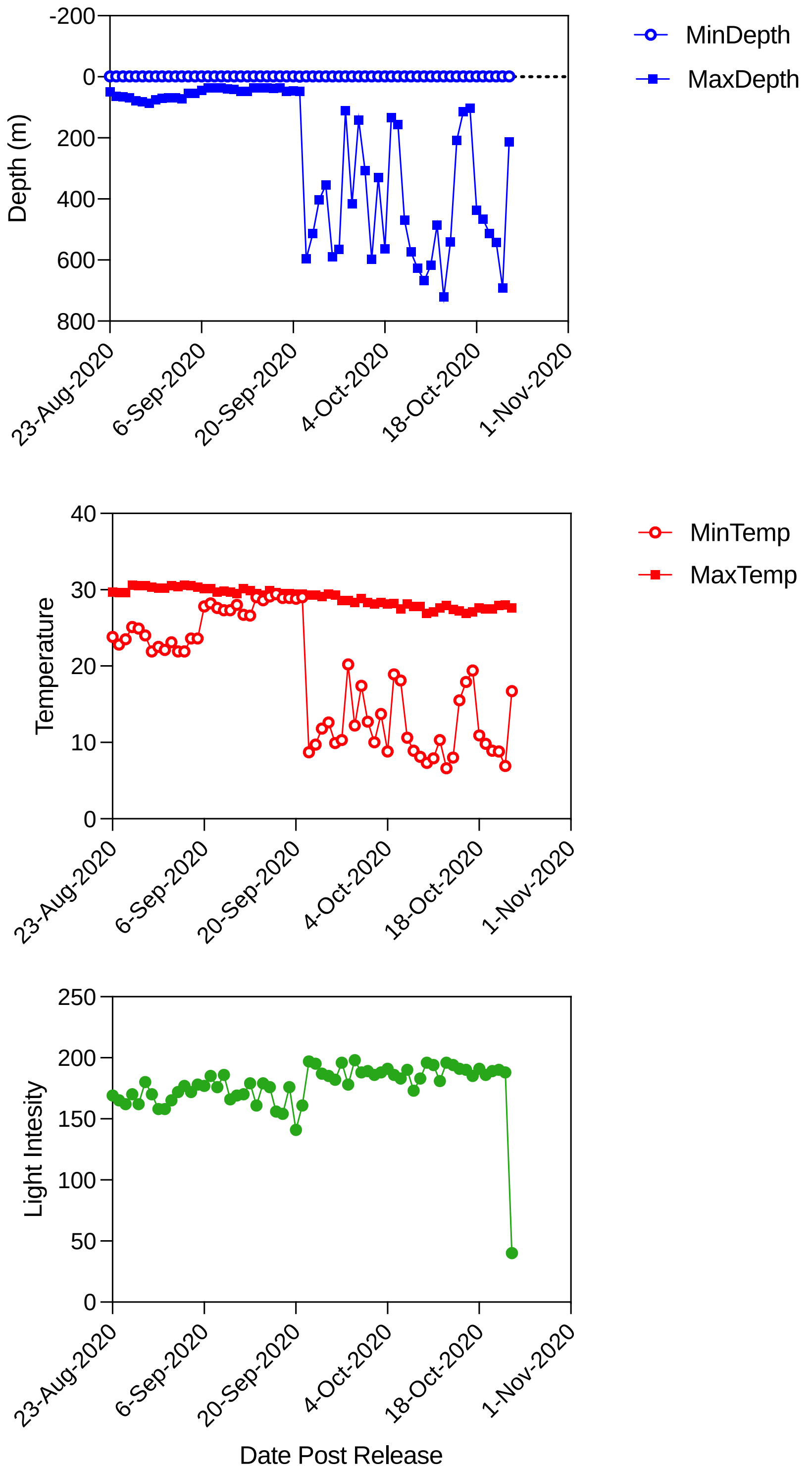
C_leu07_P: PSATLIFE tag recovered with 28 days of archived data reveal consistent changes in depth, temperature, and light level, indicating **survival**



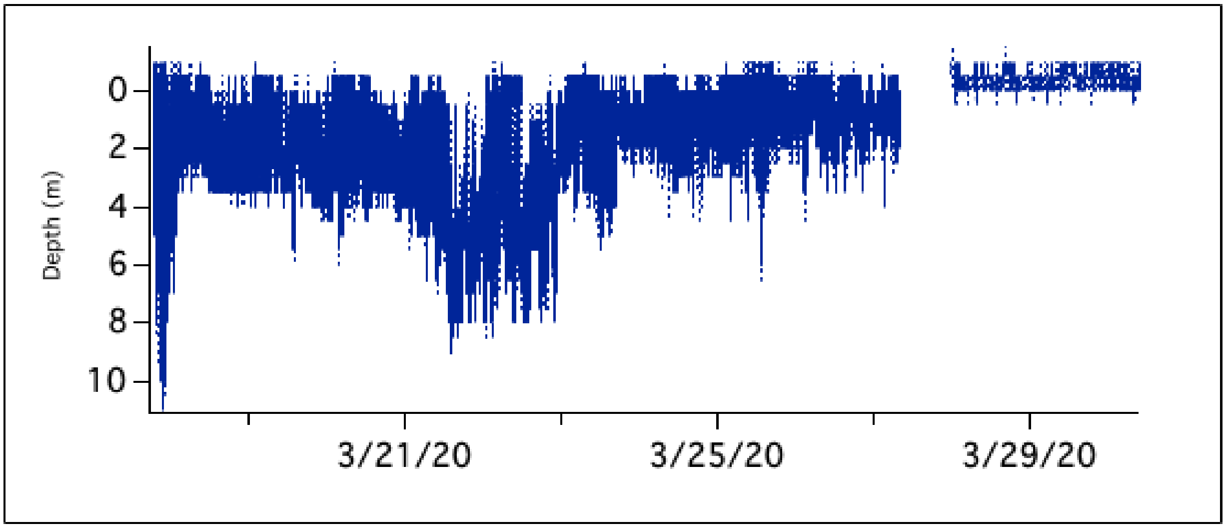


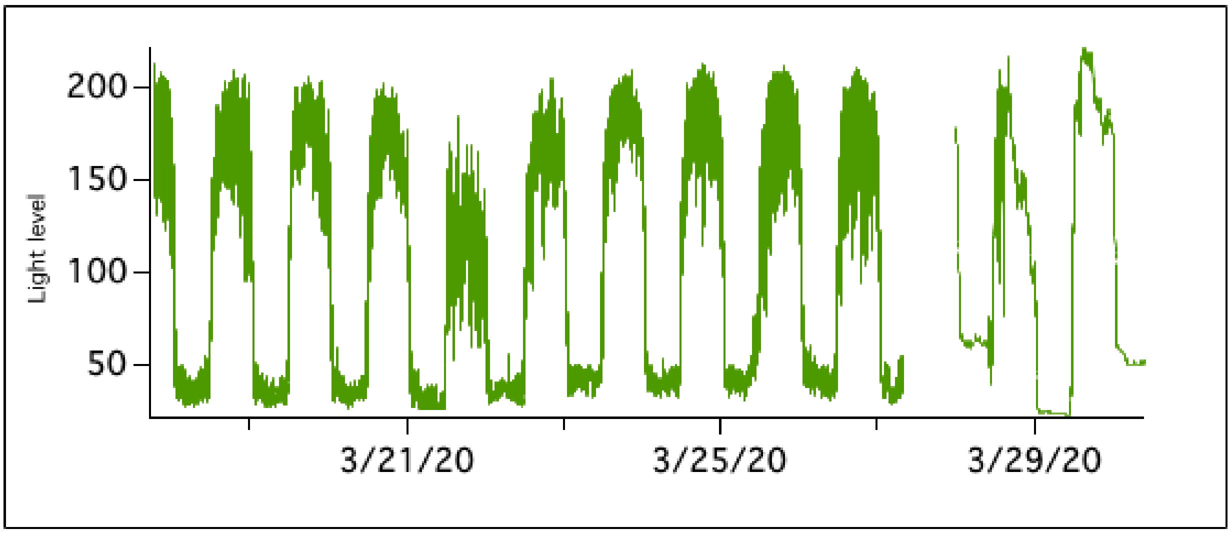


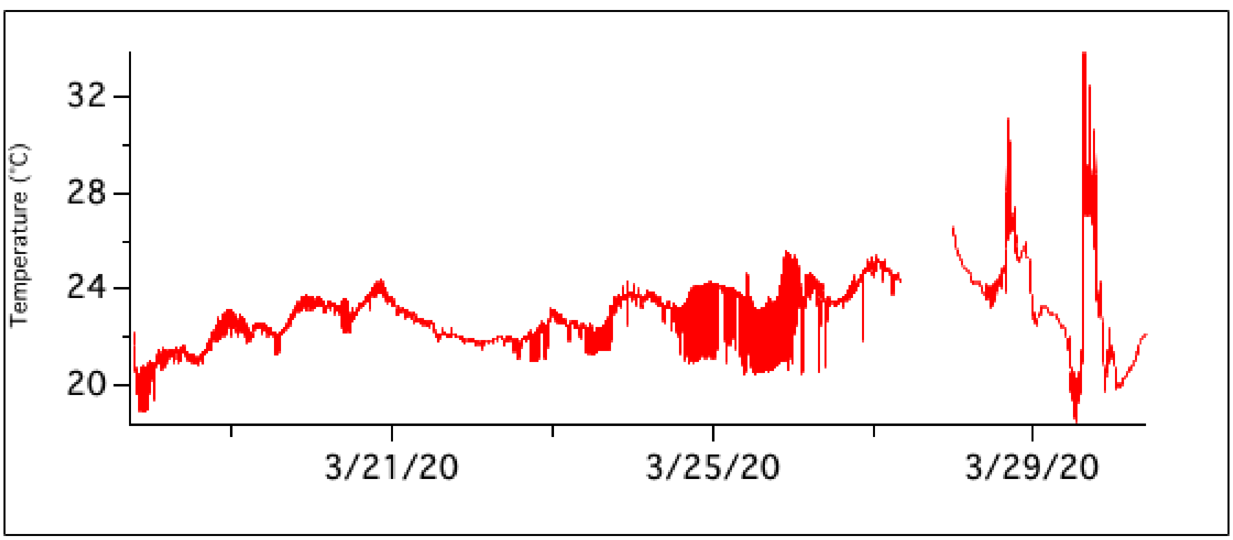
G_cuv02_P: sPAT tag with 60 days of transmitted data from daily summaries. The shark exhibited depth variation between the surface and about 80 meters for the first 30 days. It then made extremely deep dives from the surface to over 700 m depth for another 30 days before the tag released. The tag on this female tiger released over 1000 km to the east of the tagging location.



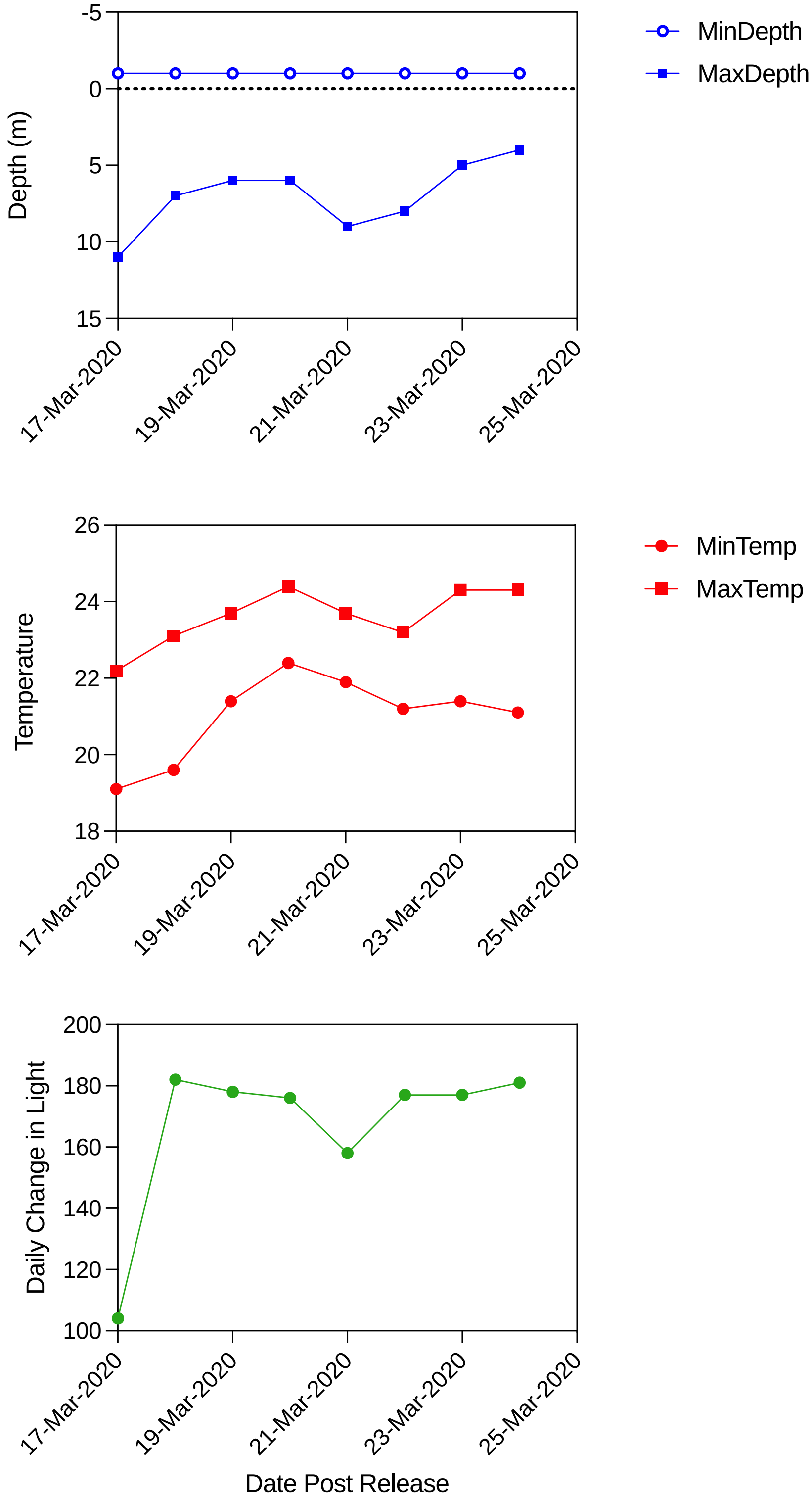
C_leu04_P: sPAT tag recovered with 10 days of archived data reveal consistent changes in depth, temperature, and light level, indicating **survival.** Daily min/max summaries below



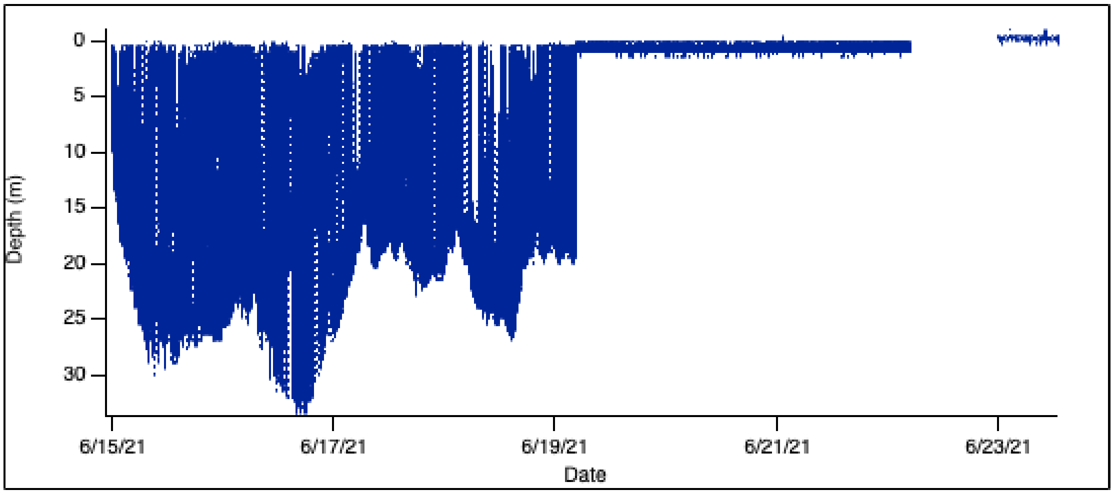


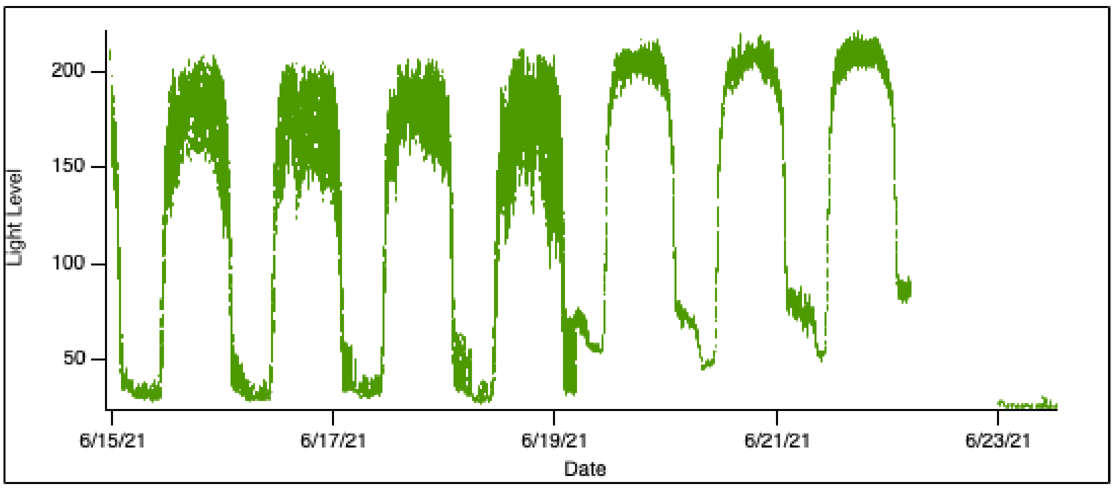


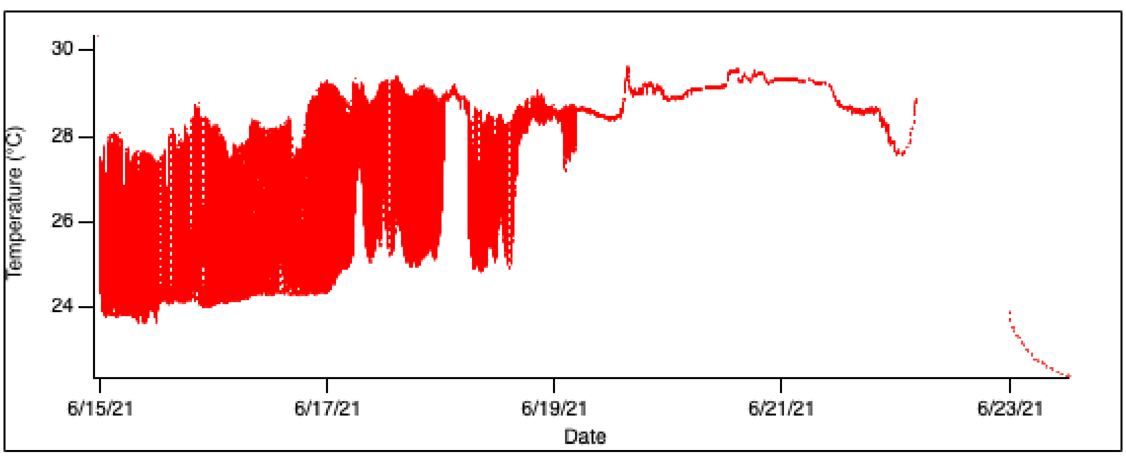
C_leu04_P: sPAT tag (transmitted tag data shown here) with 10 days of daily changes in depth, temperature, and light indicate **survival**



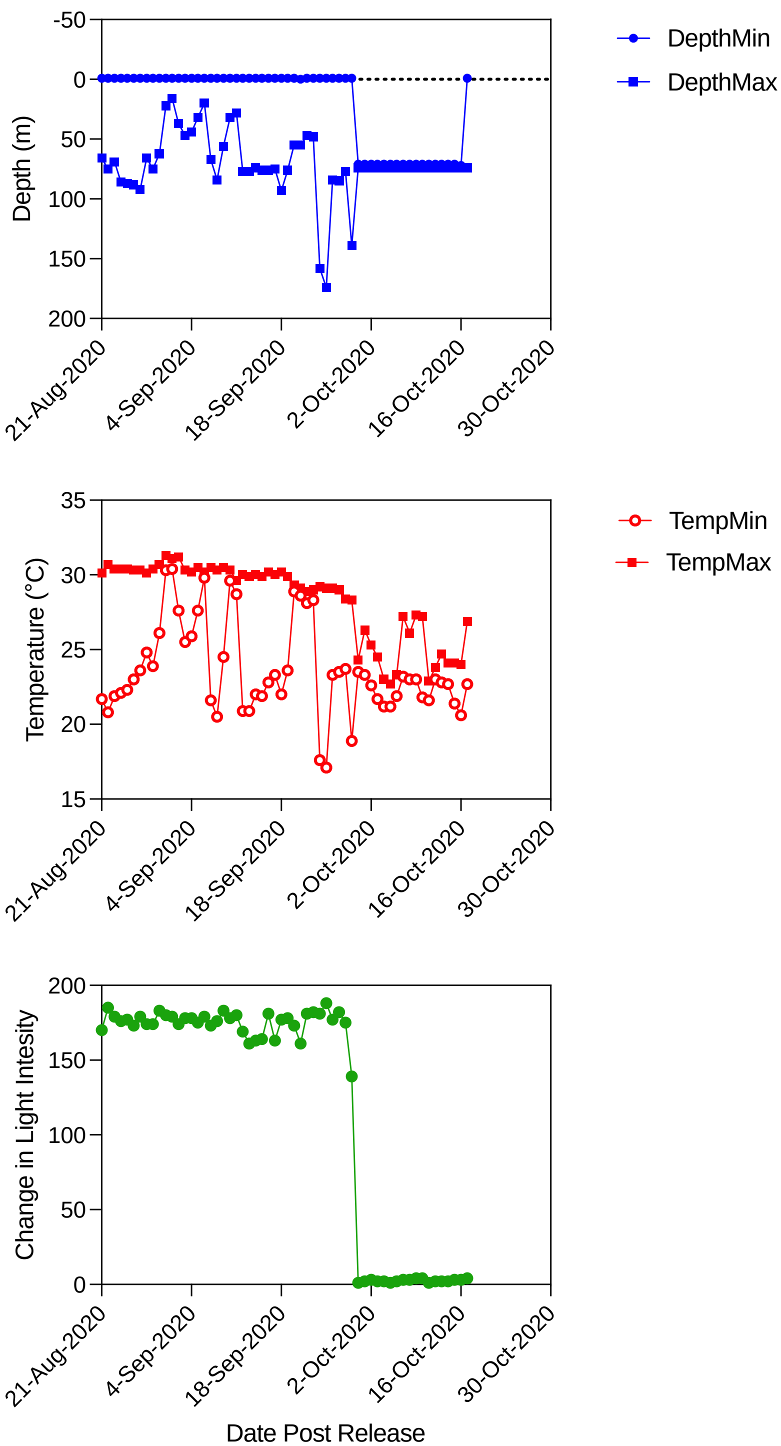
G_cuv03_P: sPAT tag recovered with 5 days of archived data reveal consistent changes in depth, temperature, and light level, indicating **survival.** Tag experienced unknown pre-mature release



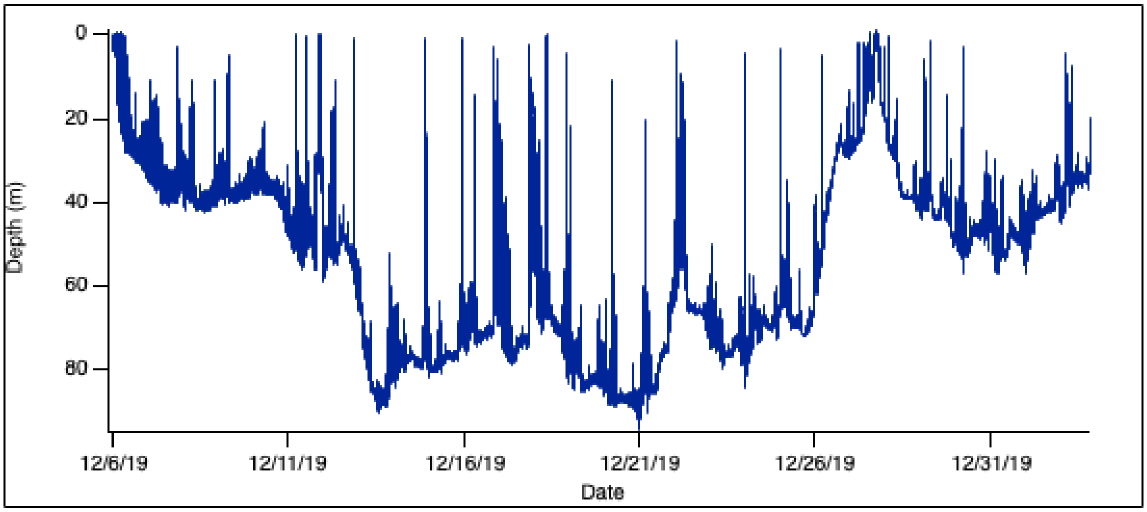


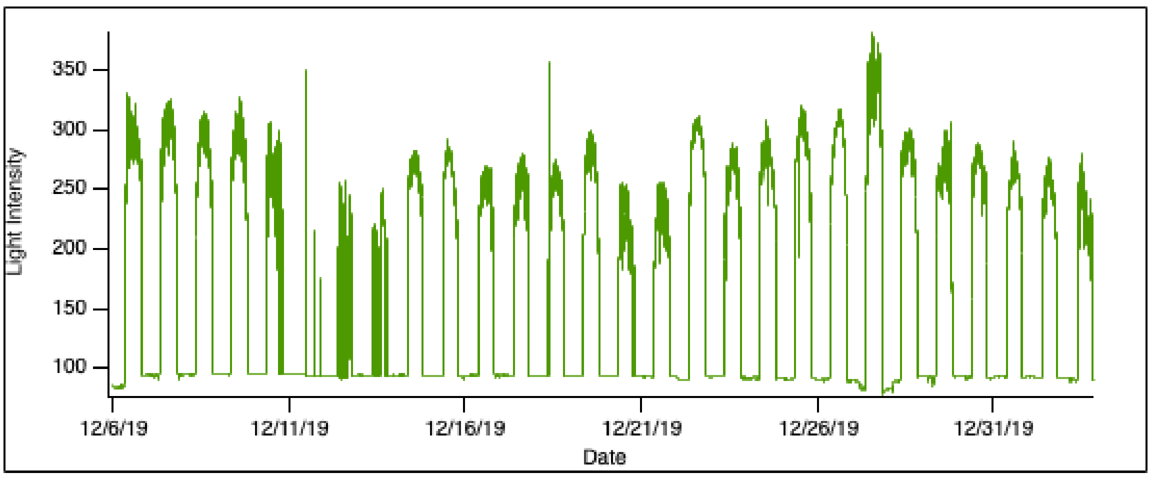


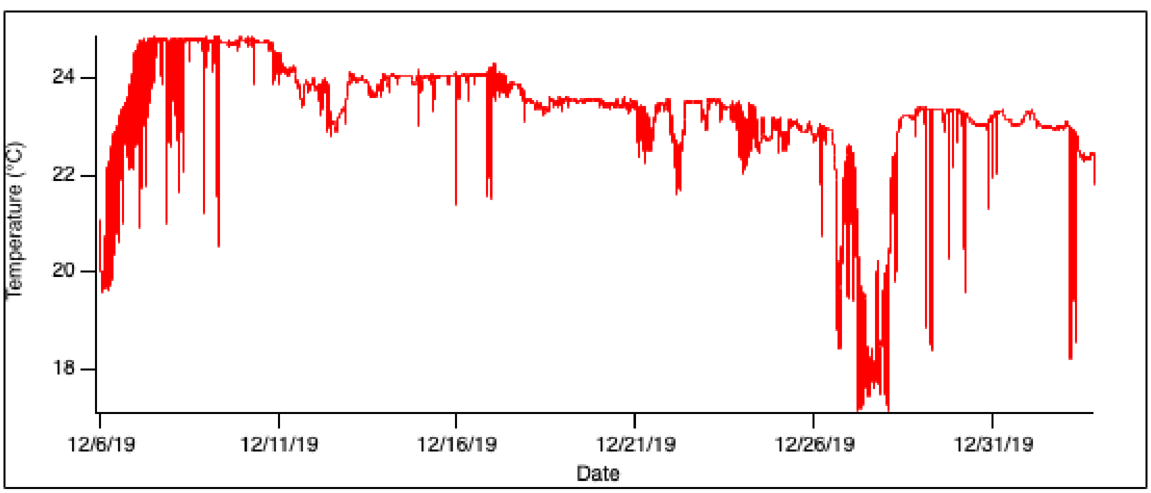
G_cuv01_P: sPAT tag with 58 days of transmitted data from daily summaries and high-resolution depth data for the final 5 days of recording. Daily summaries reveal normal variations in light, temperature, and depth until 40 days later (9/29) at which point the shark settled at 71m and remained there until recording ceased on 16 October 2020. Normal variations in light, depth, and temperature for this first 40 days indicate **survival**, with a potential natural mortality occurring after tagging.



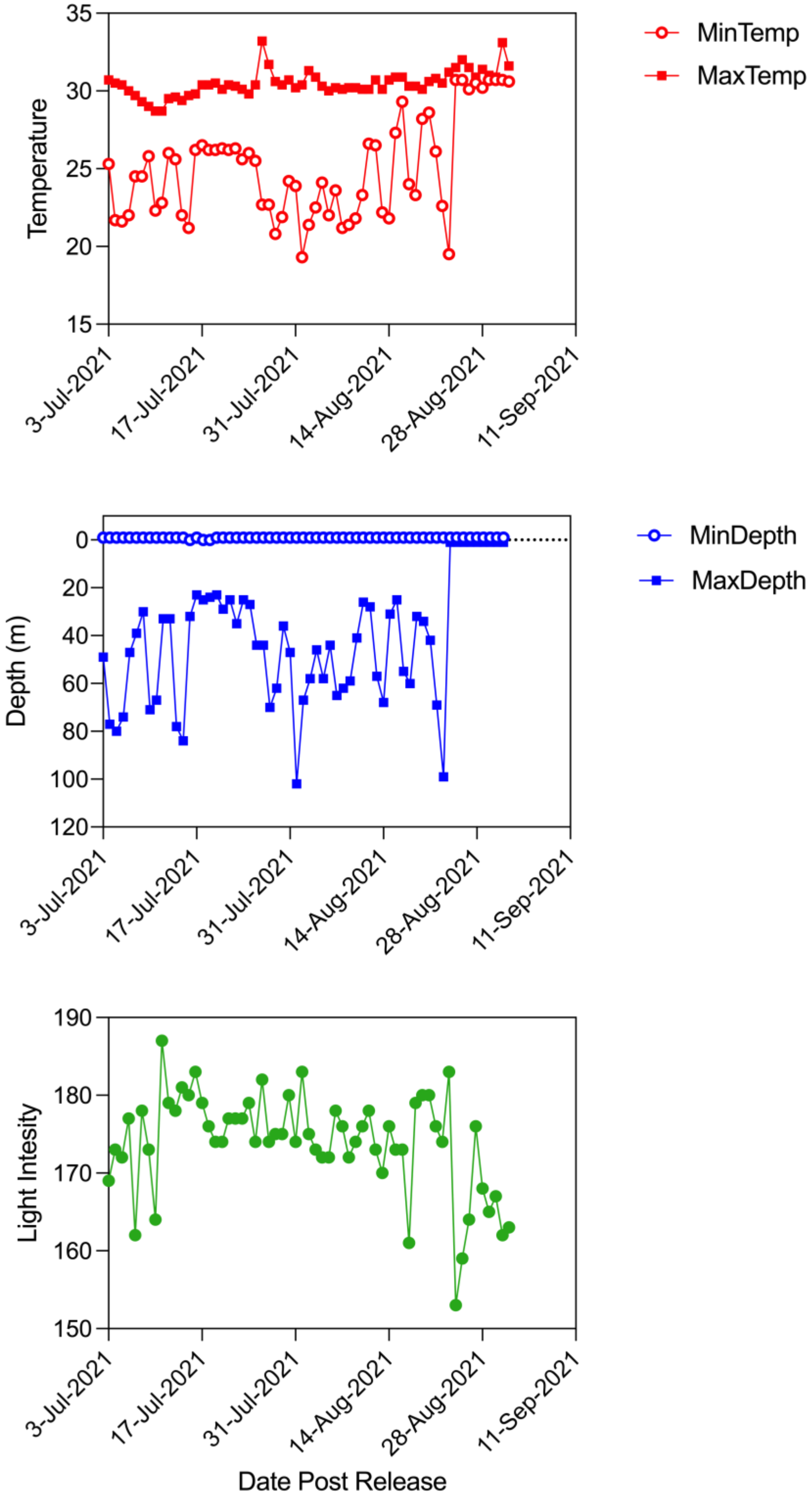
C_lim03_P: PSATLIFE tag recovered with 28 days of archived data reveal consistent changes in depth, temperature, and light level, indicating **survival.**



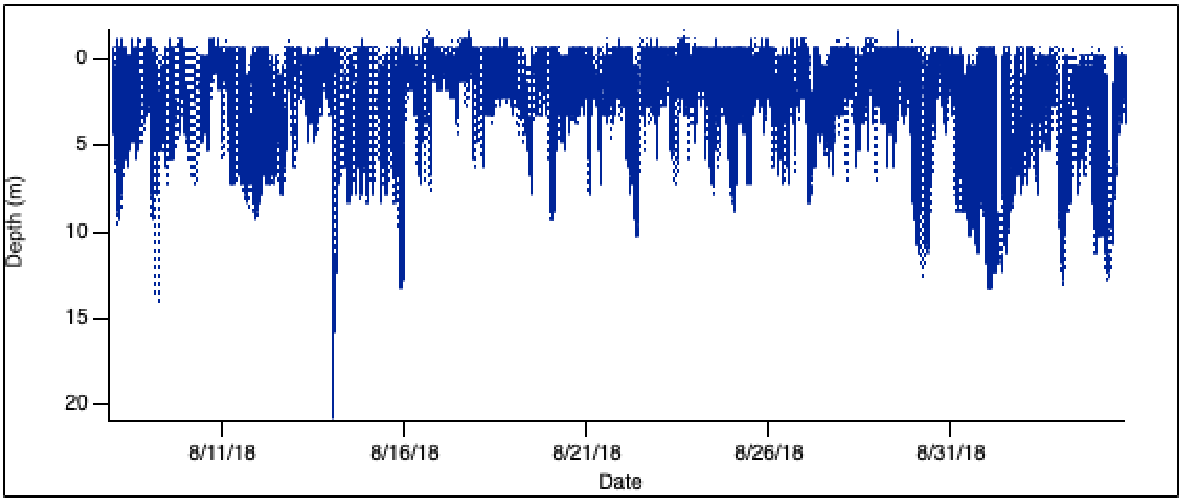


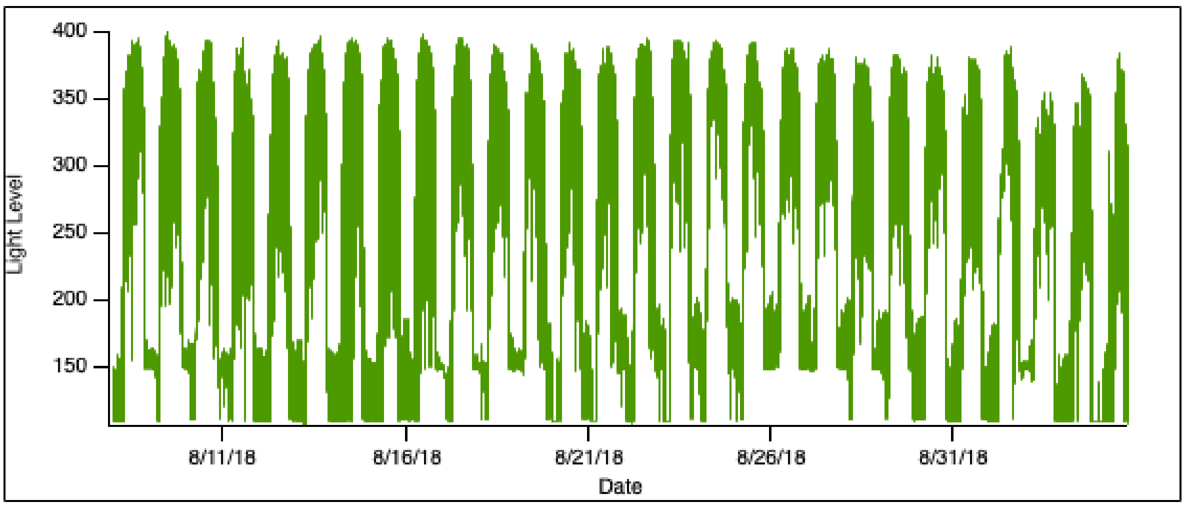


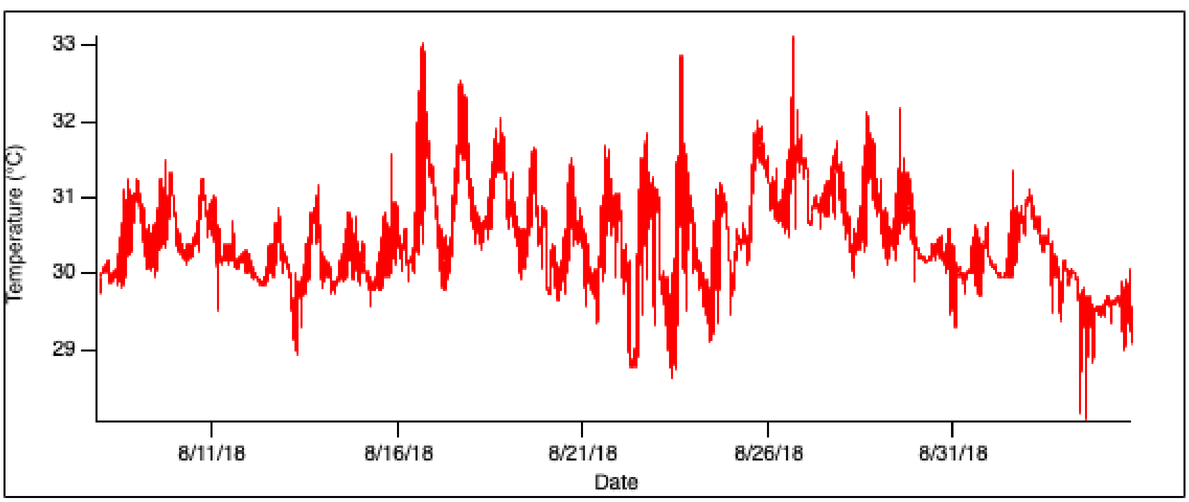
G_cuv04_P: sPAT tag with 51 days of transmitted data from daily summaries reveal normal variations in light, depth, and temperature, indicating **survival**. Tag released 9 days early.



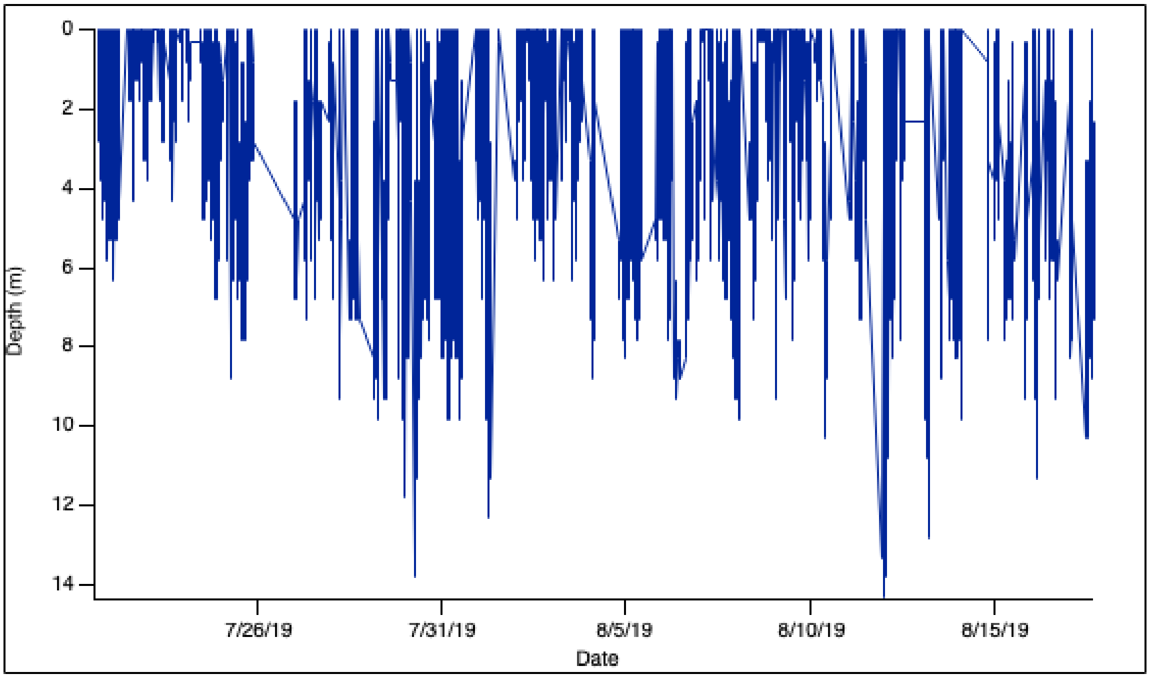
C_leu06_P: PSATLIFE tag recovered with 28 days of archived data reveal consistent changes in depth, temperature, and light level, indicating **survival.**

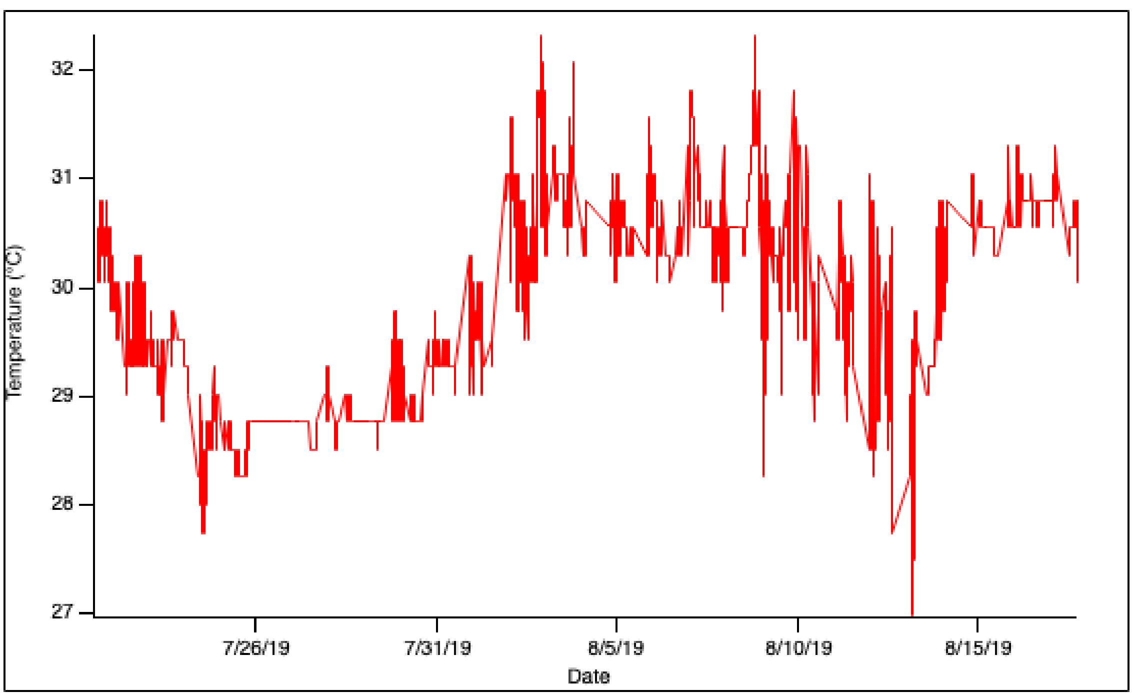




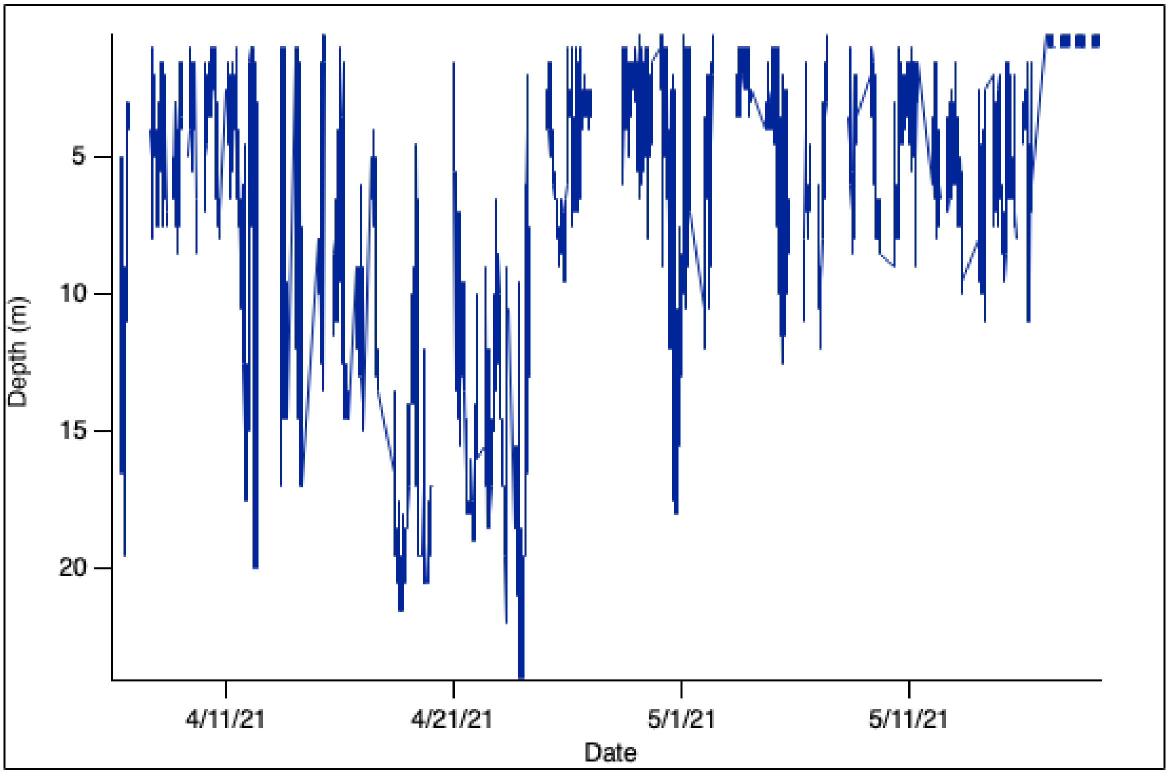


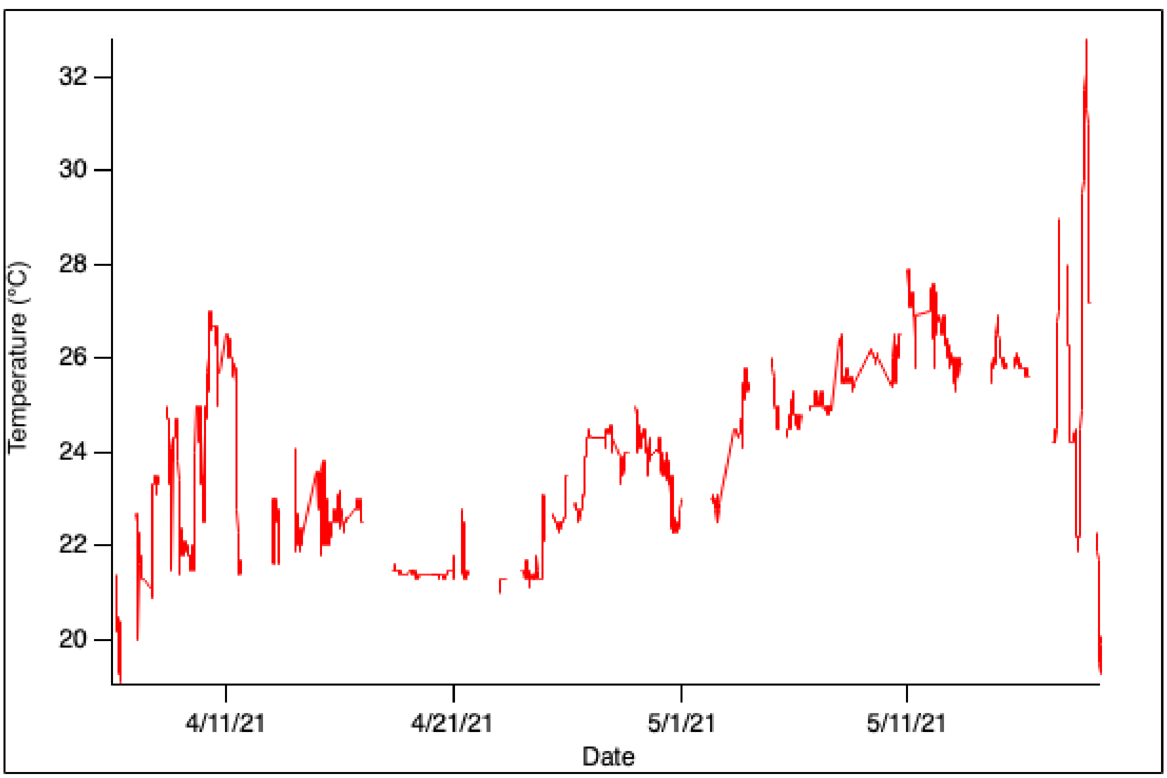
C_leu08_P: PSATLIFE tag with 28 days of transmitted data reveal consistent changes in depth and temperature, indicating **survival.** No data for light level and gaps in the data indicate that data transmission was limited but sufficient to determine survival outcome.





C_leu09_MP: Mini-PAT tag with 47 days of transmitted data reveal consistent changes in depth and temperature, indicating **survival,** though data transmitted by satellite was limited.

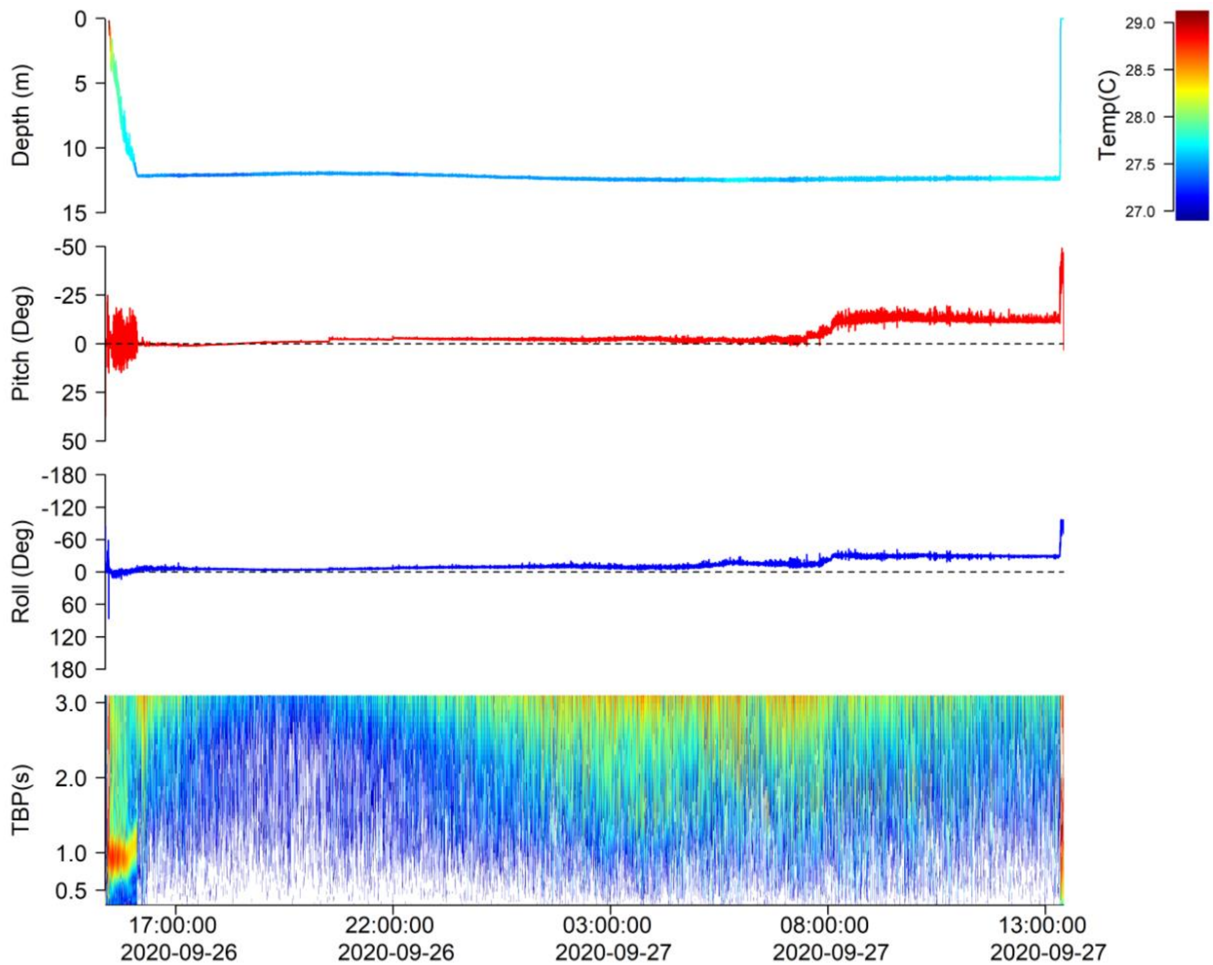




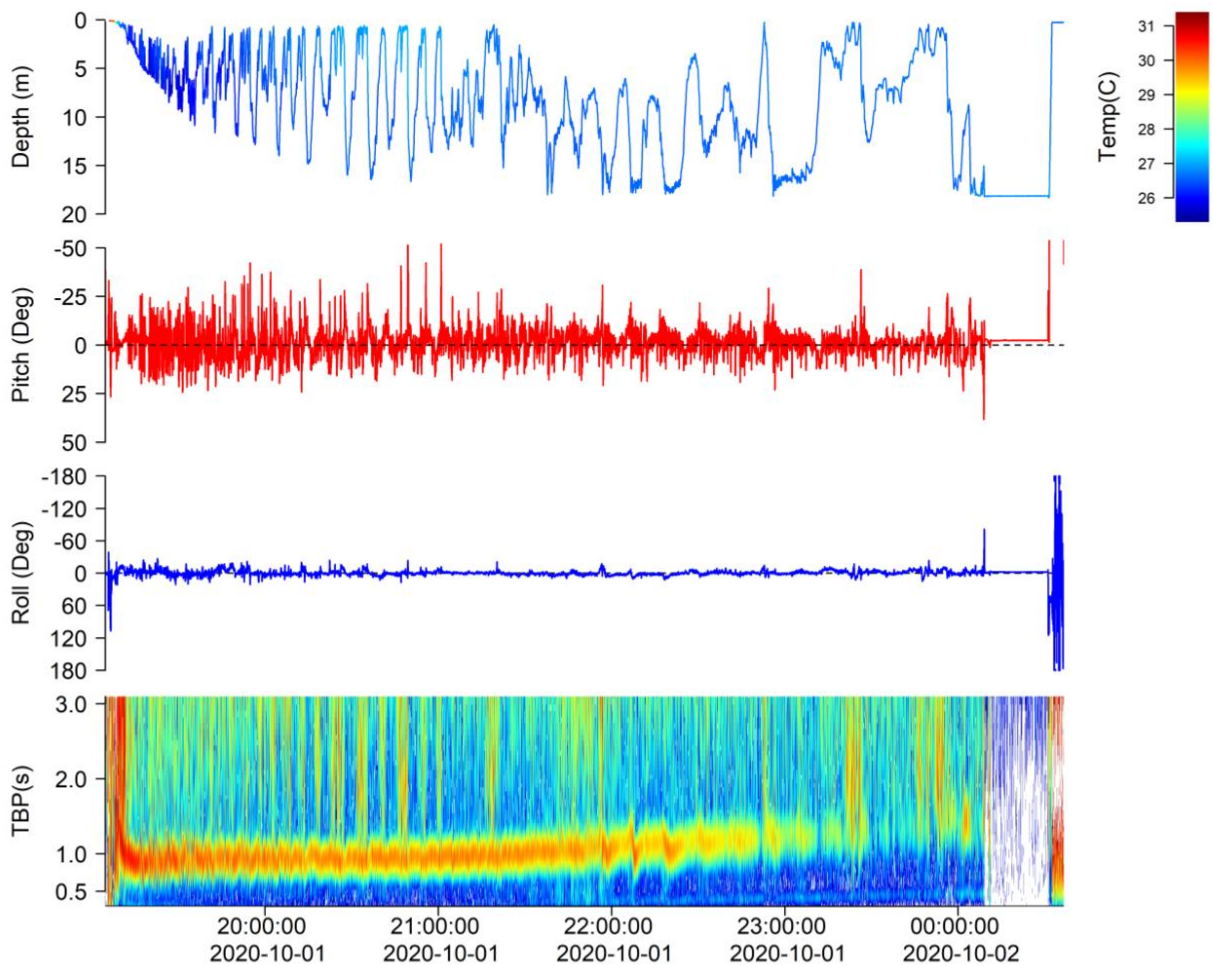
APPENDIX 2.

ADL tag time series from confirmed MORTALITIES (N=5)

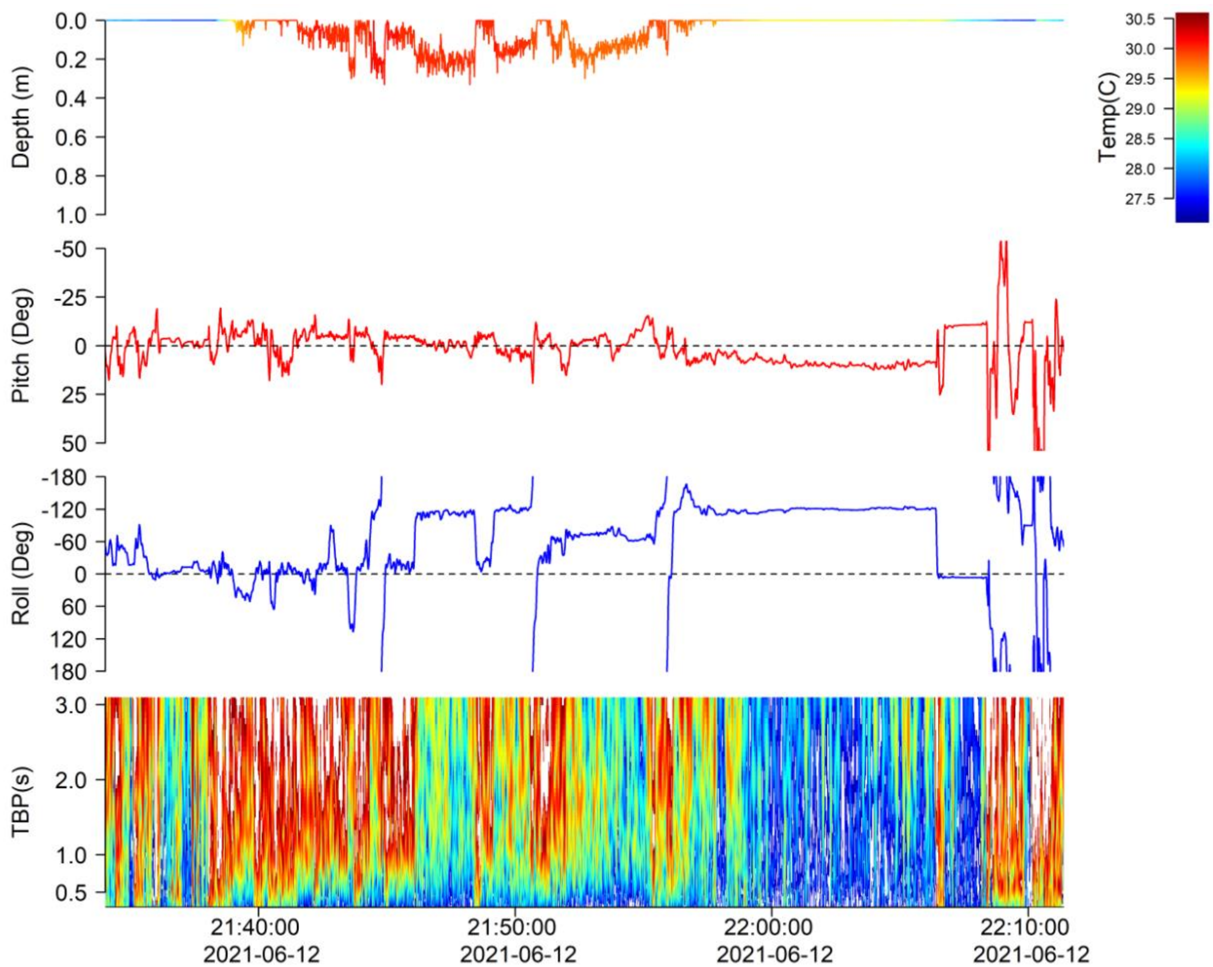
C_lim02_A: After tagging, this shark swam away into increasing deeper water, with a tail beat frequency of ~1 Hz. After 40 minutes this shark landed on the seafloor in an upright (normal) posture and stopped displaying regular tailbeats. The shark remained on the seafloor without any tailbeats for a further 21 hours before the tag detached from the shark. This constant seafloor depth and lack of tailbeats on the seafloor indicates **mortality.**



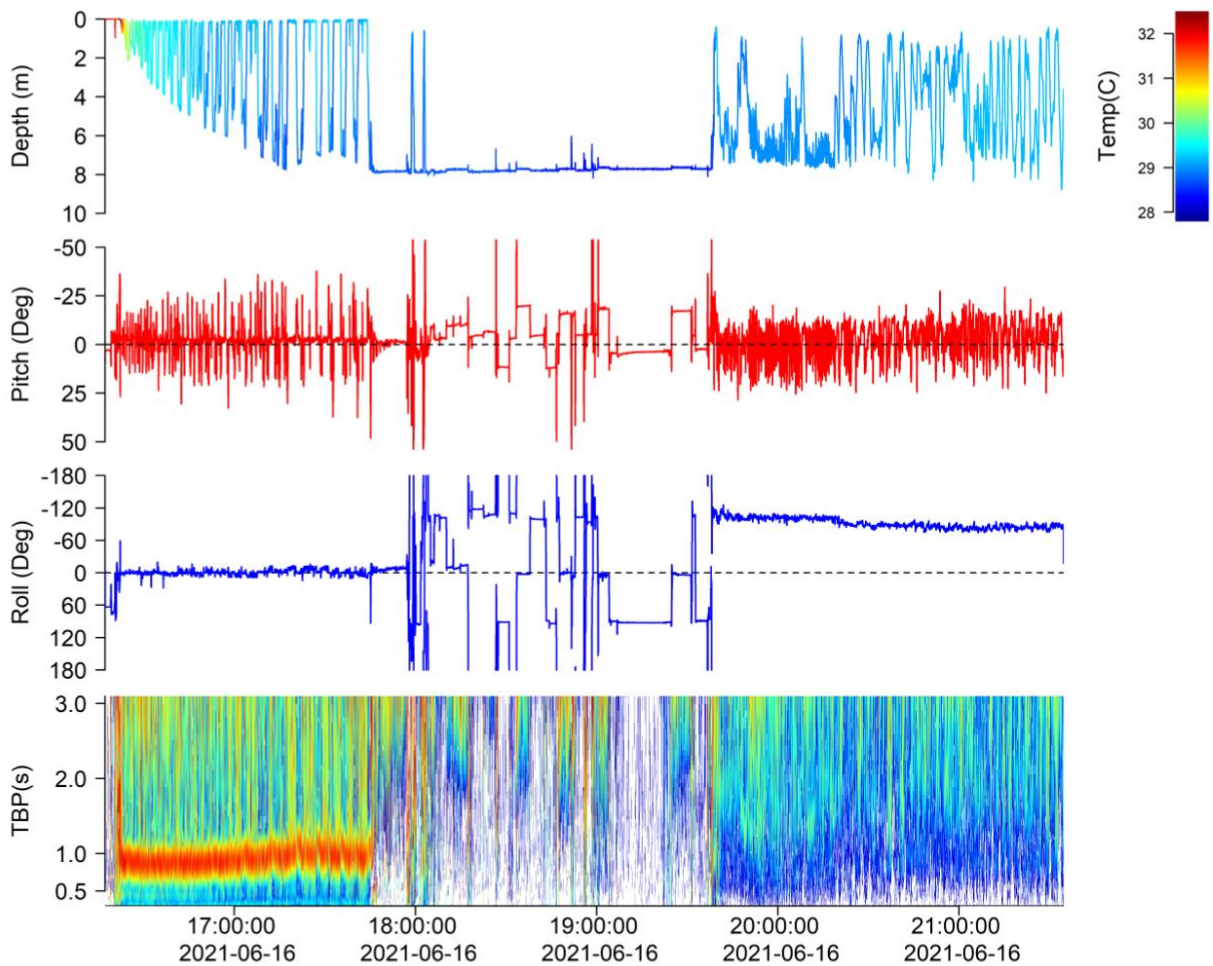
C_lim03_A: After tagging, this shark displayed consistent tailbeats around 1Hz and shark swam up and down in the water column. After 5 hours of swimming behavior, this shark gently rested on the sea floor and remained motionless on the bottom, for 30 minutes before the tag released from the individual and floated to the surface. The constant depth and lack of tailbeats indicates **mortality**



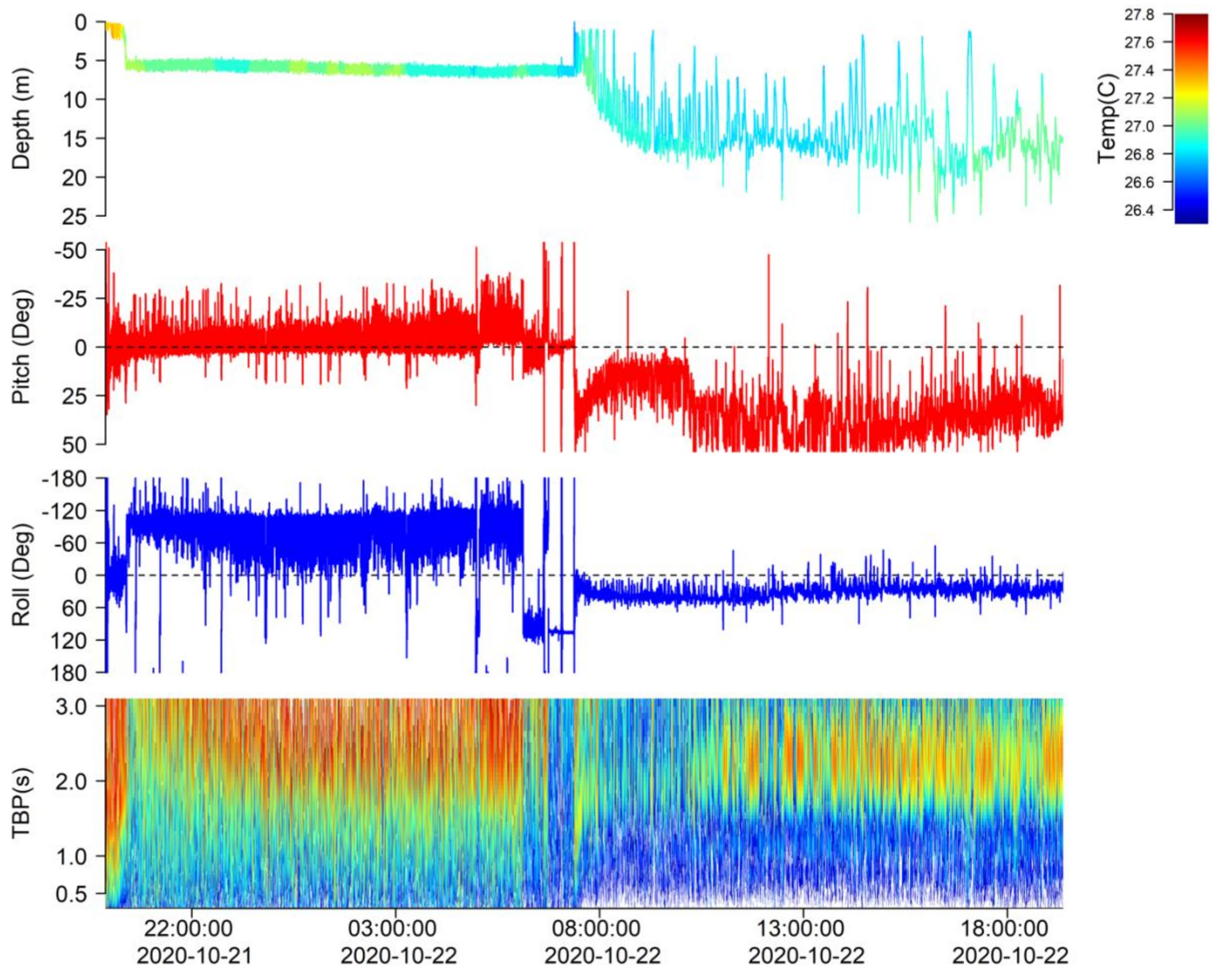
C_lim08_A: The shark was brought up on the beach and thrashed repeatedly during tagging. The tag was dislodged multiple times during the tagging process resulting in a handling time of 8 minutes. The shark was initially released at 20:38 central but had trouble clearing the first sand bar. The angler grabbed the shark again at 20:40 central, moved it past the first sand bar, and spent a couple of minutes reviving the shark. Shark was released a second time at 20:42 central. At approximately 21:10 central, the shark was seen **dead** in the surf. The ADL data shows that the shark lacked consistent tail beats while it was released and that it was not in a normal posture but was often rolled on its side.



C_lim09_A: 1 hour after tagging, the shark went to bottom where it remained for 2 hours at constant depth, indicating **mortality.** In the first hour post release there are clear tail beats, some temperature stratification and the shark is level (Roll ~ 0). However, this shark then dies as evidence of a lack of tailbeats and laying on the seafloor. After ~10 mins on the seafloor it looks like the shark begins to get scavenged as the shark begins to roll into different positions. 1.5 hours after it initially rested on the seafloor the tag appears to be ingested by a predator. The tag is rolled 120 degrees in the predator's stomach and because the tag is no longer aligned in the same way, we do not see a clear tailbeat signal in the frequency spectrum. Additionally, as this predator swims up and down in the water column we see no temperature stratification. This tag stayed in the predator's stomach for ~50 Hours before being regurgitated.

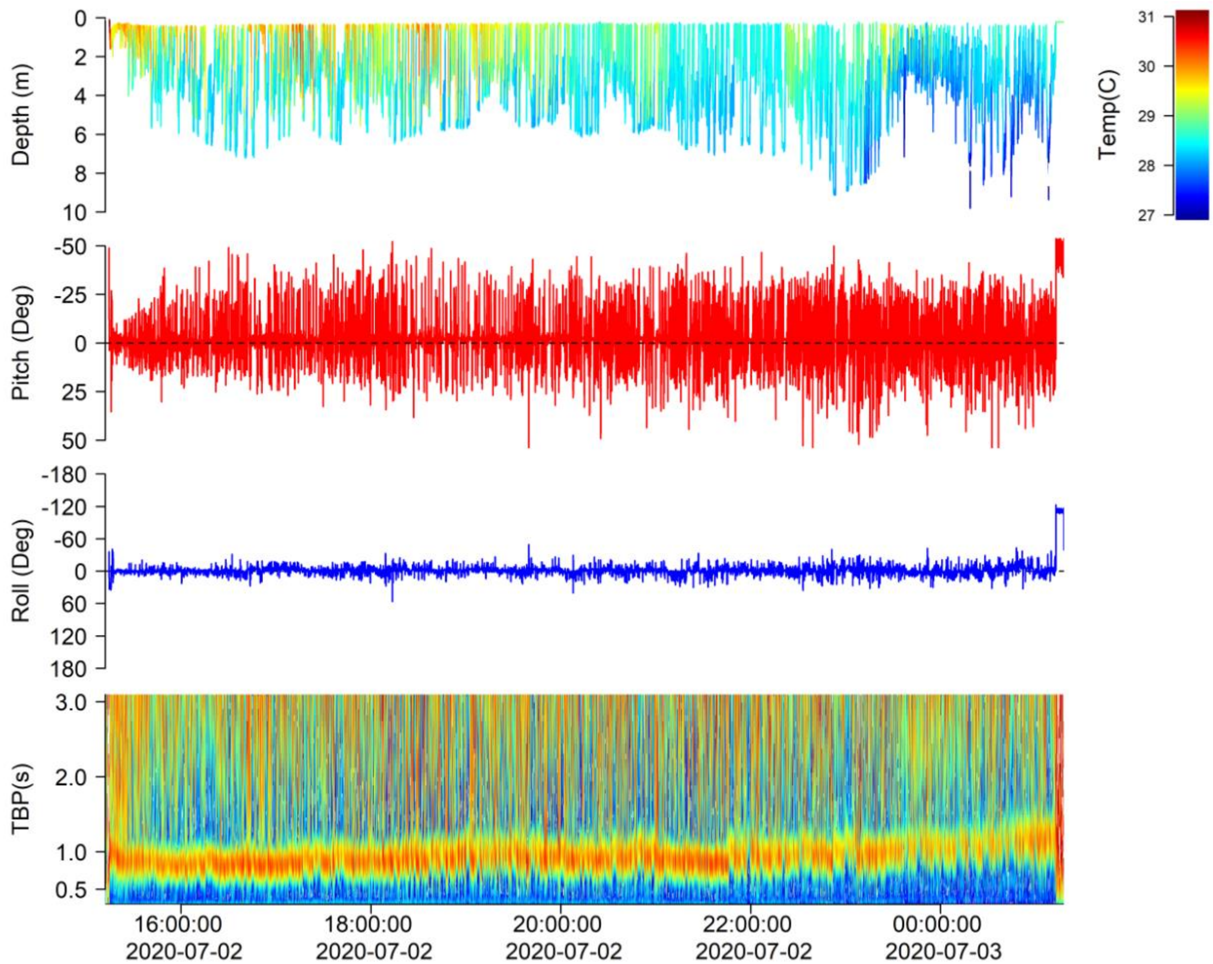


S_mok01_A: After tagging, shark moved at the surface for approximately 45 minutes, before remaining motionless on the bottom for over 10 hours indicating **mortality.** The deceased hammerhead then rolled around on the seafloor for about 8 hours before the tag was ingested by a predator. This tag stayed in the predator's stomach for ~106 hours before being regurgitated.

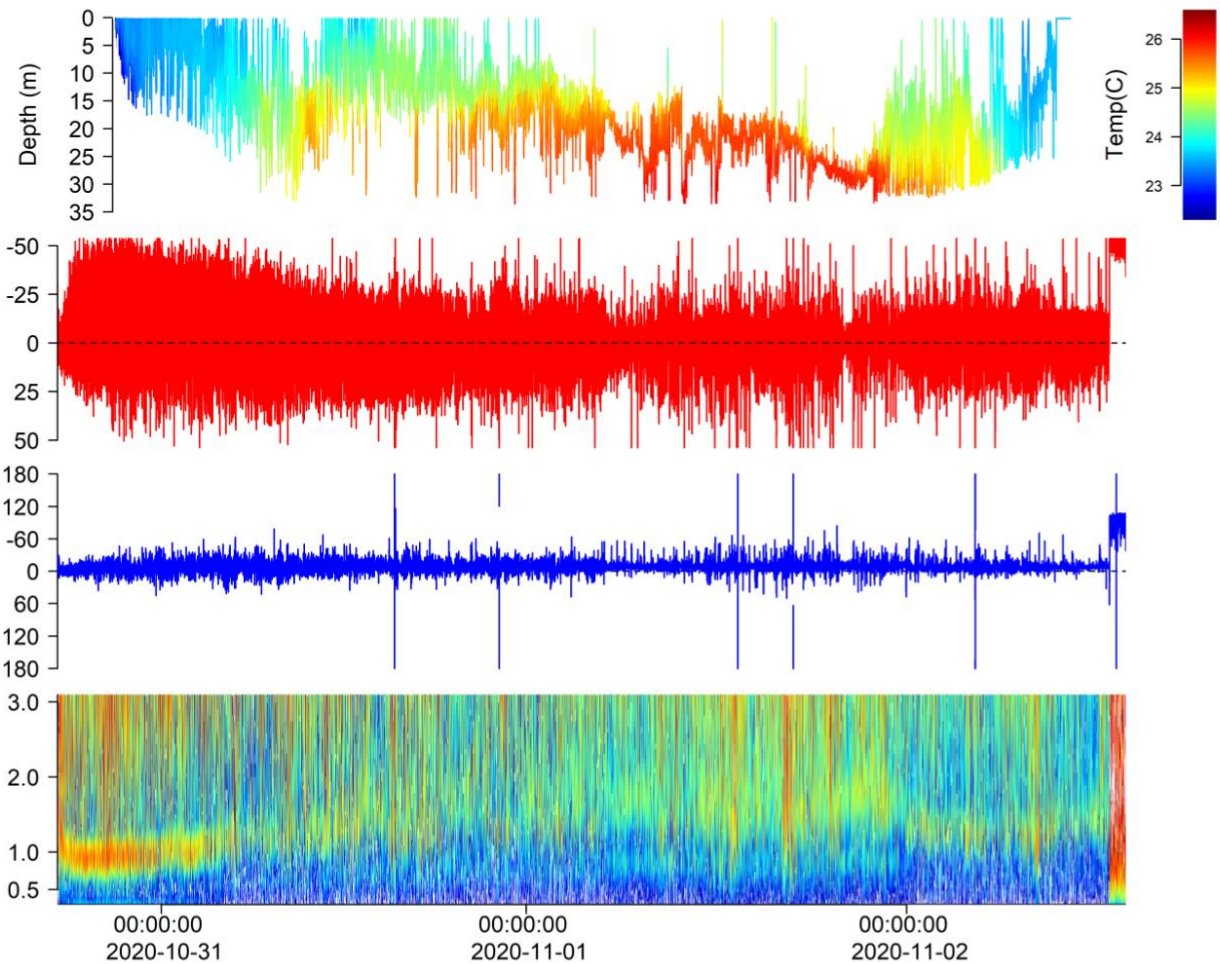


ADL Time series from confirmed SURVIVORS (N=13)

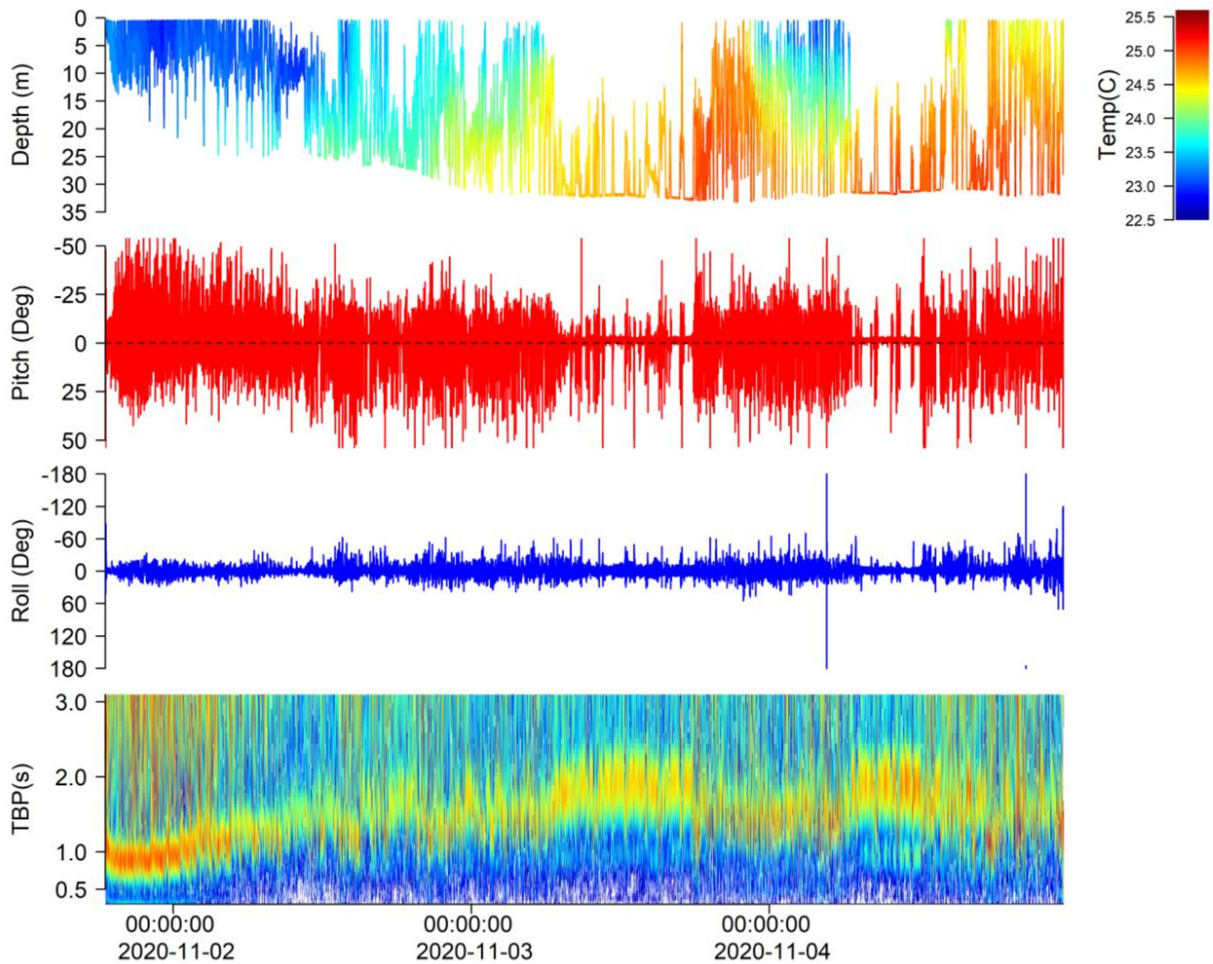
C_lim01_A: SURVIVE



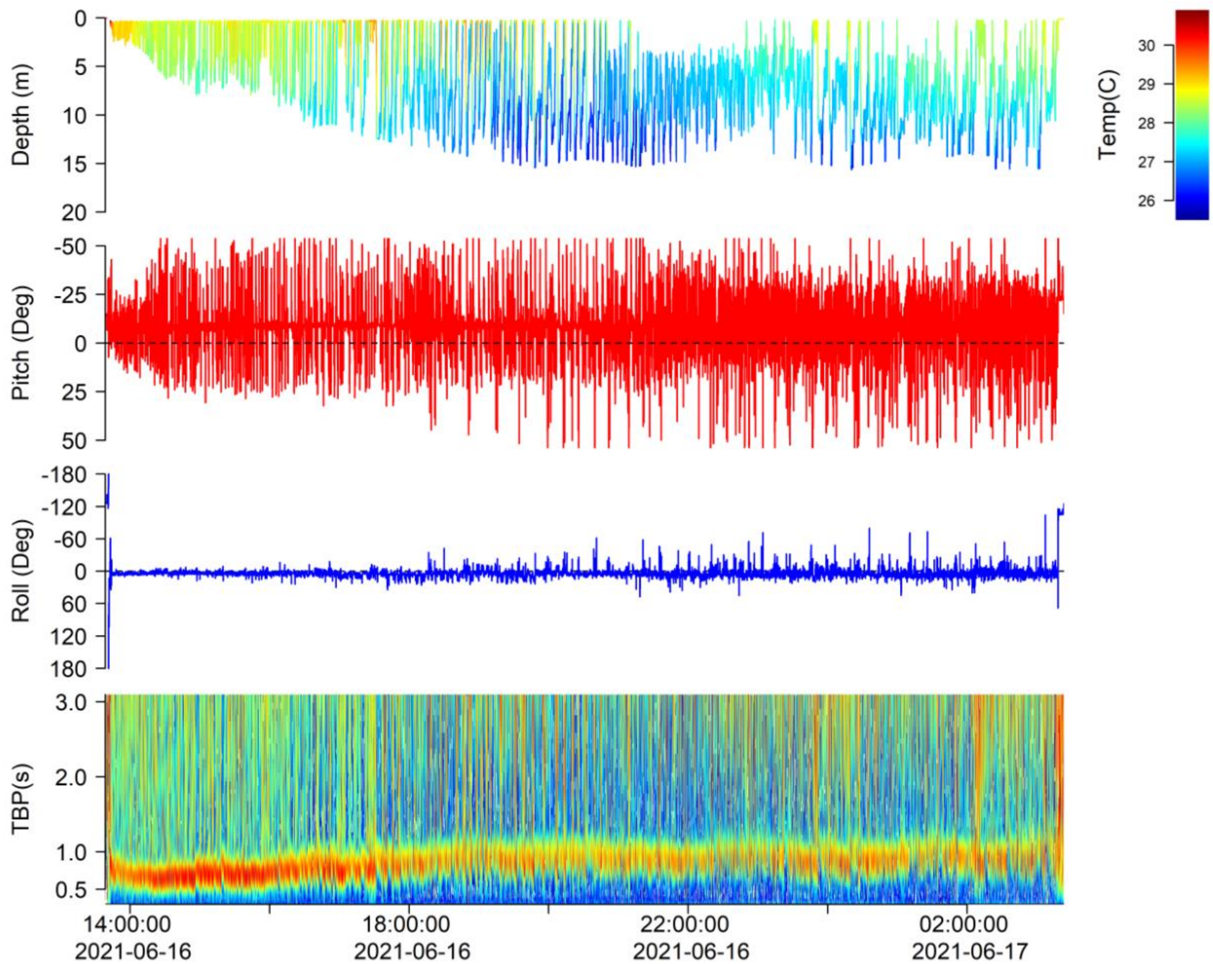
C_lim04_A: **SURVIVE**



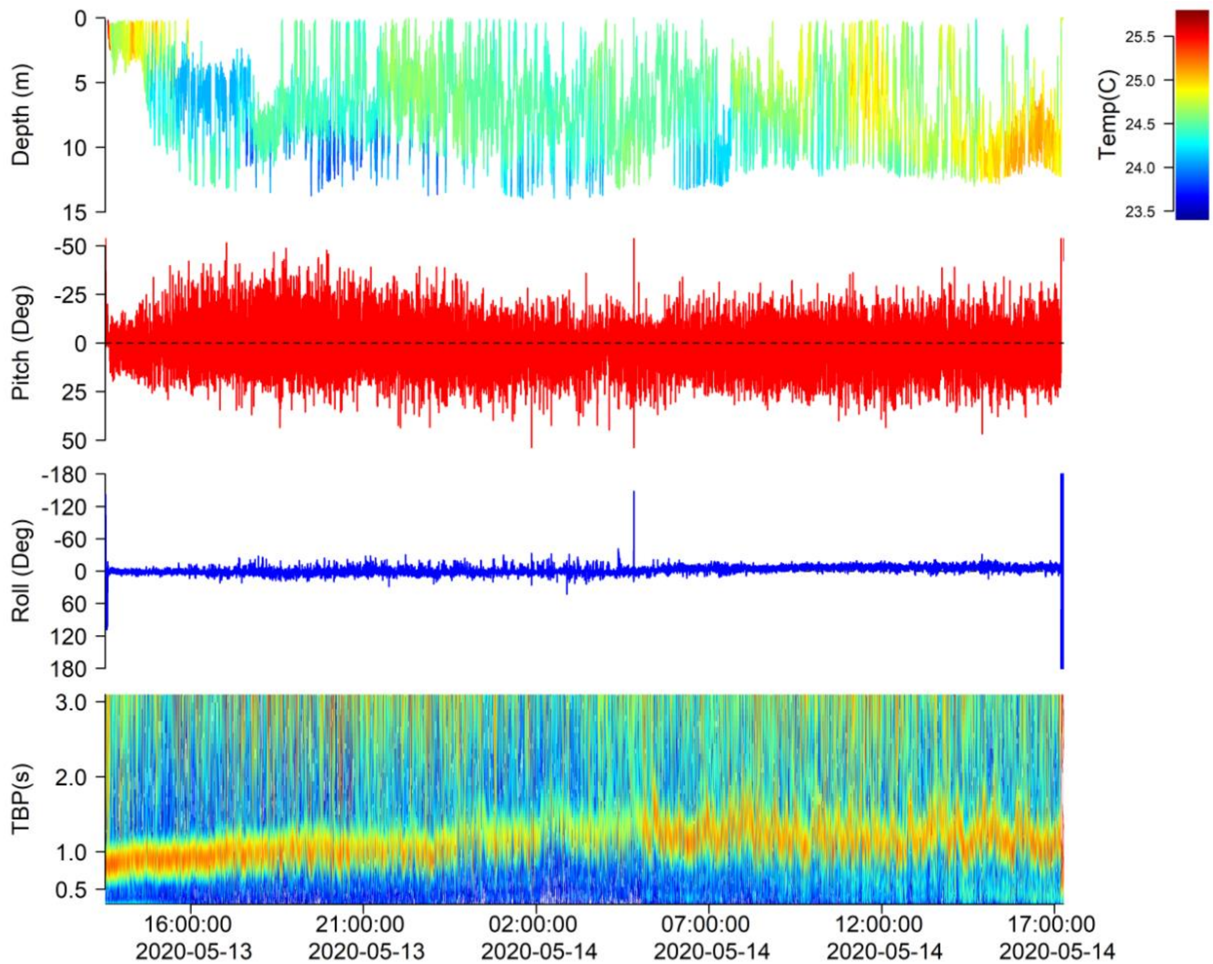
C_lim05_A: SURVIVE



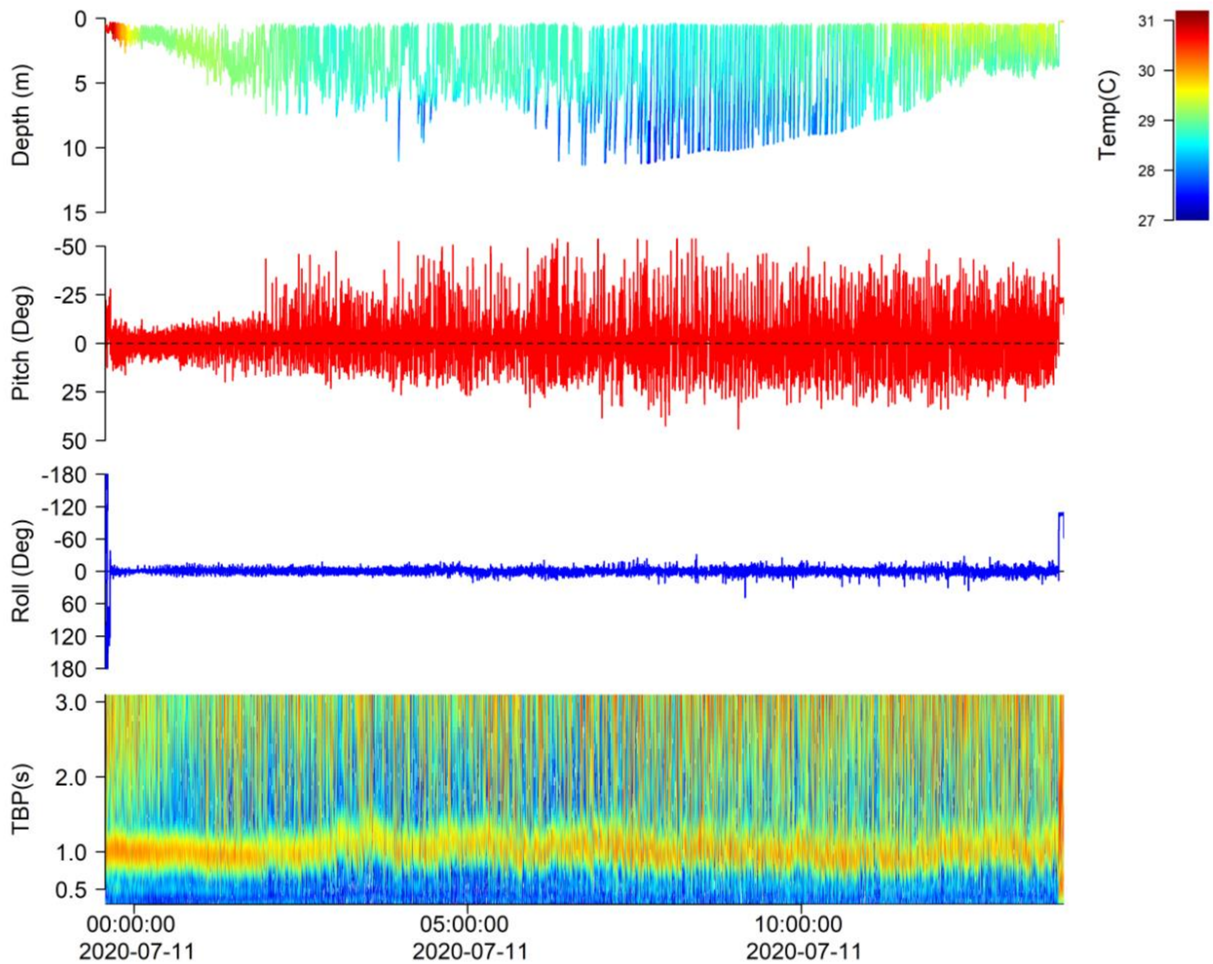
C_lim10_A: SURVIVE



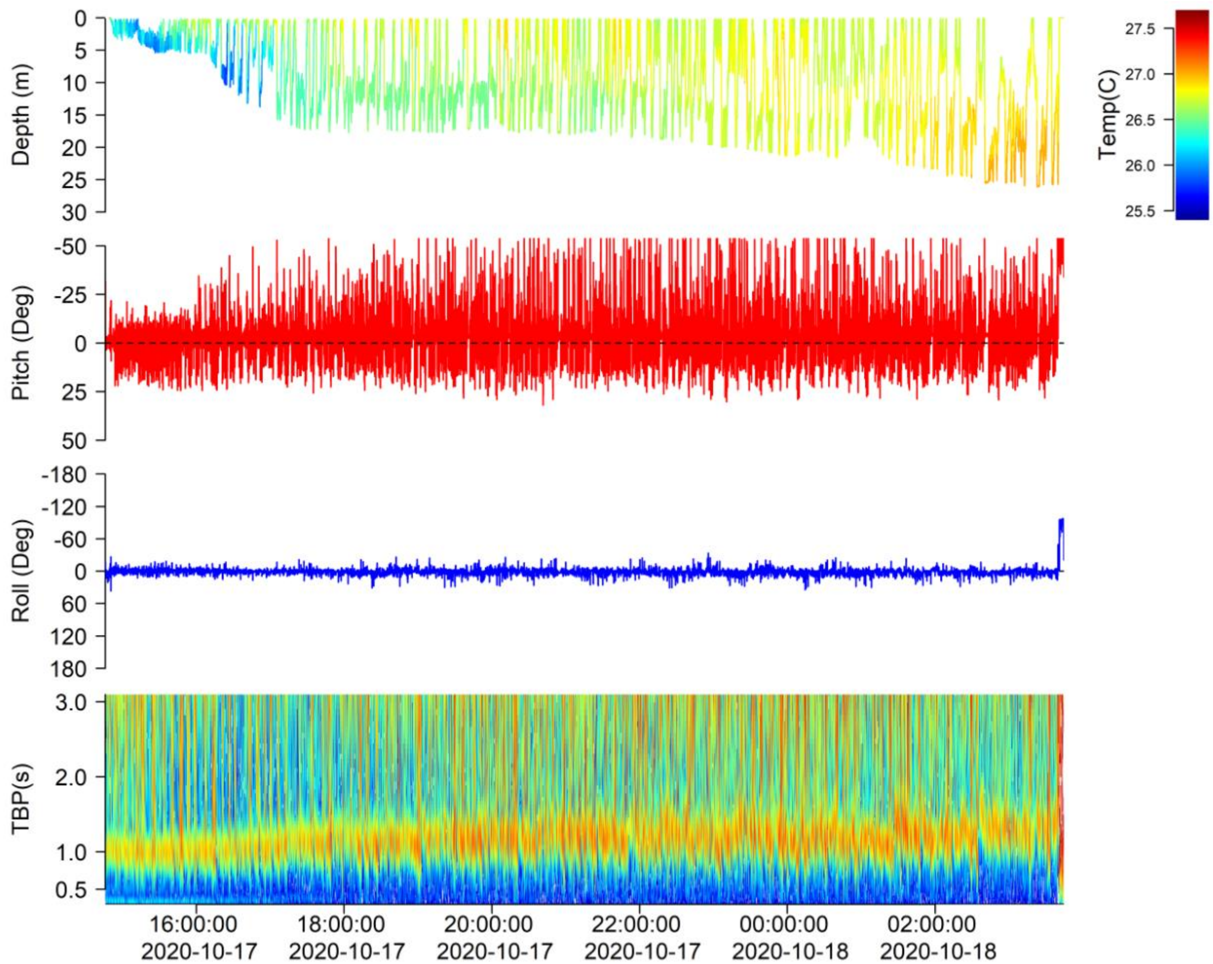
C_leu01_A: **SURVIVE**



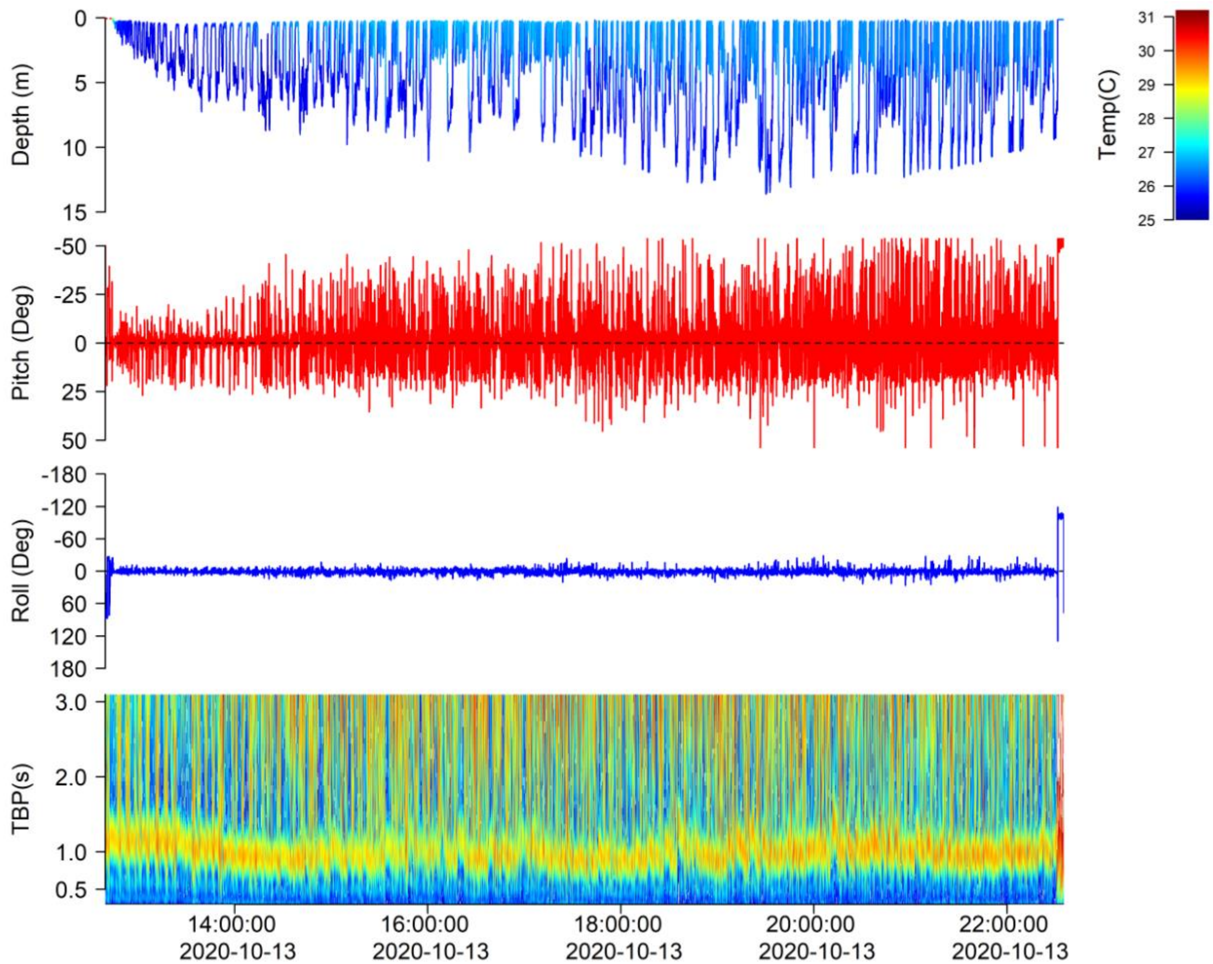
C_leu02_A: SURVIVE



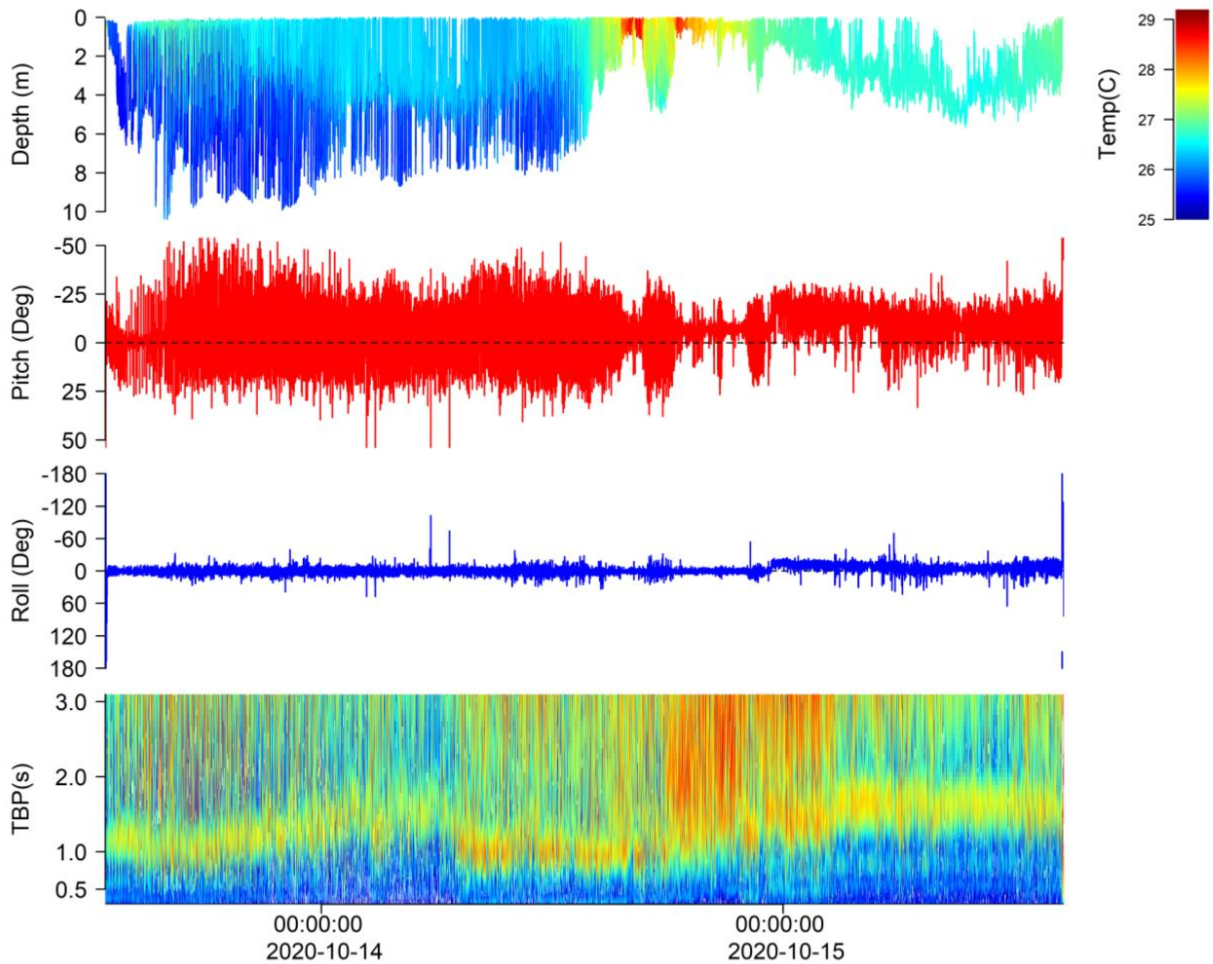
C_leu03_A: SURVIVE



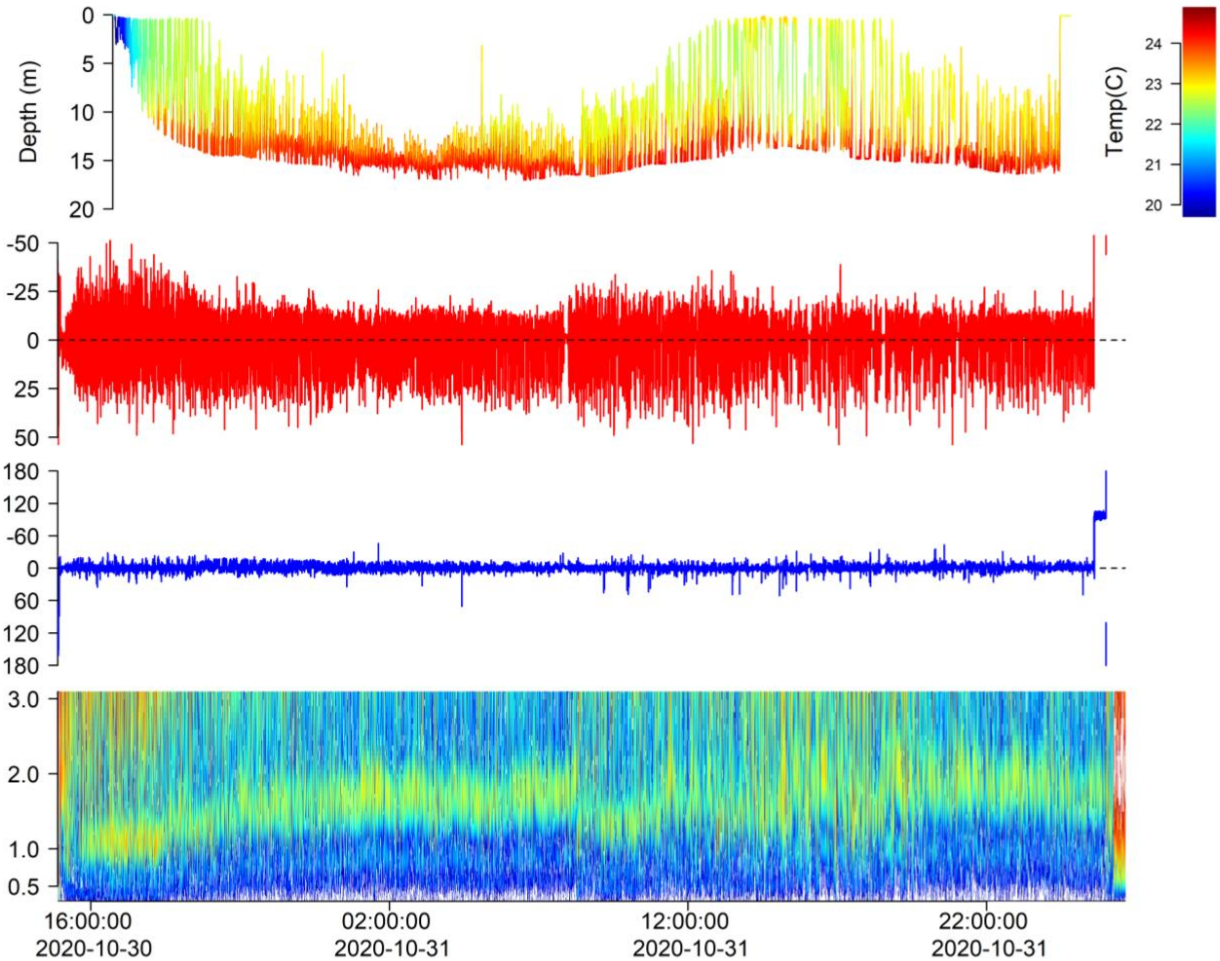
C_leu04_A: SURVIVE



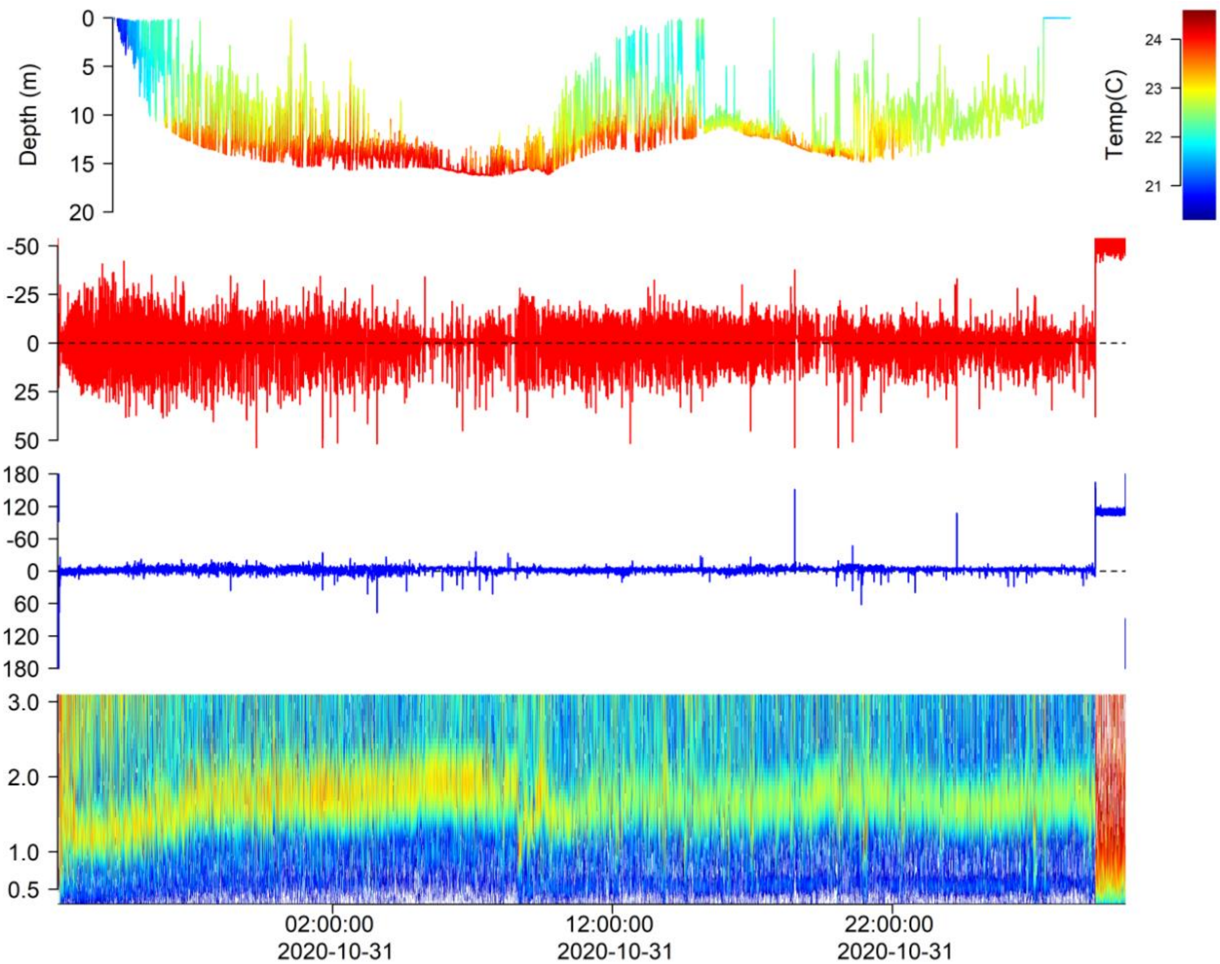
C_leu05_A: SURVIVE



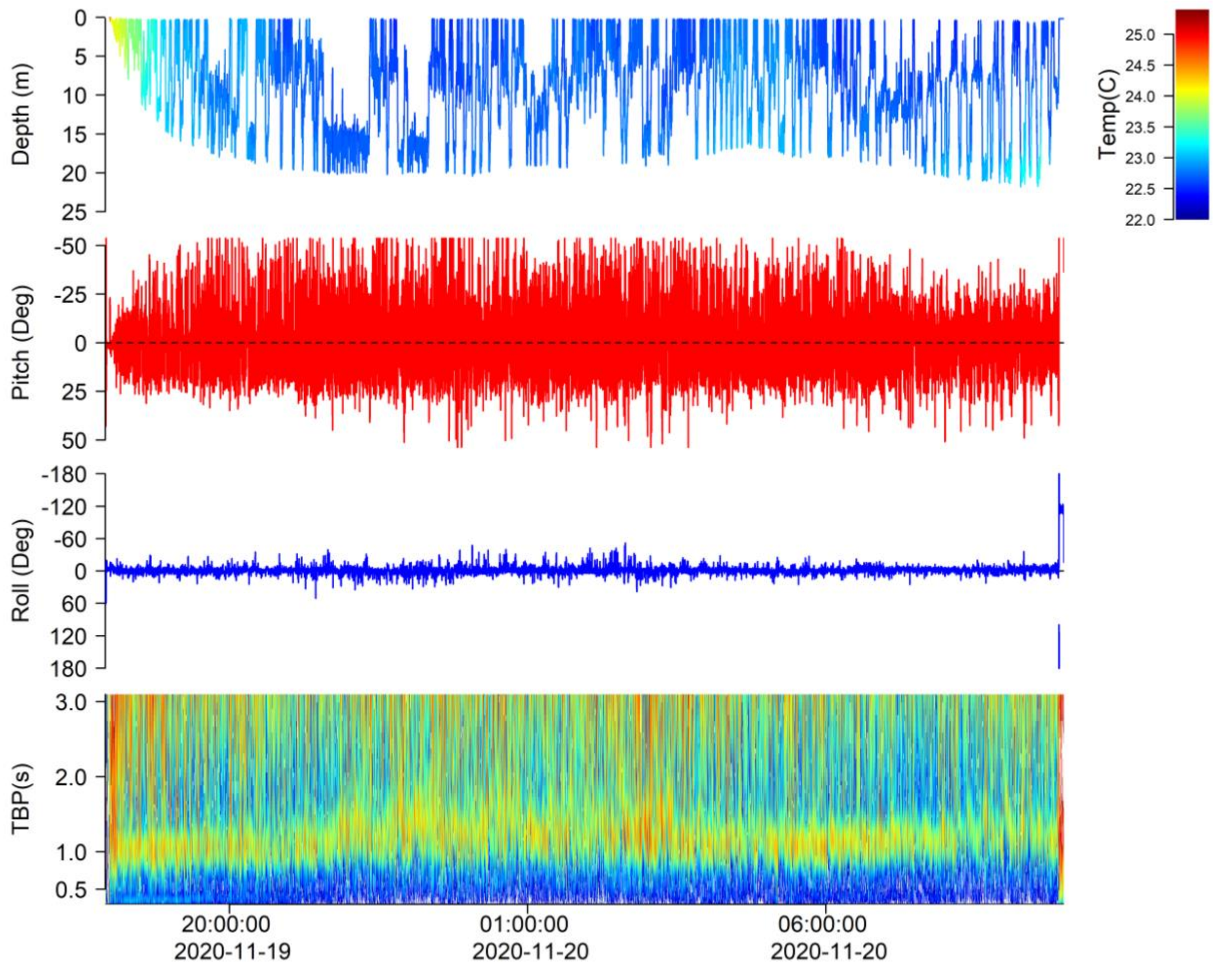
C_leu07_A: SURVIVE



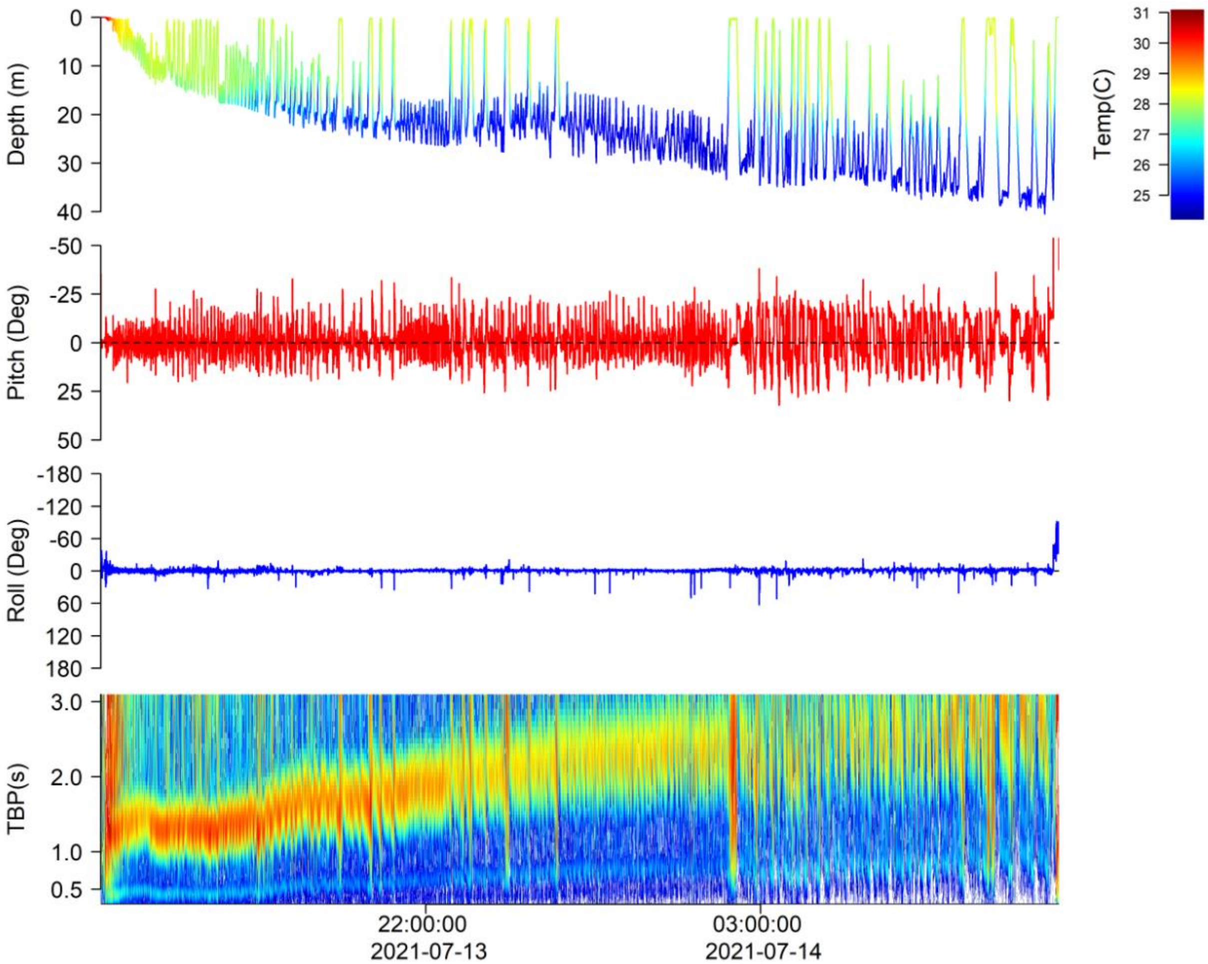
C_leu08_A: **SURVIVE**

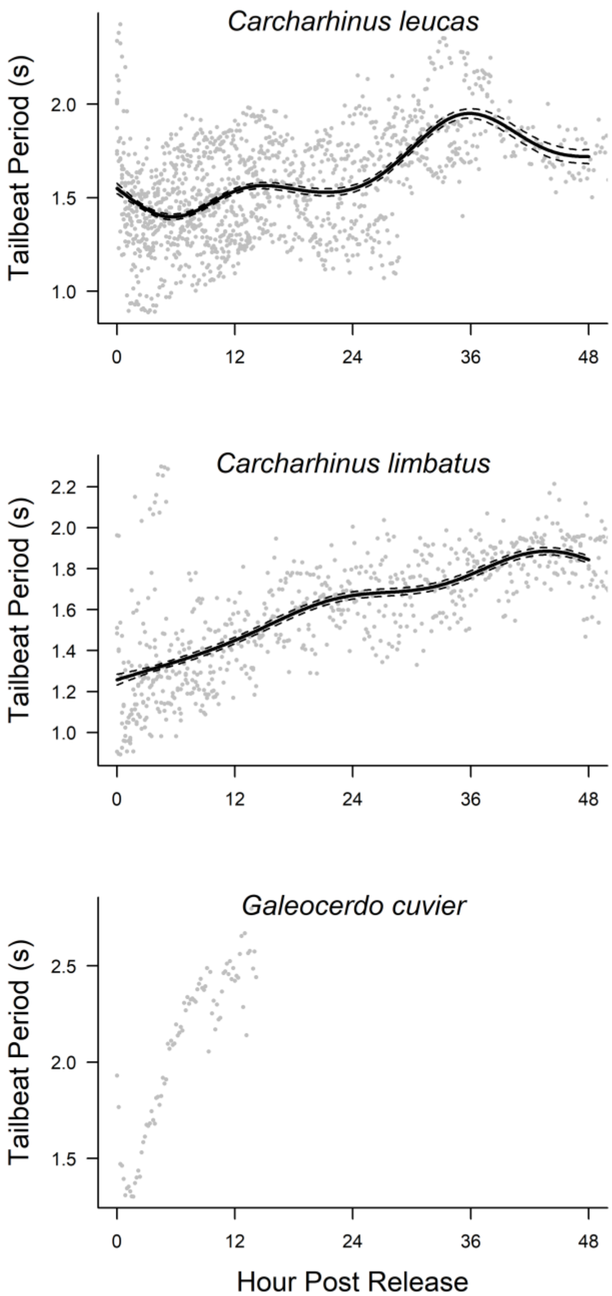


C_leu09_A: **SURVIVE**

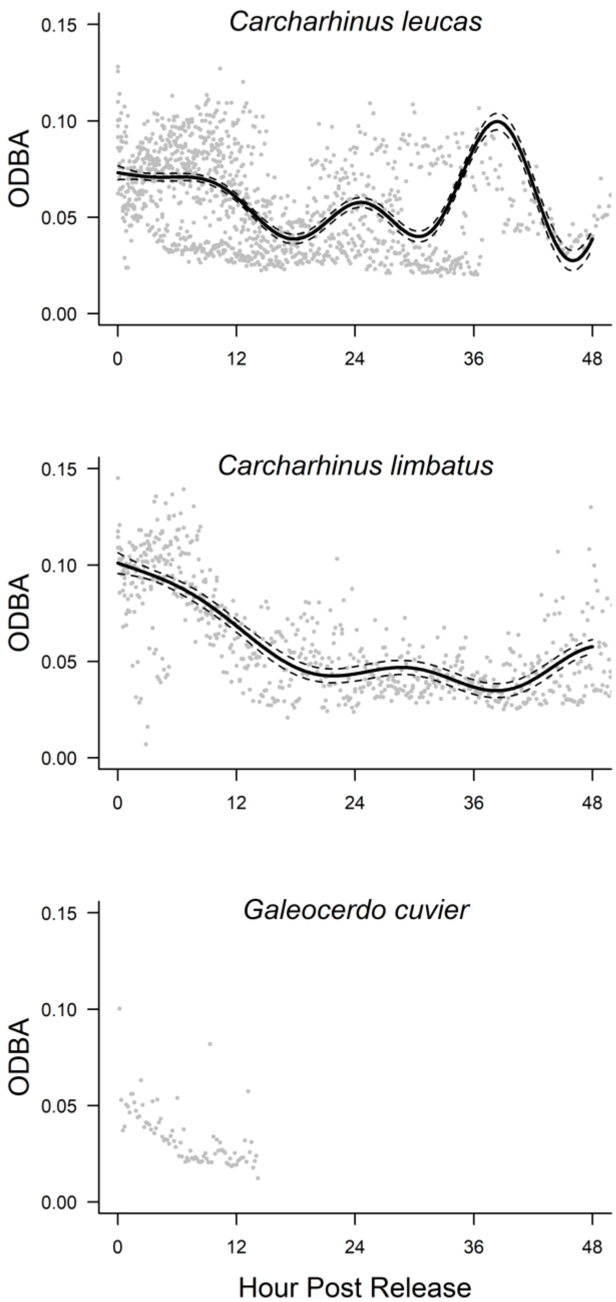


G_cuv01_A: SURVIVE





Trends in Tailbeat period over time post release for bull, blacktip, and tiger sharks from the ADL data. Generalized additive models were used to estimate the relationship between tailbeat period and time post release with grey points representing a 10-minute mean of tail beat period for a single individual. Limited number of individuals for each species prevented definitive estimates of recovery period, however, trends in the data were observed for some species. Blacktip sharks were observed to have increasing tail beat period (i.e. slower tailbeats) over the entire 48 hours post release. In comparison there were not clear trends for the bull sharks and the one tiger shark seems to potentially reach an asymptote by 12 hours post release.

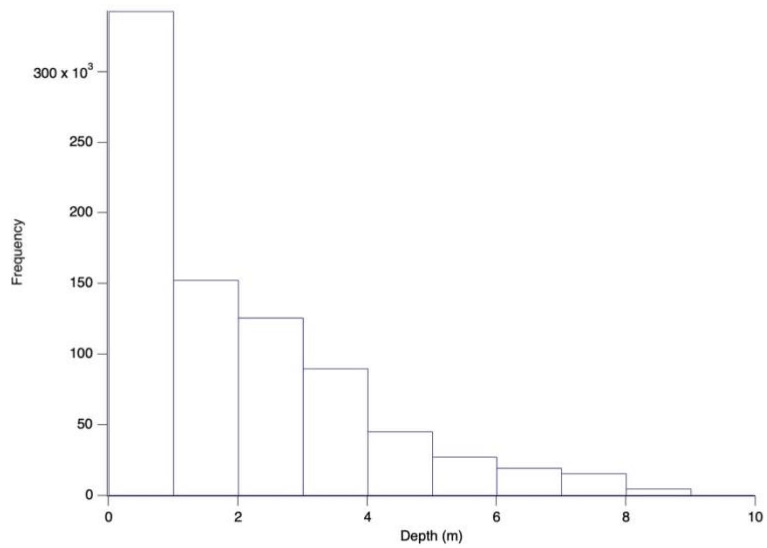


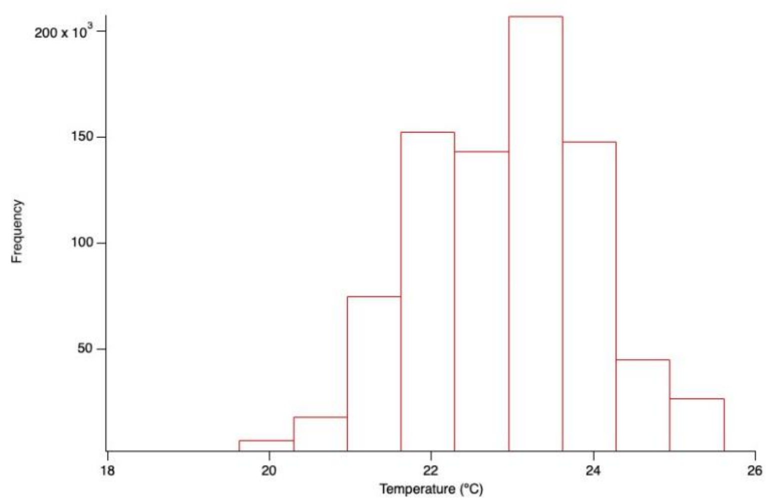
Trends in overall dynamic body acceleration (ODBA) over time post release for bull, blacktip, and tiger sharks from the ADL data. Generalized additive models were used to estimate the relationship between ODBA and time post release with grey points representing a 10-minute mean of ODBA for a single individual. Limited number of individuals for each species prevented definitive estimates of recovery period. Blacktip sharks were observed to have decreasing ODBA (i.e. lower activity level) over the first 16 hours post release. In comparison there were not clear trends for the bull sharks and the one tiger shark only experienced decreasing ODBA over the first 8 hours post release.

APPENDIX 3

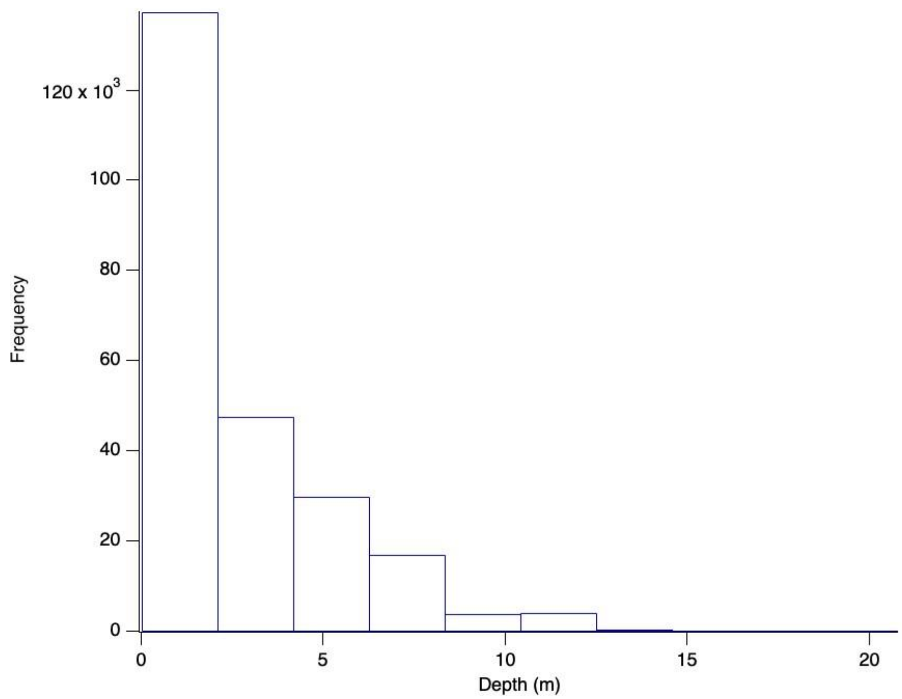
Histogram plots exploring the frequency distributions for depth and temperature values for all PSAT tags from confirmed survivors.

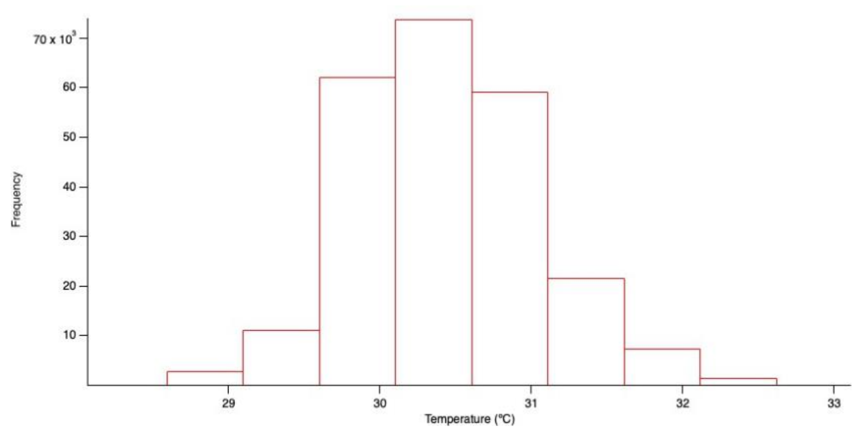
C_leu04: recovered sPAT tag recording for 10 days from 3/17/20-3/27/21



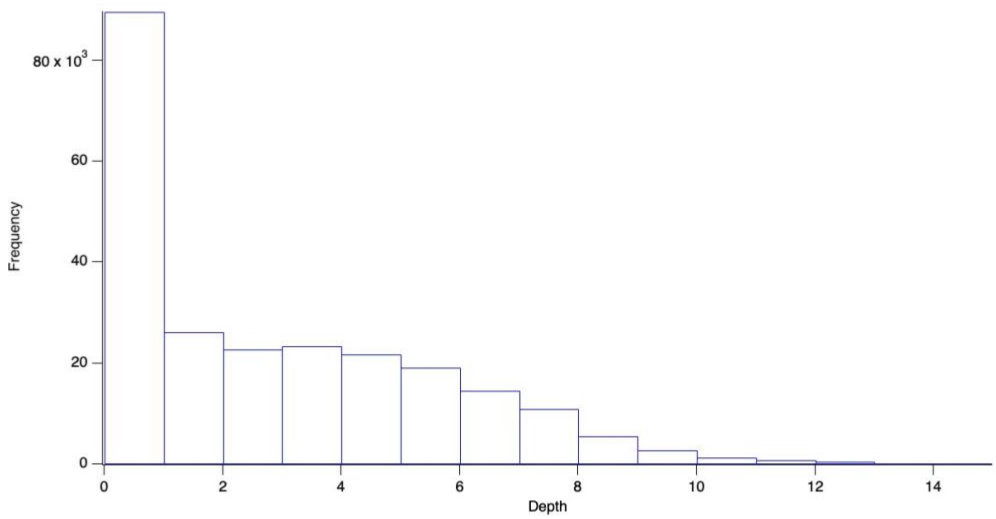


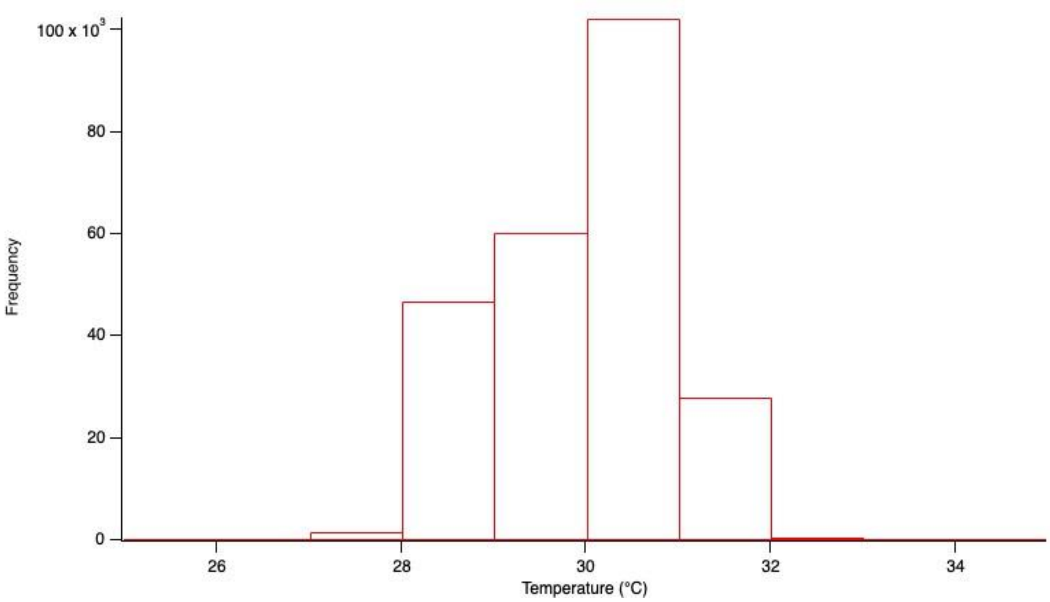
C_leu06: recovered PSATLIFE tag recording for 28 days from 8/7/18-9/4/18



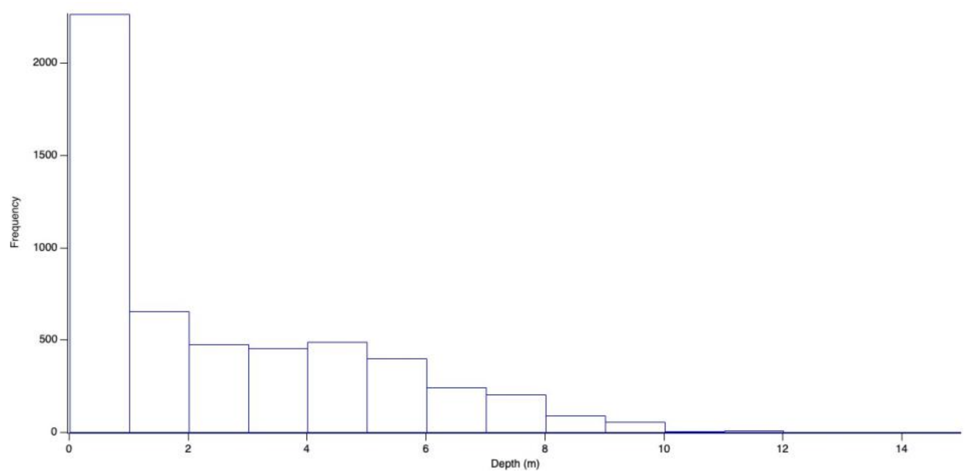


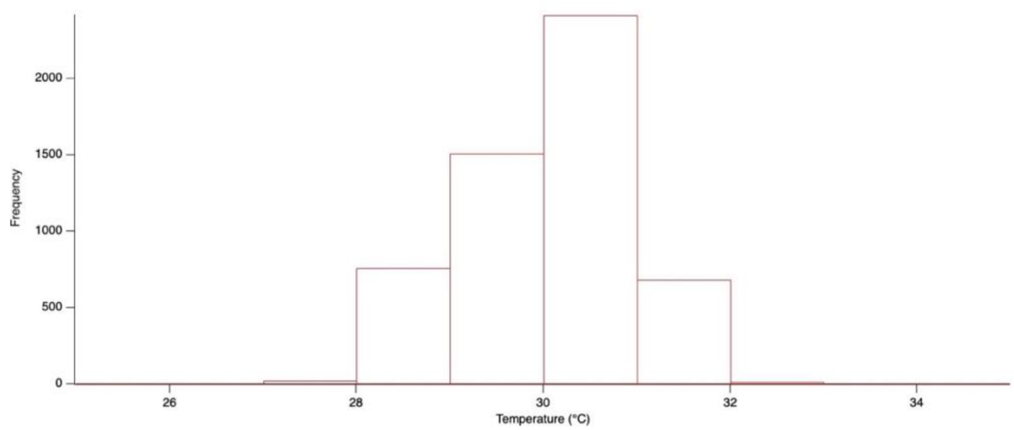
C_leu07: recovered PSATLIFE tag recording for 28 days from 7/20/19-8/17/19



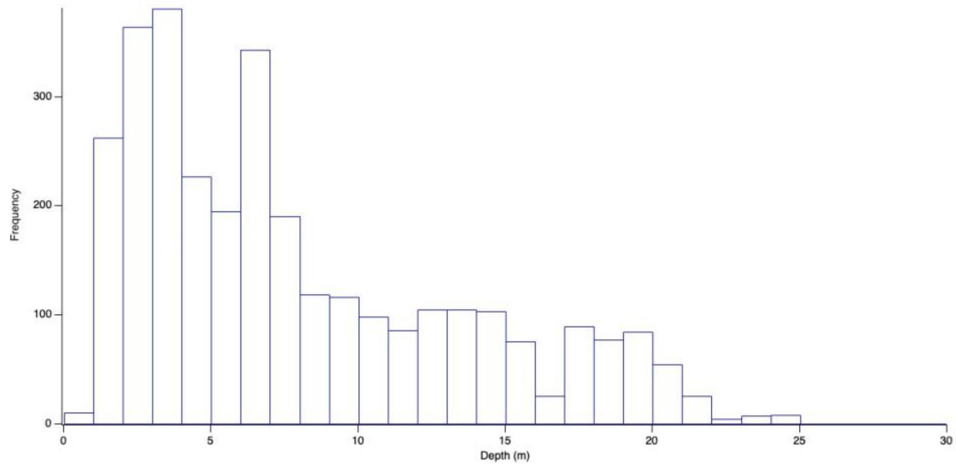


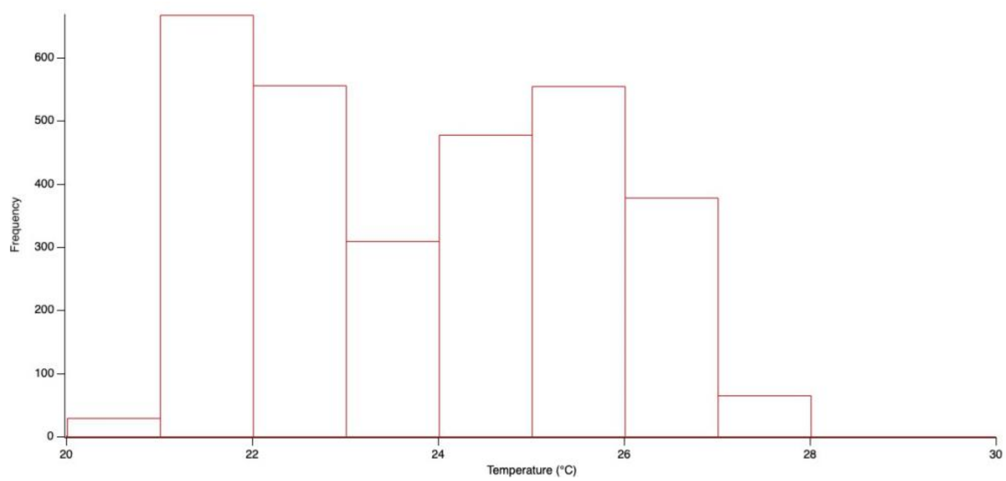
C_leu08: recovered PSATLIFE tag recording for 28 days from 7/20/19-8/17/19





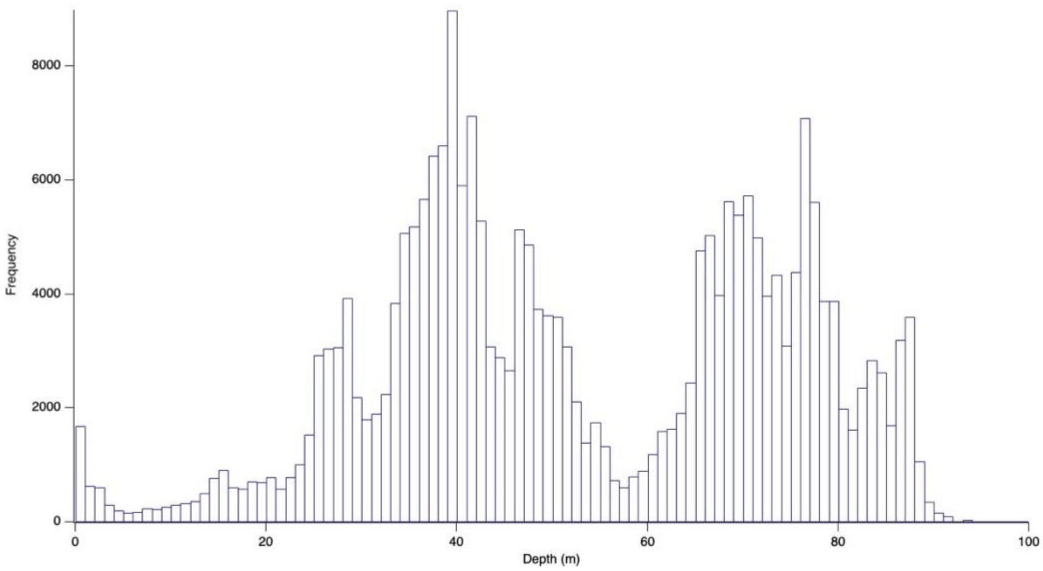
C_leu09: Mini-PAT tag with 41 days transmitted data from 4/5/21-5/16/21

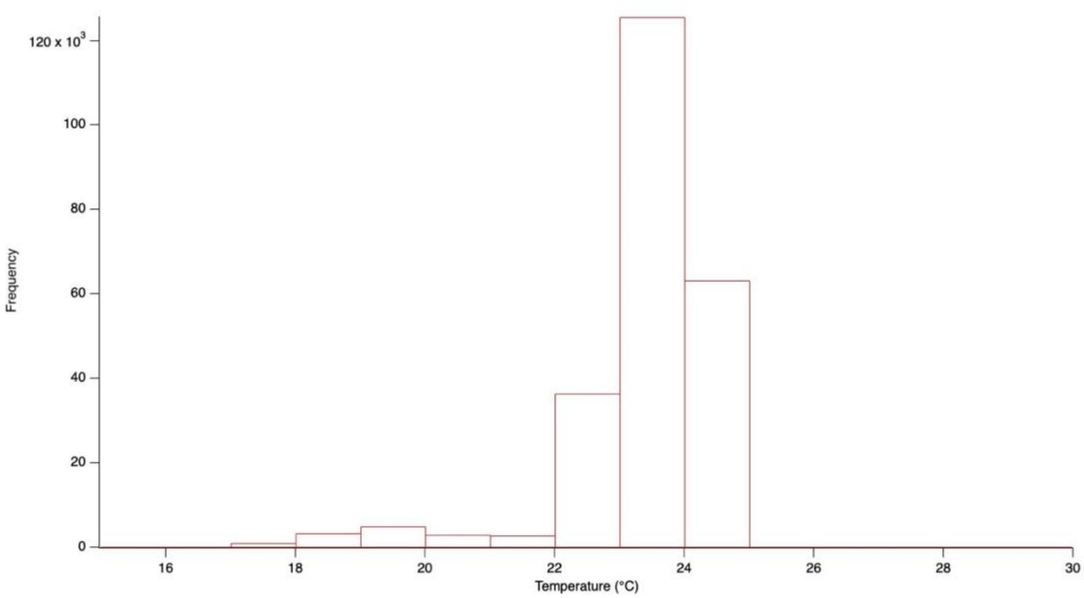




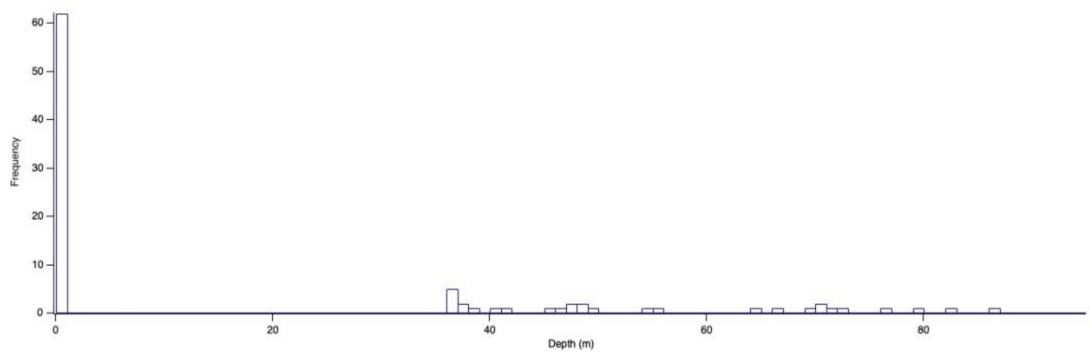
C_lim03: recovered PSATLIFE tag recording for 28 days from 12/5/19-1/2/20

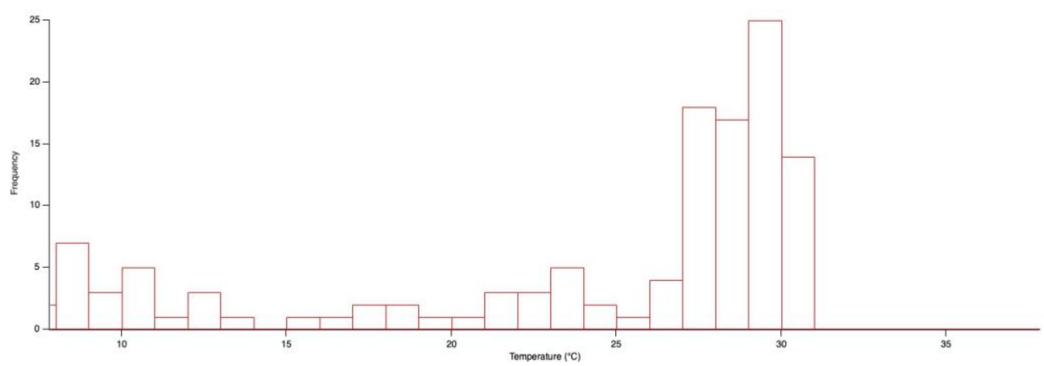
*This represents the only surviving Blacktip shark for which we have high resolution PSAT tag data



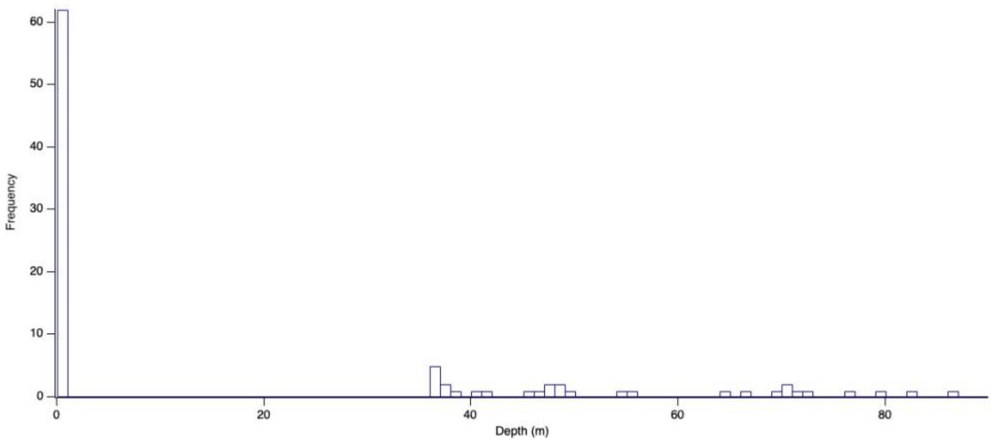


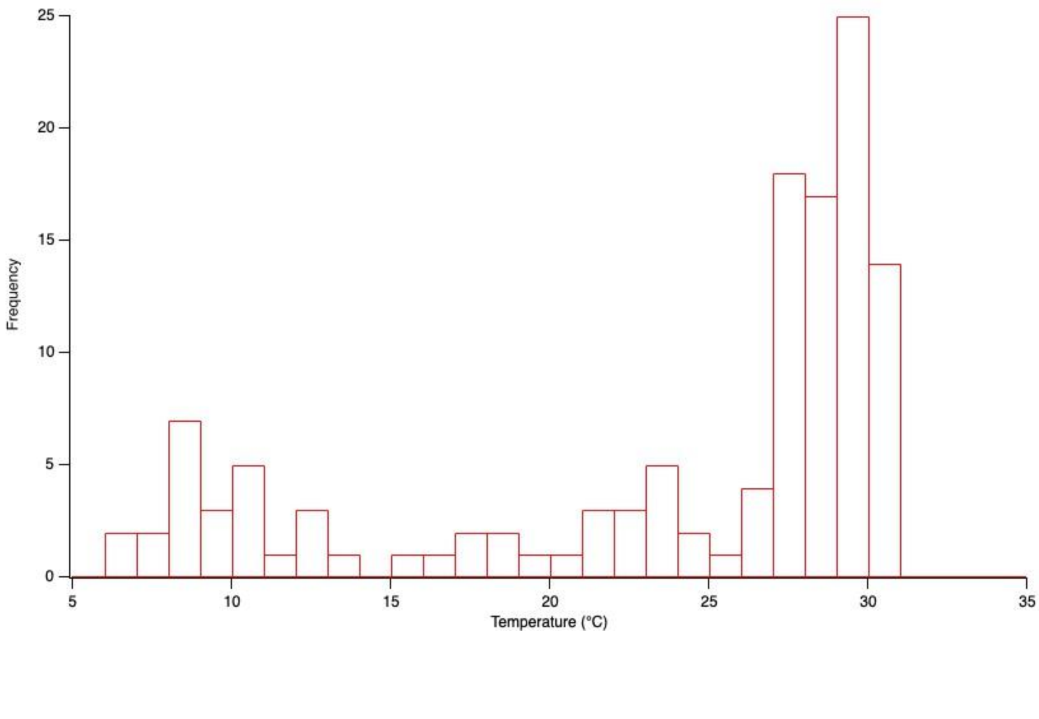
G_cuv01: sPAT tag with 41 days transmitted data from 8/20/20-9/30/20



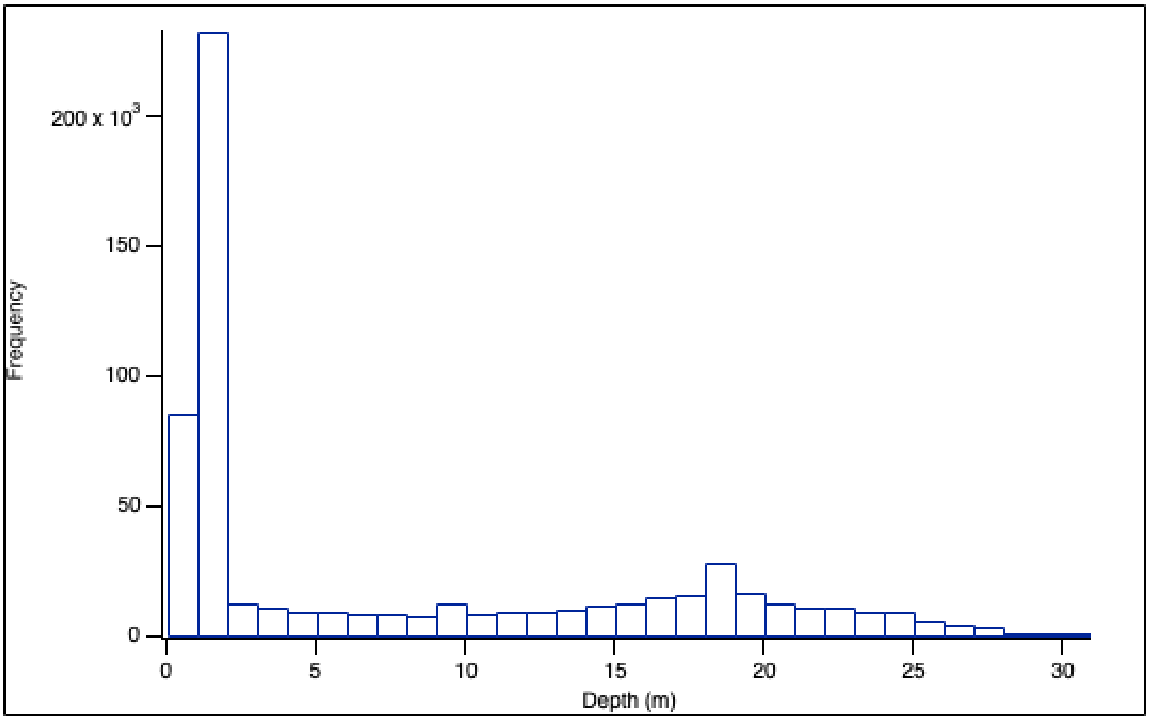


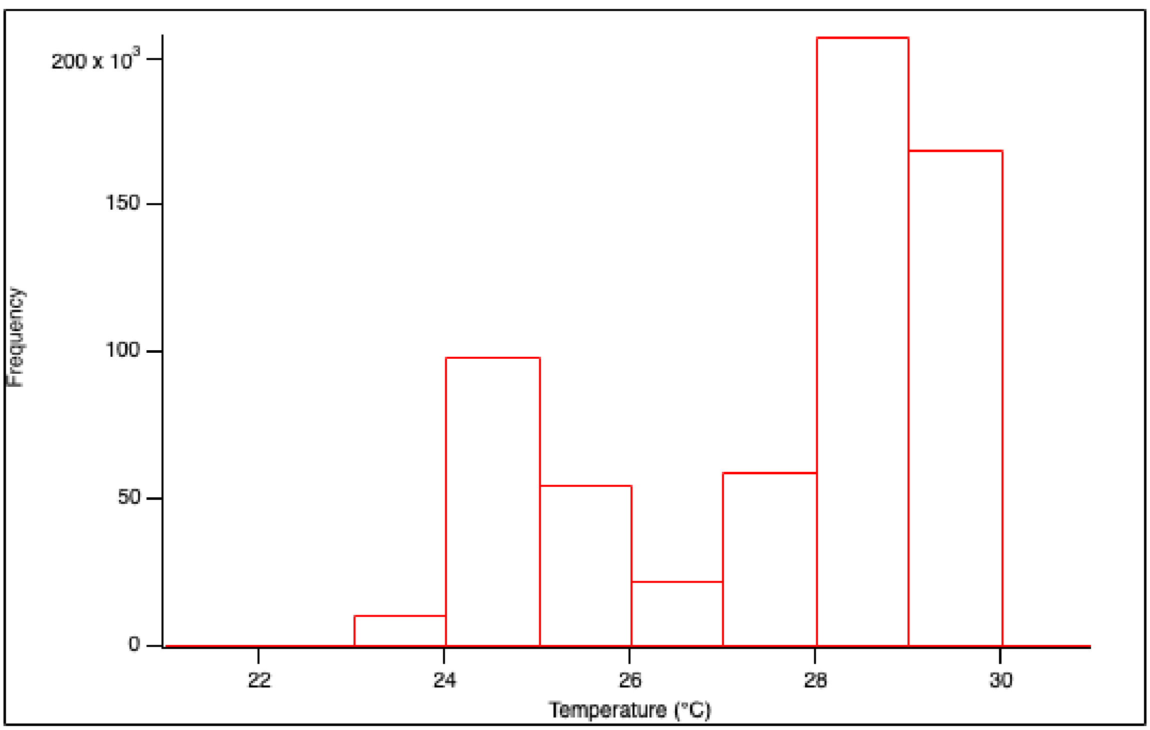
G_cuv02: sPAT tag with 62 days transmitted data from 8/22/20-10/23/20



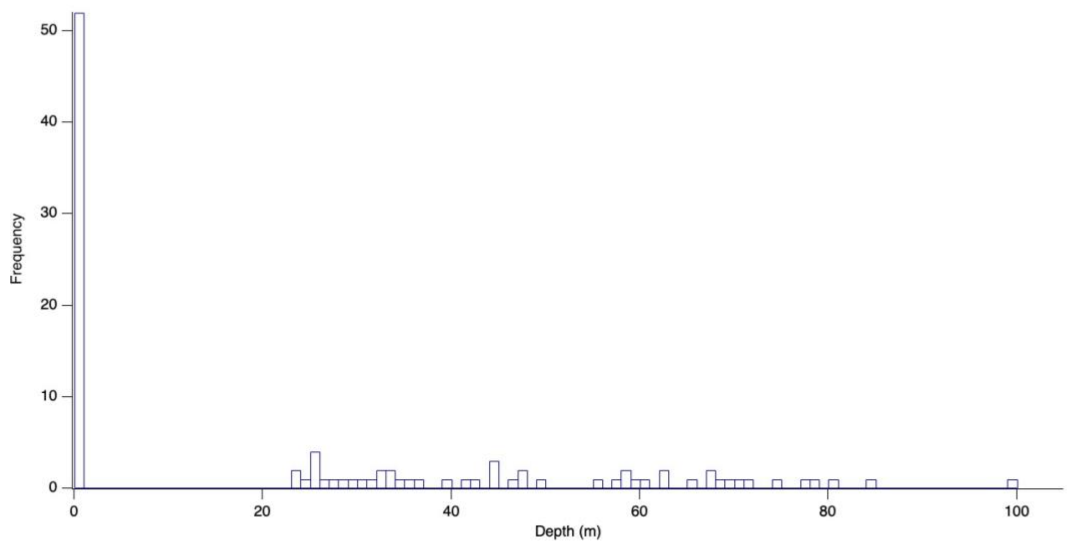


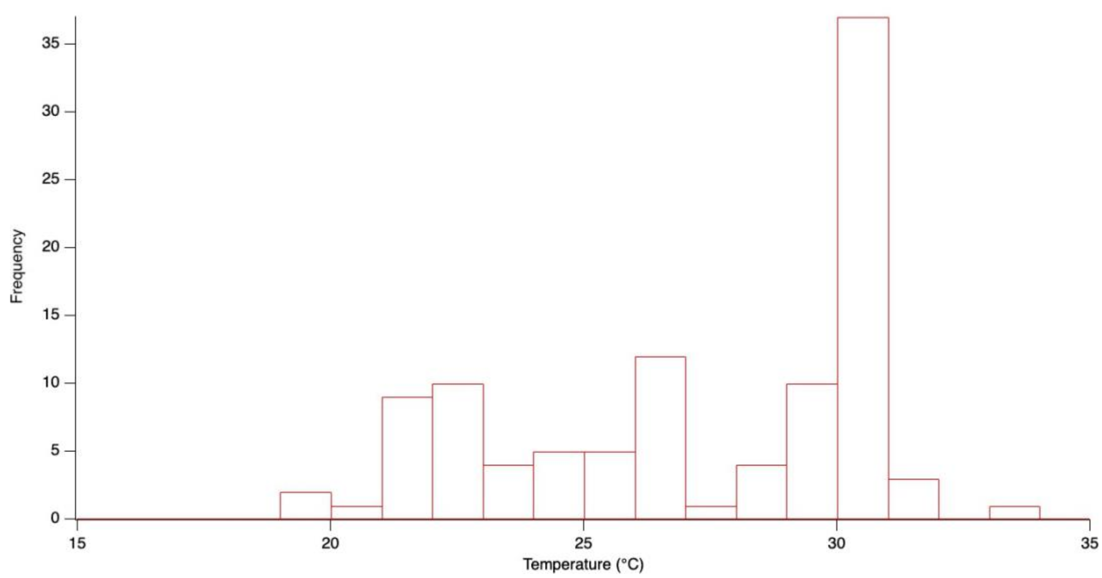
G_cuv03: recovered sPAT recording for 5 days from 6/14/21-6/19/21



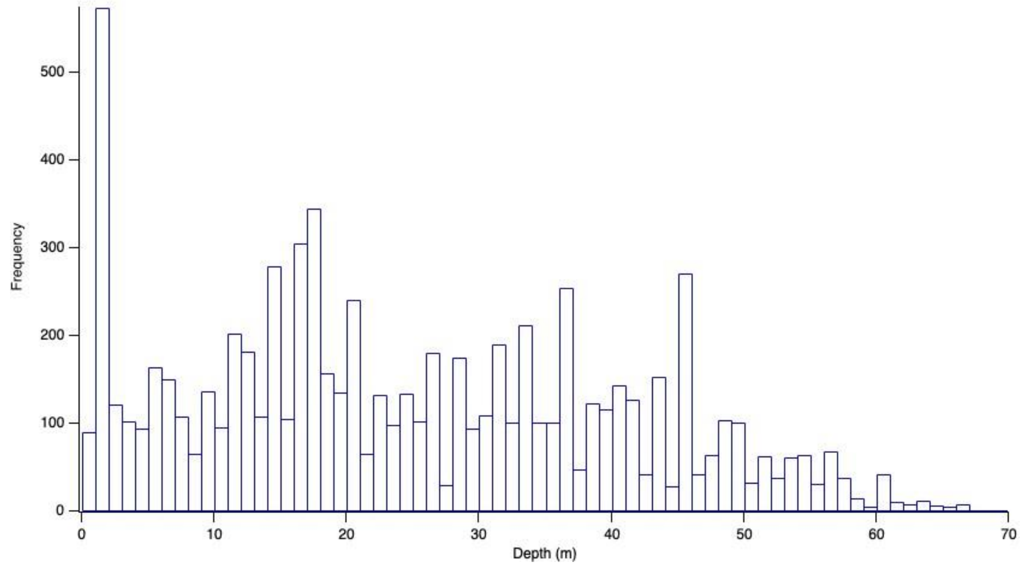


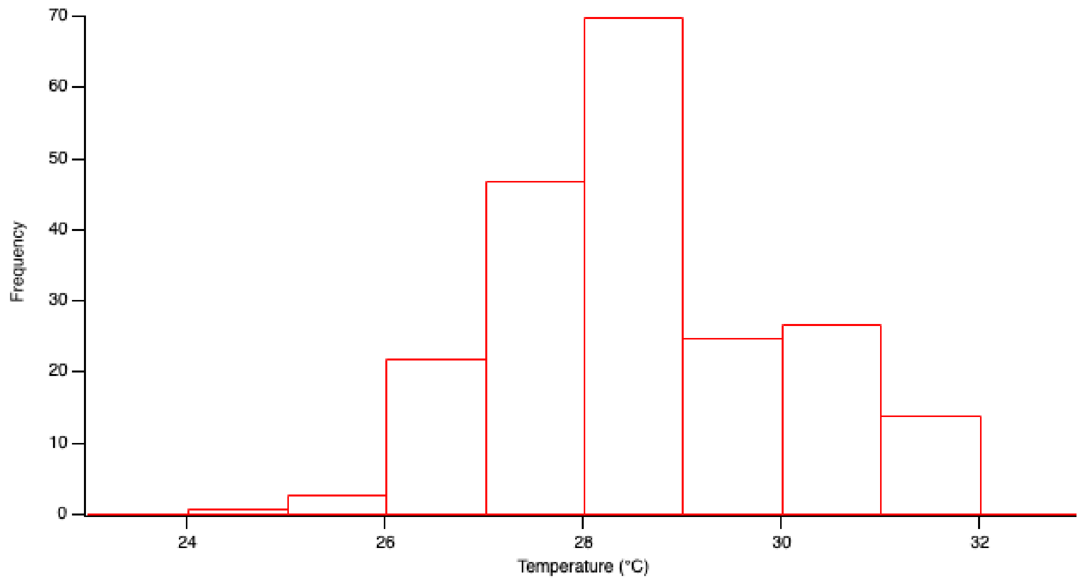
G_cuv04: sPAT with 51 days transmitted data from 7/3/21-8/23/21





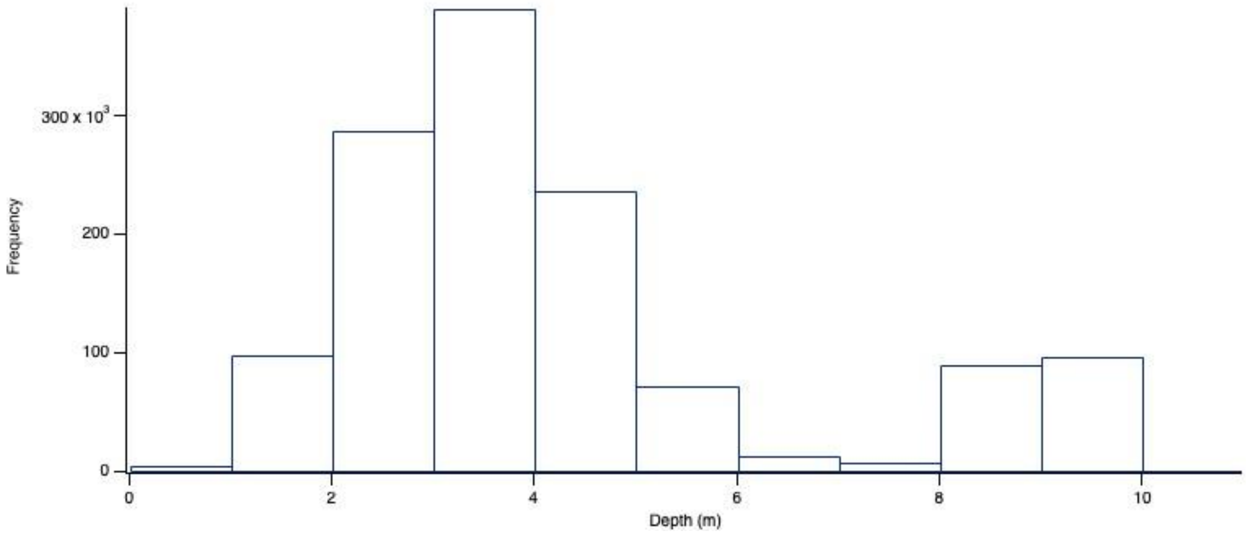
G_cuv05: Mini-PAT with 57 days transmitted data for depth over 8/26/21-10/22/21

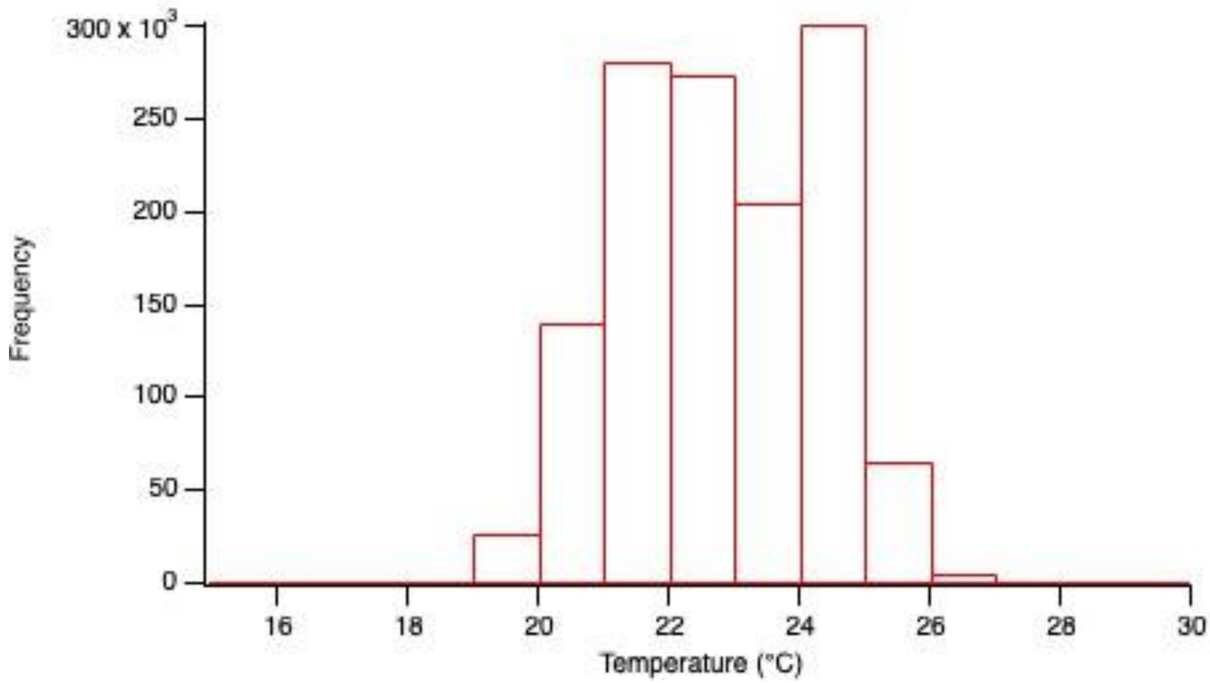




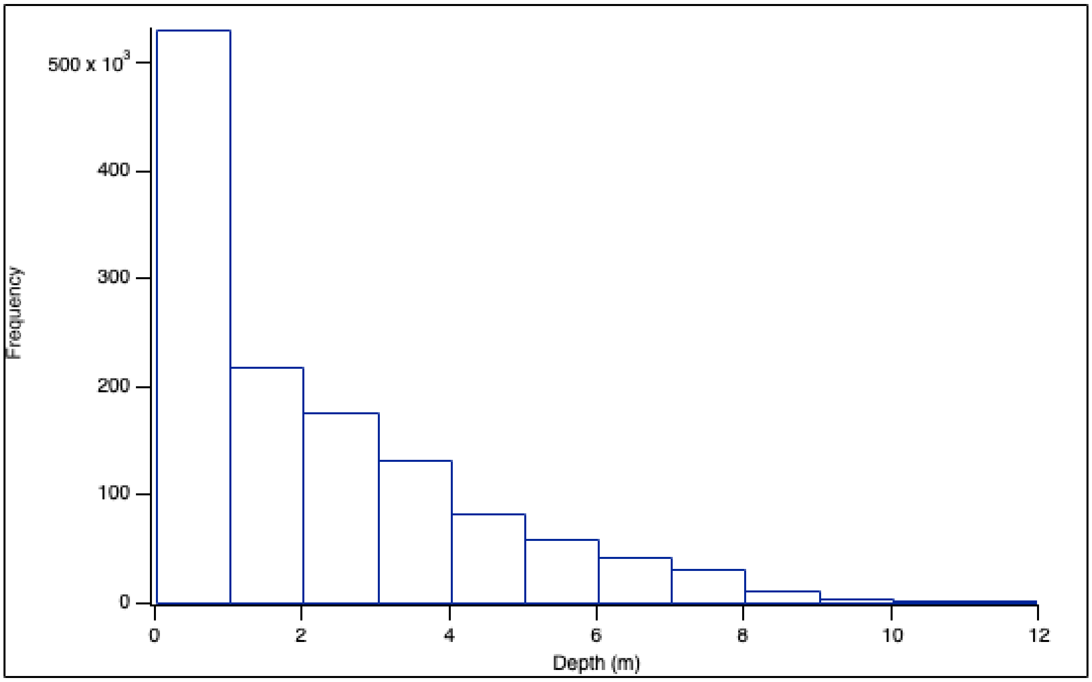
S_mok02: recovered sPAT tag with 16 days recorded data from 4/12/2021-5/1/2021

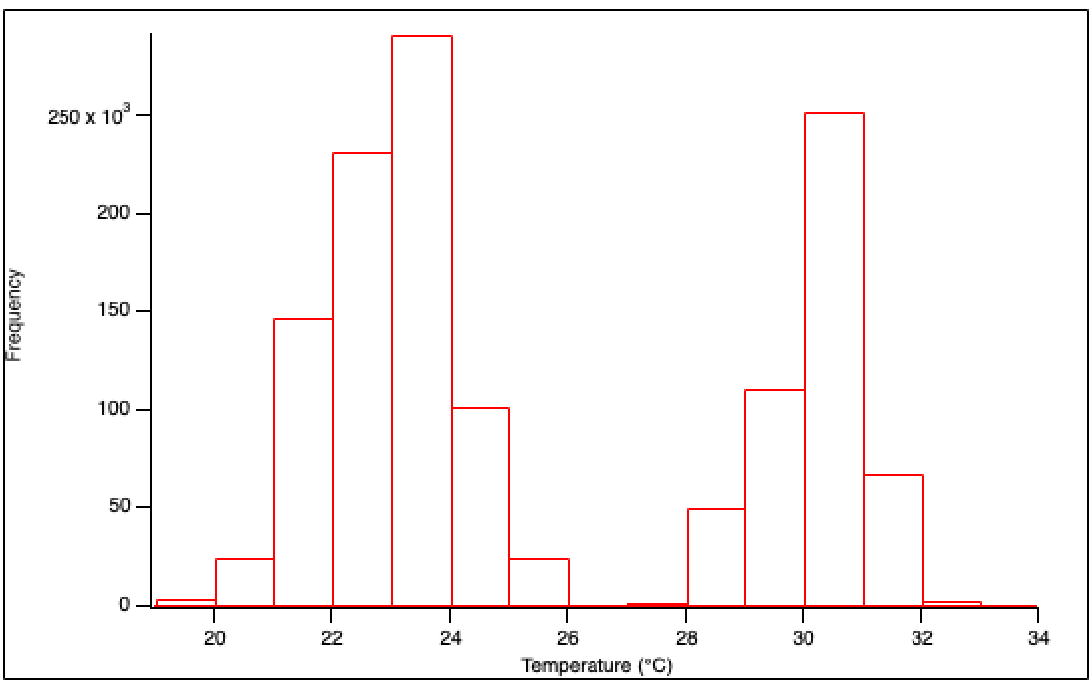
*This represents the only surviving Great Hammerhead shark for which we have high resolution PSAT tag data



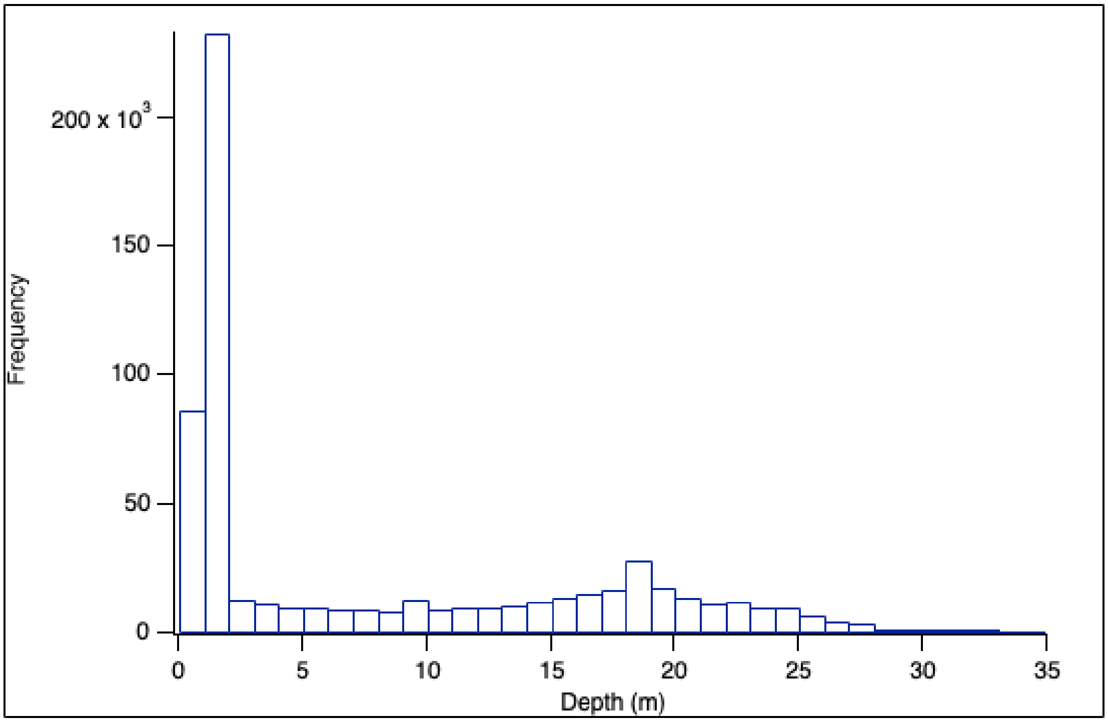


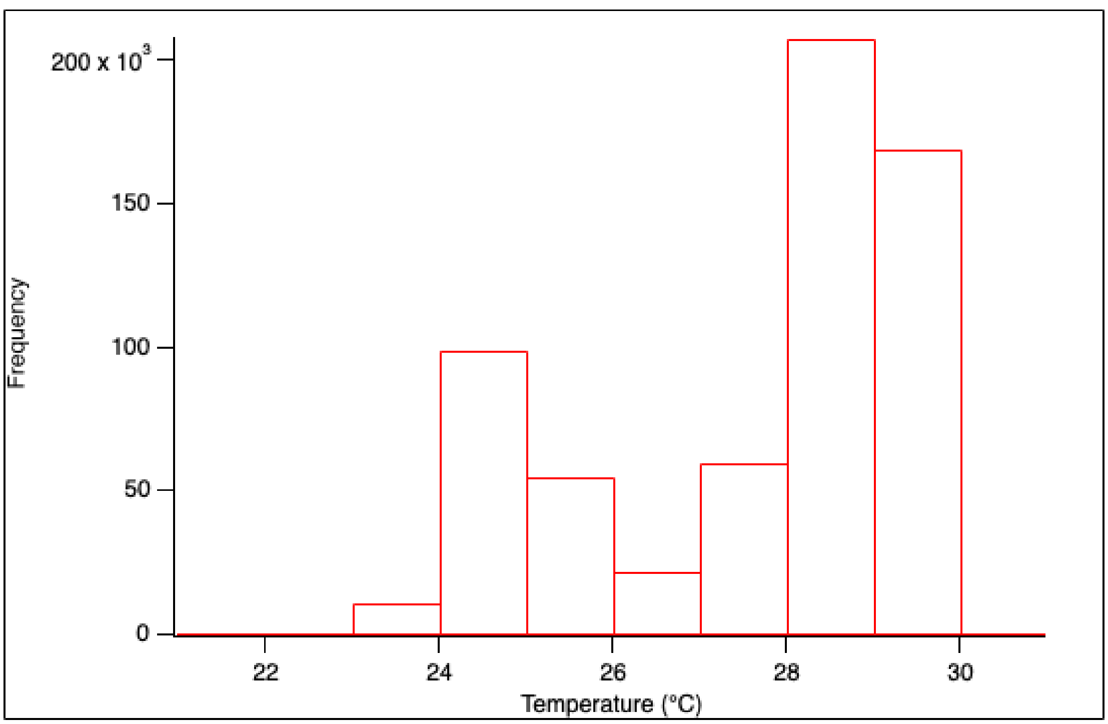
C. leucas: frequency distribution of depth and temperature for all surviving Bull sharks for which we have PSAT data (n=5)





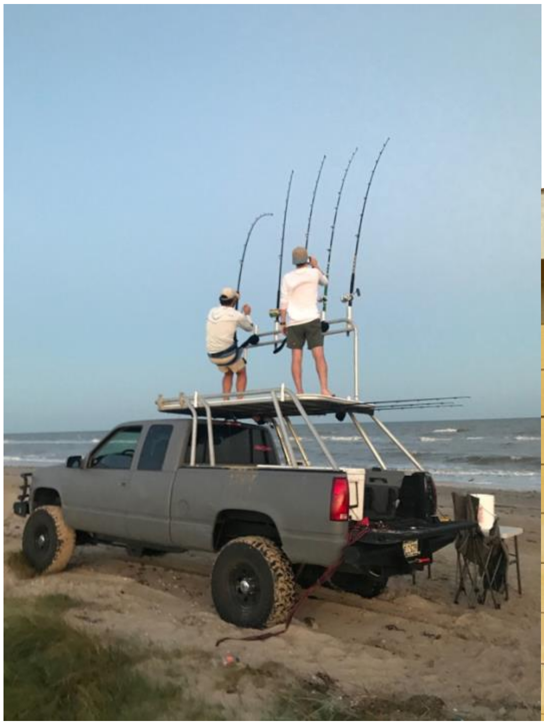
G. cuvier: frequency distribution of depth and temperature for all surviving Tiger sharks for which we have PSAT data (n=5)



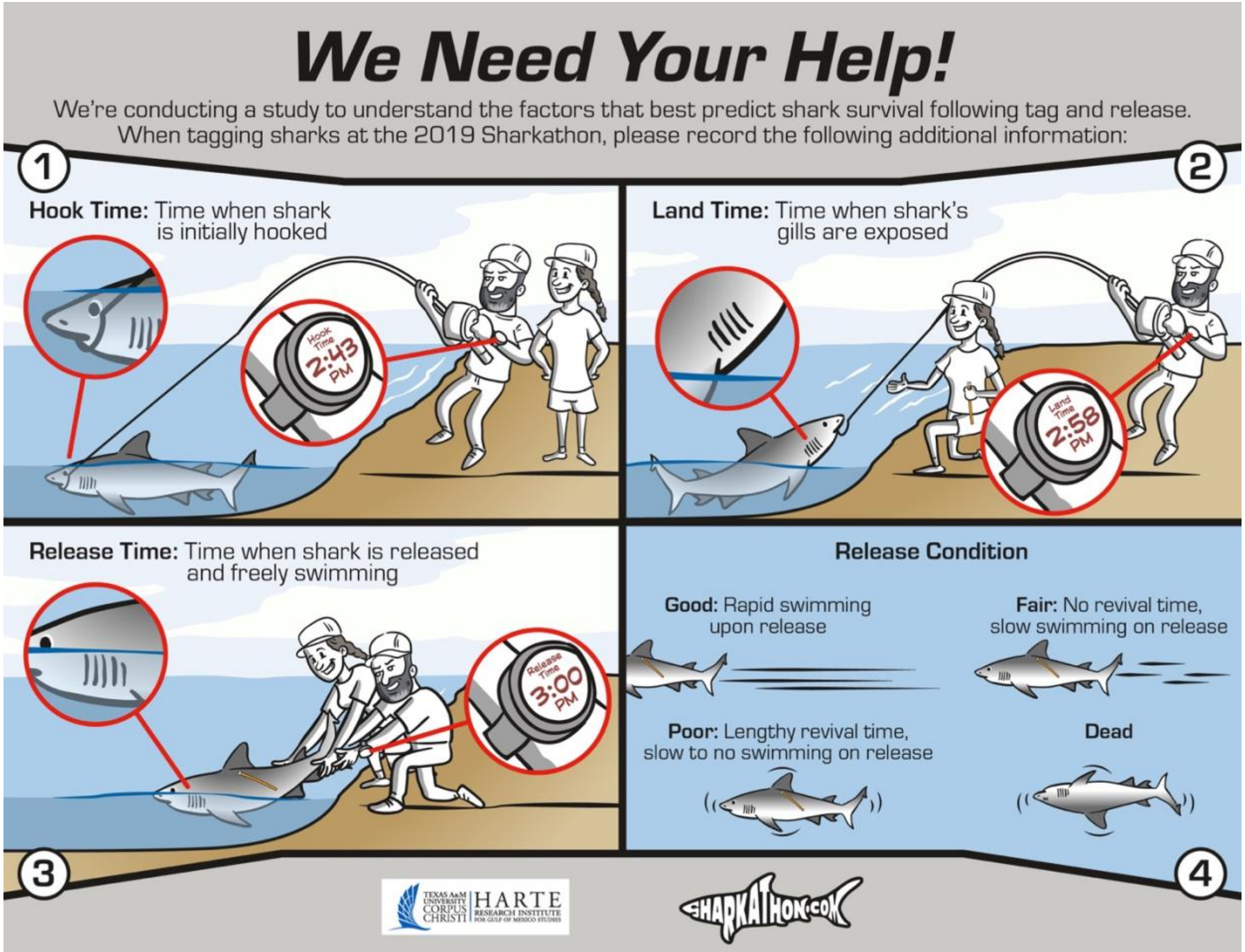


APPENDIX 4

Photographs of shark fishing, citizen scientists, tagged sharks and outreach materials






We Need Your Help!
We're conducting a study to understand the factors that best predict shark survival following tag and release.
When tagging sharks at the 2019 Sharkathon, please record the following additional information:
1
Hook Time: Time when shark is initially hooked
Hook Time 2:43 PM
2
Land Time: Time when shark's gills are exposed
Land Time 2:58 PM
3
Release Time: Time when shark is released and freely swimming
Release Time 3:00 PM
4
Release Condition
Good: Rapid swimming upon release
Fair: No revival time, slow swimming on release
Poor: Lengthy revival time, slow to no swimming on release
Dead
TEXAS A&M UNIVERSITY CORPUS CHRISTI
HARTE RESEARCH INSTITUTE FOR GULF OF MEXICO STUDIES
SHARKATHON.COM