

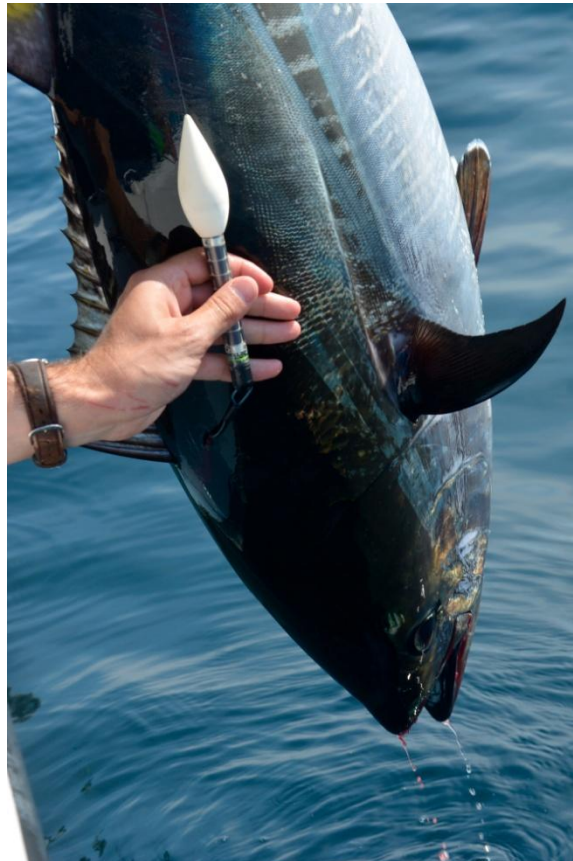


SeaTag-S.A.M.

Stock Assessment and Mortality
PSAT Tags for Fisheries Management

Experiment Designers and Operators Manual

Version 1 15MAY2016



On-Line Resources for SeaTag S.A.M. Tags

Resources for SeaTag S.A.M. including the latest version of this manual, the SeaTag software suite, tag selector, price list, configuration form and the latest edition of the SeaTag performance report are available on line.

desertstar.com/SAM/



Stock Assessment and Mortality

PSAT Tags for Fisheries Management

PSAT is a powerful technology to gain high-resolution insights on the life history of individual animals. Building on experience we have gained with our high capability SeaTag-MDQ, collaboration with our researcher partners and over 1800 tag deliveries, we have now optimized the S.A.M. tags specifically for effective stock assessment, mortality studies and other applications in fisheries management.

Software

SeaTrack

The software used to create a position track using the data collected by SeaWatch.
Download Version 2.4.0 | Tutorial

SeaWatch

The Desert Star Systems program used to automatically download and process the data collected by the SeaTags and transmitted to the Argos Satellites.
Download Version 2.6.0 | Tutorial

SeaConvert

The QSS program used to convert .del files into .csv bundles, a collection of .csv spreadsheets that contain processed packet information.

Download Version 1.0.0 | Tutorial

Manual

Tag Selector

Price List

Performance
Report

Tag
Configuration

Published Works

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How to Succeed with PSAT Tagging

The SeaTag S.A.M. PSAT tags are specifically designed for large sample size deployments in fisheries management related studies. Our experience has taught that the key to success in such PSAT tagging is a methodical and transparent process, driven by a conversation in which your expertise of the tagged animal's biology and Desert Star's engineering expertise and prior experience with our products are combined to arrive at the best outcome. This manual is structured to follow such a process, starting with experiment design and concluding with a review of the final data product. The following is a top level view and summary of the process. Color coding is used here and in the section headers to identify the major phases of the tagging. Note that the manual links to many external documents, tutorials and videos. It is thus designed primarily for on-line study.

Experiment Design and Tag Selection: The PSAT tagging experiment must be based on a thorough understanding of the tag's capabilities and limitations. The best tag model, or in many cases a combination of PSAT models must be identified. This includes trade-offs of technological capability, available data return, cost and its impact on available sample size. The data return strategy must consider the options of Argos data delivery or physical tag recovery or a mix of these two. The experiment must be made robust by considering a range of outcomes for each tag from non-reporting to yearlong reporting with the opportunity of detailed time series data recovery. Consequently, over-tagging must be planned, and the financial implications must be considered including assuring the outcome through a tag replacement policy (ST-GOLD) and defining the data delivery costs such as using unlimited fixed-price data delivery through the CLS Track&Loc plan.

Tag Acquisition and Preparations for Tagging: The tags should be acquired and an Argos account set up with sufficient time allowance to test and learn the tag use prior to deployment. The tag configuration settings must be defined to reflect the experiment design, and forwarded to Desert Star for review and tag programming. The tagging hardware is selected and the imprinting for the tether defined. Tag retention depends significantly on the species being tagged and its behavior characteristics, the selected tagging hardware and the tagging method. Most taggers have their own honed procedure, suggesting that there is a significant impact of prior experience and improvements. Yet variable outcomes are common. This is clearly demonstrated by Mike Musyl's tag performance study, where only 18% of tags attained the desired retention [2]. Thus, prior tagging results with the species should be reviewed and the potential for initially a short or inconsistent retention acknowledged. Once you have received your first batch of tags, a 'mini mission' to familiarize yourself with the tags and the data retrieval process and test the experiment settings is in order.

Tag Handling and Tagging: The tagging process with SeaTag is very simple, designed to support partnering with non-scientific tagging partners such as fishermen. A tagging campaign should scale up, starting with a smaller quantity and close monitoring of the results, before tagging in larger numbers.

Real-Time Monitoring: SeaTag S.A.M. supports the real-time monitoring of a PSAT tagging campaign through a combination of tag features and the SeaTag software suite. Real-time monitoring enables ongoing supervision and quality control of the tagging process and early detection of any failures, providing an opportunity to make adjustments. SeaTag tags transmit whenever exposed to light and

reach the Argos system whenever at the surface. Prior to tagging, Argos will pick up the recommended test transmissions from the tags floating in a bucket, verifying their proper performance and operating state. Once tagged, opportunistic Argos messages are available when the animal is at the surface, providing track anchor and accuracy verification points. If caught by fishers, the opportunistic transmissions might reveal the location of the event. If tags start shedding early, this can be detected right away and the tagging method perhaps adjusted. The SeaWatch utility runs in the background on your machine, accessing the CLS server once an hour and assembling a consistent data file for each tag. SeaConvert serves to individually or batch decode the data, providing a bundle of .CSV files sorted by packet type and statistics. Seatrack processes a position track by plotting the intersection of daily measurements, testing the quality of positioning before final Track&Loc results are available.

SeaTag Data Product Review: SeaTag software suite results can and are used for publication. The CLS Track&Loc program delivers presentation ready tracks and figures to your e-mail account. This is in particular useful for large tagging programs, where considerable time can be saved. The Track&Loc geo-position processing considers all available data to statistically estimate a most probable track connecting the known tagging and pop-up positions, and in compliance with animal migratory capabilities coast line avoidance etc. The tracks include 50% and 90% confidence intervals. The method is not immune to errors and due to the multiple track constraints can sometimes present actual measurement disturbances or model errors as plausible track excursions [5]. The results can be checked against the independently (and by a different method) computed Seatrack tracks, providing a validation and improved confidence of the results intended for publication.

Experiment Design and Tag Selection

1. PSAT Optimization for Large Sample Size Studies

Pop-up satellite tags (PSAT) provide far more detailed data about individual animals than is possible with non-electronic 'conventional tags'. And, with reporting rates commonly exceeding 75%, the data returns for a given number of tagged animals is much greater than is the case with fisheries dependent tags, including conventional and electronic implantable archival.

However, while conventional studies commonly involve thousands of animals per year, and some programs cumulatively even hundreds of thousands since inception [1], PSAT studies generally tend to be on few or tens of animals per individual study or tagging season [2]. This is due to the traditionally very high cost of tags and data delivery, the inconsistent density and quality of the returned data, and the high overall effort of tagging and data processing [3]. Tagging at small sample sizes in combination with a geographic bias of tagging locations (for reasons of access often near the coasts) however can be problematic for stock assessment. Modeling reveals that in some cases not even a single tagged animal may be expected to reach some of the mid-oceanic sectors covered by a stock assessment [4].

SeaTag S.A.M. (Stock Assessment and Mortality) is a family of currently three PSAT tags built on the experience we gained starting with our high-capability SeaTag-MOD tag and input from the research community. The S.A.M. tags are optimized specifically to enable large scale, generally fisheries management related studies. The first tag of this family, SeaTag-GEO, was introduced in 2013 targeting primarily precision horizontal migration studies enabled by a magnetometer. SeaTag-LOT was added next as a very simple tag optimized for mortality studies in tuna and billfish as well as coarse scale horizontal migration based on light and SST observations. Its very low cost also makes this PSAT suitable for applications requiring just basic functionality such as a pop-up positions or Argos satellite tracking while at the surface. SeaTag-3D, introduced in late 2015, added a depth sensor for vertical migration studies and a large memory to archive high resolution time series data. In late 2015, we also modified the operating firmware and method of the tags. This made them more simple to use and improved data return reliability and density. Overall, about 800 S.A.M. family PSAT tags had been delivered by May 2016, with first results reaching conference presentations and journal publication.

1.1. Advantages of the SeaTag S.A.M. PSAT family for large sample size studies

SeaTag S.A.M. tags incorporate a number of improvements responsive to identified shortcomings of PSAT and their practical use in large numbers:

- ✓ **Low Tag Cost:** The low cost of the S.A.M. PSAT provide a sample size sufficient for stock assessment within a realistic budget. The three tags offer a range of price and performance points.

- ✓ **Fixed price data delivery & processing:** Argos satellite data delivery and track processing is available at 30% of the cost of the tag through an agreement between CLS and Desert Star. For an additional \$150, data delivery is unlimited, supporting large data sets and the long reporting endurance of the solar powered SeaTag devices.
- ✓ **'Assured' Results:** Tags in the ocean face many risks that may result in loss of reporting, minimal reporting or compromised data returns. The ST-GOLD program covers these contingencies. Any tag that does not report, reports minimally only or returns engineering reports that indicate a defect is replaced free of charge. Replacement includes Track&Loc data delivery and processing if purchased.
- ✓ **Higher Confidence and Improved Accuracy Tracks:** SeaTag-GEO and SeaTag-3D incorporate a magnetometer to provide stable and accurate tracks, reflecting the stability and generally smooth intensity gradient (except where disturbed by significant crustal magnetic anomalies) of the earth's main magnetic field [5]. Quality tracks are available by a simple method of the intersection of a magnetic based latitude measurement and a light based longitude measurement, maintaining transparency of the results.
- ✓ **More position points:** The geomagnetic method and the uniform light measurements achieved with the wrap-around solar panel also make the geoposition foundation data highly compact and easy to transmit via Argos. Thus, position data density is high and it is not uncommon to receive over 90% of all available daily summaries.
- ✓ **Presentation Ready Results:** We recommend obtaining final, presentation ready tracks and figures for your tags through the CLS Track&Loc program. Track&Loc considers all tag observations, environmental models and animal capabilities to produce a consistent track. The delivered data package is standardized and suitable for publication, saving considerable data processing effort and making your results more readily comparable to other research.
- ✓ **Consistent & simple operation:** All SeaTag S.A.M. tags share the same operating method and are simple to use, supporting engagement of tagging partners such as commercial and sport fishermen.
- ✓ **Improved reliability of data return:** To provide the best possible opportunity for data return, the solar powered S.A.M. tags transmit archived data whenever exposed to the sun, independent of if it might be underwater or at the surface, on the tagged animal or floating, or in any of the operating states. Each message incorporates the most essential status information in a status byte to indicate outcome even if nothing else should be heard from the tag. For SeaTag-3D, priority modes let you specify the most critical data to be transmitted including high-resolution monitoring of exceptional deep dives or events in the immediate post-release period.

- ✓ **Extended monitoring and large data sets:** Solar power means S.A.M. tags can transmit data for long periods of time, enabling the return of large data sets of time series data. For example, Van Houton et. al. [6] used SeaTag-GEO as ocean drifters to determine Hawksbill turtle hatchling dispersal trajectories experienced reporting times of 3.3 to 14.2 months with three tags including the 14.2 months tag still reporting at the cut-off time. Pohlot et al. [7] relied on the extended reporting of SeaTag-MOD to transmit accelerometer time series behavioral data.
- ✓ **Small, low-drag design for a longer tag retention opportunity:** The drag of a tag is proportional to its frontal area [8], i.e. the area of largest cross section typically at the float body. S.A.M. tags have a streamlined design with a slim float body that for SeaTag-LOT measures 30mm, currently the smallest for commercial PSAT tags and used as part of the study. Based on first principles, this drag reduction provides an opportunity to extend tag retention; however tag retention depends on many factors [3].
- ✓ **Real-time monitoring of tagging:** S.A.M. tags transmit whenever exposed to sunlight. Opportunistic transmissions occur when a tagged animal reaches the surface, and the tag will transmit as soon as shed from the animal. Real-time monitoring through the SeaTag software suite lets check on your experiment status at any time, and make responsive changes if the situation demands. The *SeaWatch* utility auto-retrieves the latest data from the CLS server once per hour. *SeaConvert* decodes the available data, one tag at a time or as a batch for all your tags, into a set of sorted .CSV files. *SeaTrack* uses the geomagnetic method [5] to quickly compute a track from the archival records for the magnetometer equipped tags (-GEO and -3D).
- ✓ **Physical tag recovery and re-use:** Physical recovery of SeaTag-3D in particular means you can recover the complete high-resolution dataset stored in its memory; far more data that can be transmitted by Argos. The long post pop-up transmission period of SeaTag devices enhances the opportunities for recovery. Radio homing to SeaTag post pop-up is common, and part of the experiment design for some users [9]. Other practiced methods include the observation of a tag until beached, and subsequent use of social media to entice local beach combers to find a tag. Due to solar power, the S.A.M. tags are re-usable but with limitation: The integrated release section is designed for one time use. While subsequent kinetic releases may or may not be practical due to burn chamber electric contact fouling, the tag can be re-used without the release mechanism, relying instead on eventual shedding to release from the animal in subsequent deployments.
- ✓ **Transparency & Re-Processing:** The original data packets transmitted by the tag are available and may be used for example to re-process tracks based on improved models or algorithms. The content of each data packet type is specified in the Experiment Design & Operator's manual, and the most recent decoding key is available on request from Desert Star. Custom data packet types including specialized *in-situ* processing by the tag are available on request to support your research.

2. Tag Selection & Specifications

The method of operation (activation, tagging, real-time monitoring, final data delivery) is the same for all S.A.M. tag varieties. The three tags vary in terms of the sensors available, the amount of archival memory, the type of data returned and an option for a internal battery that supports extended operation in darkness or fast post pop-up transmissions in low light for an accurate Argos position fix.

Overall, the line of tags is designed to support 'multi tagging', i.e. the use of a mix of tags in your program to achieve the best balance of data return and sample size (cost). The data return types of each tag are designed to overlap with that of the other tags in the S.A.M. family. For example, SeaTag-LOT and SeaTag-GEO do not integrate a depth sensor, but they provide the minimum temperature observed in their Daily Summary messages. SeaTag-3D provides a depth sensor, and its Depth & Temperature Histogram message associates each depth bin with the mean temperature observed at that depth. Thus, if location data shows SeaTag-3D tagged animals in the same area as those tagged with the lower cost -GEO or -LOT, then the maximum daily diving depth of -GEO and -LOT equipped animals may be inferred from the temperatures profile observed by -3D.

2.1. S.A.M. Model Selection

Tag Model	Best Track Confidence & Accuracy	Vertical habitat studies	Extended operation in darkness	High resolution time series data	Optimized for mortality studies	Smallest size & lowest drag	Lowest cost / highest sample size
-LOT		M			✓	✓	✓
-GEO	✓	M	L		L	L	
-3D	✓	✓	✓	✓	L		

✓: Applicable

M: Applicable if part of a multi-tagging program (see notes)

L: Limited applicability or conditional based on configuration (see notes)

Table 1: Tagging Requirement Selector Table

Notes & Selection Guidance:

- **Track confidence and accuracy:** Select a model with magnetometer (-GEO or -3D) if a high confidence and best accuracy of the position tracks is important. For SeaTag-LOT, position tracks are based on light and SST observations; original data sources in many cases of lesser quality or more noisy than geomagnetic measurements. The advanced 'biased random walk' processing for SeaTag-LOT implemented in Track&Loc will weigh all available factors including animal dispersion capabilities to provide a most probable track connecting the known start and pop-up positions. Through the use of these constraints however, the method may also obscure substantial track errors that are not necessarily fully reflected in the tracks confidence interval [5]. The accuracy for both methods will be location specific, reflecting the

steepness and modeling error of the SST and magnetic field intensity gradient in a given area. Based on an evaluation of global SST and magnetic field intensity gradients between 45° N and 45° S, and identified gradient modeling and measurement error sources, error modeling predicts a mean latitude error of 39 nautical miles for the geomagnetic method. For the light and SST based method, the mean error prediction is 91 to 303 nautical miles under best and reasonable worst case SST model error and measurement assumptions respectively [5]. This is at the point of their full manifestation because the biased random walk constraints of Track&Loc will act to limit track errors resulting from fleeting or temporary model or measurement errors. Longitude accuracy and confidence will be similar for any S.A.M. model (on the order of 0.5° longitude / 30 nautical miles) because longitude is always based on light observations and all S.A.M. tags use the same light observation approach and sensing elements to determine local apparent noon.

- **Vertical habitat studies:** Only SeaTag-3D includes a depth sensor. Use this tag either exclusively or in a mix with the other S.A.M. models for tagging incorporating vertical habitat studies. Maximum diving depth of -LOT and -GEO tagged animals can be inferred in some cases from the minimum daily temperature reported by these tags as interpreted in the context of depth & temperature histograms returned by -3D.
- **Extended operation in darkness:** Specify S.A.M. tags with a small internal battery augmenting the stored solar power for studies of animals that may not experience significant daylight each day. A battery is not available for -LOT, is an option for -GEO and is standard for -3D. Without a battery, S.A.M. tags will sustain geo-positioning observations for about three days in darkness, and maintain the clock for another three days thereafter. Tags experiencing power loss will fire their release upon returning to sunlight (tag shed by a life or decomposing animal), report the power loss status and transmit collected archival data.
- **High resolution time series data:** Specify SeaTag-3D when time series sensor data is needed. Data is transmitted as sensor scan messages. Each time stamped message contains the momentary values of all sensors. Sampling rate is selectable at a fastest of 16 seconds, and memory capacity is sufficient to hold 78 days worth of sensor scans at that rate, or 3.2 years at the commonly used 4 minute interval. Sensor scan messages can be prioritized for preferred Argos transmission if depth readings are beyond a specified threshold (deep dive profile transmission) or for the first specified number of days after tagging (post-release recovery or mortality monitoring). Full dataset recovery is possible through physical recovery of the tag, supported by its long transmission endurance and resulting opportunity for radio homing or recovery upon beaching.
- **Optimization for mortality studies:** SeaTag-LOT is capability and cost optimized for mortality studies in pelagic species that commonly visit the proximity of the surface and exhibit vertical dive behavior that subjects them to temperature gradients. Target species include tuna and

billfish. The tag determines mortality through a drop in the maximum observed daily temperature gradient. Observations have shown that tags on life bluefin tuna generally experience temperature changes of at least 2 °C / minute while floating tags or tags on the bottom tend to exhibit less than 0.2 °C / minute when sampled at four minute intervals.

- **Smallest size and lowest drag:** SeaTag-LOT and SeaTag-GEO are best suited for tagging small animals due to their smallest size and lowest drag.

2.2. S.A.M. Tag Specifications

Tag	SeaTag-LOT	SeaTag-GEO	SeaTag-3D
Sensors	Light, temperature	Light, temperature, magnetometer	Light, temperature, magnetometer, depth
Size	15mm (tube D) 30mm (float D) 178mm (L)	No battery: 15mm (tube D) 30mm (max. float D) 178mm (L) With battery: 15mm (tube D) 35mm (max. float D) 190mm (L)	15mm (tube D) 35mm (max. float D) 210mm (L)
Weight	41.7g	41.7g (no battery) / 52g (with battery)	60g
Drag relative to SeaTag-LOT based on frontal area (at max. float D) [8]	1.0	1.0 (no battery) 1.36 (with battery)	1.36
Battery for extended darkness operation	No	Optional	Yes
Argos reported messages	Daily Summary, Engineering	Daily Summary, Engineering	Daily Summary, Depth & Temp. Hist., Sensor Scan, Engineering
Archival memory size (number of messages such as daily summaries, histograms or sensor scans)	832 (daily summaries only)	416 (daily summaries only)	425,984
Year of first tag deliveries	2015	2013	2015

Table 2: SeaTag S.A.M. Specifications

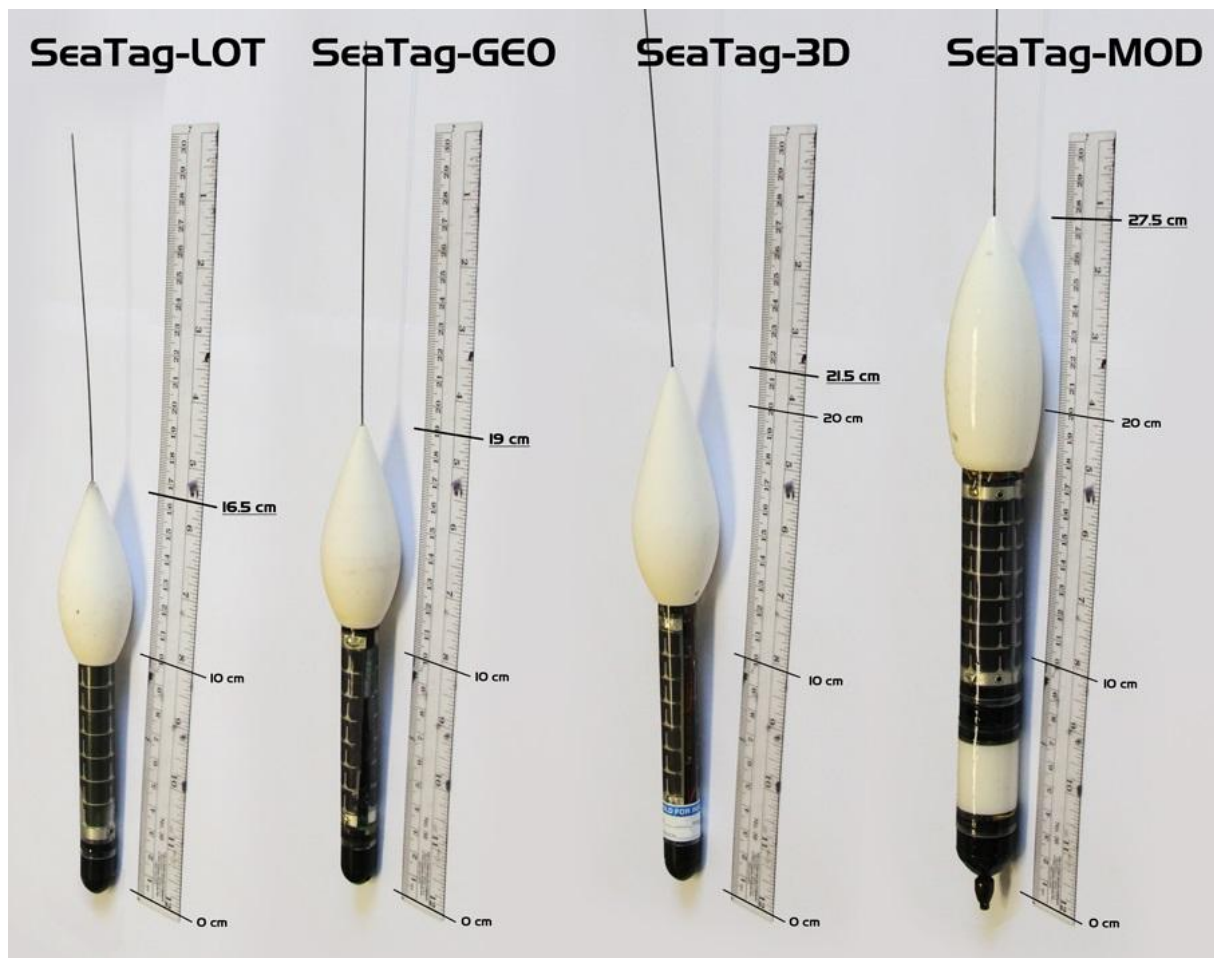


Figure 1: The three S.A.M. tags (-LOT,-GEO,-3D) plus the high-capability SeaTag-MOD

2.3. S.A.M. Data Packet Types

SeaTag tags transmit Argos data in the form of messages. And each 19-byte Argos message contains one archived or current data packet. The types and composition of packets archived and messages transmitted are tag model specific.

Since the data packets define the data return of a given tag model, they are an important factor in tag selection and experiment design. The following is a summary providing a general overview of the packets. The current data packet definition file is available on-line on the Desert Star Systems Knowledge Base. This section also describes how the contents of the daily summary packets are used by the SeaTrack processing software and by the CLS Track&Loc service to compute an estimated position track.

Be aware that data packet definitions may be changed over time to optimize the performance of the tag. You may also request the collection and transmission of custom data packet types reflecting *in-situ*

observation data processing and transmission specific to your research objective. Such customizations will generally involve an engineering fee or a minimum tag purchase requirement.

Tag Status Byte (SSTAT8)

The tag status byte is not a data packet, but the second byte in each packet transmitted by any S.A.M. model. This byte provides the current and most essential status information for the tag. This byte is the highest of all transmit priorities and will let you know what the fundamental status of the tag is even if no further information is obtained. The status byte contains this information:

Tag State: The current state of the tag including *SaveShipping*, *Armed*, *OnFish* and (post pop-up) *Reporting*. The tag states define the current operation of the tag and are described in the chapter S.A.M. Operation. The tag state is useful to verify correct deployment of a tag, and monitor its progress while at liberty. For example, a tag at sea indicating *Reporting* means it fired its release and is floating on the surface. Similar a tag indicating *SaveShipping* while at liberty indicates the tag has not been activated prior to deployment, and no data will be collected.

Release Condition: The release condition shows if and why the tag is fired its kinetic release and transitioned to the Reporting state. If in *SaveShipping*, *Armed* or *OnFish* state, the release condition will always be *None*. Once in *Reporting* state, the release condition will be one of the following:

- ***TIME:*** The tag reached the programmed release time.
- ***DARK:*** The tag triggered the release due to reaching the extended darkness time threshold (dead fish indicator for SeaTag-LOT and SeaTag-GEO)
- ***DT:*** The tag triggered the release because the temperature gradient was below the trigger threshold for the specified period of time (indicative of dead fish or shed tag for SeaTag-LOT or SeaTag-GEO)
- ***MINT:*** The minimum specified temperature has been breached for the specified time (indicative of sinking fish or extreme dive condition for SeaTag-LOT or SeaTag-GEO)
- ***RESET:*** The tag has experienced and then recovered from a power loss (capacitor and battery empty)
- ***CDR:*** The tag has been in a narrow depth range for the specified period of time and triggered its Constant Depth Release (indicative of dead fish or shed tag for SeaTag-3D)
- ***CRUSH:*** The tag has breached the crush depth of 2000m (indicative of dead fish or extreme dive condition for seaTag-3D)

Time Type: SeaTag S.A.M. will generally operate on *Mission Elapsed Time*, which is a count of seconds since the tag transitioned to *OnFish* state either by means of a manual light signal or by the sleeve of an *Armed* tag being removed (see Tag Operation for details). This method has the advantage that a time at liberty before the tag fires its release can be defined independent of the mission start time. If fish aren't caught, the tag can simply be reset to *SaveShipping* and be used at the next opportunity with the same mission duration setting. An alternative is tag operation in *UTC* (Universal Coordinated Time), which allows tag release on a specific calendar day. For S.A.M. devices, UTC operation is considered an

advanced method that requires a technical or science support technician to configure each tag to a release calendar date using a docking station.

Daily Summary Packet (-LOT, -GEO, -3D)

All S.A.M. models generate and archive a **Daily Summary Packet** once per day. The packet includes the apparent noon time , magnetic field intensity, observed day length and maximum observed temperature (SST) for geo-positioning. It also includes other daily sensor statistics. The format and the reporting resolution of the sensor readings is specific to the tag model. Since the Argos transmitted packet size for S.A.M. tags is limited at 19-bytes, tags that transmit more sensor values or statistics use lower reporting resolutions for some of these values and statistics. This is in particular the case for SeaTag-3D, but higher resolution depth and temperature reports are then available in the histogram and in the tag's sensor scan packets.

	SeaTag-LOT	SeaTag-GEO	SeaTag-3D
Packet Name	SDPT_SAMDAILY2	SDPT_GEODAILY2	SDPT_3DDAILY3
Tag Status Byte	✓	✓	✓
Local Apparent Noon	1-second	1-second	1-second
Day Length	2-seconds	2-seconds	2-seconds
Mean Capacitor Voltage	0.016V	0.016V	0.016V
Mean Solar Panel Voltage (light intensity, ~100 Lux/V)	0.016V	0.016V	0.016V
Min. Temperature	0.01 °C	0.2 °C	0.2 °C
Max. Temperature	0.01 °C	0.2 °C	0.2 °C
Mean Temperature	0.01 °C	0.01 °C	0.2 °C
Max. Temp. Rate	0.001 °C/min	0.001 °C/min	n/a
Avg. Magnetic Field Intensity	n/a	10nT	10nT
Min. Depth	n/a	n/a	10m
Max. Depth	n/a	n/a	10m
Mean Depth	n/a	n/a	10m

Note: Fields marked in **dark blue** are used by both SeaTrack and CLS Track&Loc to find the daily position estimate. Fields marked in **light blue** are used by CLS Track&Loc to further constrain estimates.

Table 3: Data Fields and Reporting Resolution of the Daily Summary Packet

How the Daily Summary is used by SeaTrack and Track&Loc to find position estimates

- **Local Apparent Noon:** Used to determine the tag longitude. This time is the half-way point between the light level rising above 1.4 Lux in the morning and falling below 1.4 Lux in the evening as perceived by the solar panel. 1.4 Lux is slightly above full moon light level (~1 Lux), but well below sunrise light level (~400 Lux). This level is crossed typically about 30-45 minutes before actual sunrise and 0-15 minutes before civil sunrise. During this twilight period, light levels rise and fall rapidly, about by a factor of 100 within 30 minutes. This minimizes errors caused by vertical animal dive activity. All light is indirect, averaging out clouds and other unevenness, and the light is detected uniformly almost independent to tag orientation by the wrap-around solar panel. Further, factors such as tag fouling or water turbidity will equally affect the morning and evening transition, leaving the local apparent noon time undisturbed. These various factors combine to maximize accuracy and confidence of longitude estimates. Longitude estimation accuracy is typically about $\pm 0.5^\circ$ Longitude, equaling 30 nautical miles at the equator.
- **Day Length:** Used to determine the confidence of longitude measurements (all tags) and is one factor for estimating the latitude (SeaTag-LOT only). This is the time elapsed between the morning and evening light threshold crossing. If the animal is near the surface, this time is typically 0-30 minutes longer than the civil day (sun six degrees below the horizon), and 60-90 minutes longer than the sunrise to sunset period. The observed 'day length' is used to determine the confidence of the longitude measurement. The longer the observed day, the more accurate the local apparent noon is likely to be because there is little 'slack' between the observation and the length of the actual day period for a location, which is limited by the definite transition to and from darkness. (Think of a bolt snugly fitting into a hole, and therefore centering well, or loosely and therefore being subject to being off-center). For SeaTag-LOT, lacking a magnetometer, Track&Loc uses day length to roughly estimate the latitude, which is then further refined using SST (Max. Temperature).
- **Average Magnetic Field Intensity:** Magnetic field intensity is sampled every four minutes. The mean of the center 80% of measurements is reported and used to estimate the tag latitude. Magnetic field intensity generally increases with distance from the equator, and is modeled with a typical accuracy of 152 nT by the World Magnetic Model (WMM) [10]. The north-south field intensity gradient varies throughout the oceans, but averages 5.76 nT / nautical mile between 45° S and 45° N, with higher gradients towards the poles. Including modeling and measurement errors, this translates to a predicted mean accuracy of 39 nautical miles [5].
- **Max. Temperature:** For Seatag-LOT, lacking a magnetometer, the maximum observed daily temperature is assumed to be the sea surface temperature (SST). This is under the assumption of the tagged animal visits the vicinity of the surface every day. Track&Loc

uses this measurement to further constrain the rough latitude estimate arrived at through the day length observation. The north-south horizontal SST gradient is variable throughout the oceans and often locally complex. Per climatological data, it averages 0.42 °C / nautical mile between 45° S and 45° N. The Track&Loc model compares tag observations to the 'foundation SST' provided by the OSTIA model, i.e. the temperature at the indeterminate depth not subject to diurnal heating. Assuming the stated foundation model uncertainty of 0.6 °C and an assumed total diurnal heating and sensing uncertainty of 2 °C, the predicted mean latitude error for SeaTag-LOT is from 91 to 303 nautical miles [5].

- **Max. Depth:** Depth measurements, along with coastline avoidance, are used by Track&Loc to further constrain position estimates. Locations with depths less than the maximum observed by the tag, as well as inland positions, are excluded.

Sensor Scan Packet (-3D)

Sensor Scan Packets are available for SeaTag-3D. The packets are acquired and archived at a rate specified in the tag configuration. The fastest available acquisition rate is 16 seconds. Each packet is time stamped, and contains all sensor readings corresponding to that moment in time. A sequence of sensor scan packets provides time series data for a tag's time at liberty. Sensor scan packets can be retrieved both by Argos transmission and by download from a physically recovered tag. Sensor scan data can quickly exceed the Argos data retrieval capability; even for the long, solar-powered downloads supported by SeaTag. Therefore, tag configuration supports classifying select sensor scan data as priority data for preferred transmission. The selection options are to prioritize sensor scan packets with a depth above a defined threshold (deep dive data retrieval), or packets that fall within a select number of days after mission start (close monitoring of the immediate post-release period) or a combination of the two. See the chapter **Argos Transmission Strategy** for details.

	SeaTag-3D
Packet Name	SDPT_3DSN2
Tag Status Byte	✓
Reference time (MET or UTC)	1-second
Temperature	0.01 °C
Mean Capacitor Voltage	0.016V
Mean Solar Panel Voltage (light intensity, ~100 Lux/V)	0.016V
Magnetic Field Intensity, X-Axis	10nT
Magnetic Field Intensity, Y-Axis	10nT
Magnetic Field Intensity, Z-Axis	10nT
Depth	0.1m

Table 4: Data Fields and Reporting Resolution of the Sensor Scan Packet

Depth & Temperature Histogram Packet (-3D)

Depth & Temperature Histogram Packets are available for SeaTag-3D. Histograms are acquired and archived at intervals of 1,2, 3, 4, 6, 8 or 12 hours as specified in the tag configuration. The histograms contain 10 bins, which are dynamically sized to divide the depth range experienced by the tag during the observation period into ten even parts. Both residency and the mean observed temperature is provided for each depth bin. The histogram thus provides a depth-temperature-residency profile that supports inferring the diving depth of SeaTag-LOT or SeaTag-GEO tagged animals that are in the same area as a SeaTag-3D tagged animal.

	SeaTag-3D
Packet Name	SDPT_3DHST_DT10
Tag Status Byte	✓
Histogram Start Time (MET or UTC)	256-seconds
Histogram Depth Range Start	10m
Histogram Depth Range End	10m
Histogram Temp. Range Start	2 °C
Histogram Temp. Range End	2 °C
Bin #1	Residency and mean temp.: 0% - <10% of Depth Range
Bin #2	Residency and mean temp.: 10% - <20% of Depth Range
Bin #3	Residency and mean temp.: 20% - <30% of Depth Range
Bin #4	Residency and mean temp.: 30% - <40% of Depth Range
Bin #5	Residency and mean temp.: 40% - <50% of Depth Range
Bin #6	Residency and mean temp.: 50% - <60% of Depth Range
Bin #7	Residency and mean temp.: 60% - <70% of Depth Range
Bin #8	Residency and mean temp.: 70% - <80% of Depth Range
Bin #9	Residency and mean temp.: 80% - <90% of Depth Range
Bin #10	Residency and mean temp.: 90% - 100% of Depth Range

Table 5: Depth & Temperature Histogram Packet

Depth Bin Size: Dynamically sized. 10% of the depth range experienced by the tag during the histogram observation period. Minimum 1m bin size (10m range). Maximum 200m bin size (2000m range)

Residency Reporting Resolution: 0% residency indicated for bins with no observed residency. Remainder of residency range to 100% divided into 15 equal parts, providing a residency reporting resolution of the actual residency value +/- 3.33%

Mean Temperature Reporting Resolution: The temperature range measured during the histogram observation period is divided into 16 equal parts. The minimum is a temperature range of 2 °C, with a reporting error of +/- 0.0625 °C. The maximum is a temperature range of 32 °C, with a reporting error of +/- 1 °C.

Engineering Packet (-LOT, -GEO, -3D)

Every fifth packet transmitted by a S.A.M. tag is an engineering packet. The engineering packets are not archived and always reflect the current state of the tag. The primary purposes of the engineering packets are to verify and monitor the performance of the tag, and for *in-situ* calibration of sensor readings and observations.

	SeaTag-LOT	SeaTag-GEO	SeaTag-3D	Use
Packet Name	SDPT_SAMEN2	SDPT_GEOEN2	SDPT_3DDAILY3	
Tag Status Byte	✓	✓	✓	Current tag status
Current Time (MET or UTC)	1-second	1-second	1-second	Conversion from MET to UTC or UTC clock offset adjustment by comparison to Argos message received time
Day Length (yesterday)	2-seconds	2-seconds	2-seconds	SeaTag-LOT: Calibration of day length by comparison to day length at Argos location
Mean Capacitor Voltage	0.016V	0.016V	0.016V	Tag power system performance test
Mean Solar Panel Voltage (light intensity, ~100 Lux/V)	0.016V	0.016V	0.016V	Tag light collection & fouling analysis
Tag Serial Number	✓	✓	✓	Tag identification
Argos Transmission Serial Number	Resolution: Single message	Resolution: Single message	Resolution: 256 messages	Tag transmission performance test
Max. Temperature (yesterday)	0.01 °C	0.2 °C	0.2 °C	SeaTag-LOT: SST sensing calibration by comparing to OSTIA temperature for Argos location
Current Temperature	0.01 °C	0.2 °C	n/a	Temperature sensor performance test
Avg. Magnetic Field Intensity (yesterday)	n/a	10nT	10nT	Magnetometer calibration (bias compensation by comparison to WMM

				predicted value at Argos location)
Mean Depth	n/a	n/a	0.1m	Depth sensor calibration and performance test

Table 6: Data Fields and Reporting Resolution of the Engineering Packet

3. S.A.M. Data Return Planning & Strategies

S.A.M. Tags provide these data return opportunities and mechanisms:

- **Opportunistic Argos positions and archival data.** S.A.M. tags will transmit whenever exposed to the sun. If a tagged animal lingers at or near the surface, and the tag breaches the surface, Argos position fixes are available. The tag will transmit the archived priority data (daily summaries, histograms and sensor snapshot packets that are elevated to priority status) even while the data collection phase is in progress. Thus, dependent on the opportunity, some archived data may be received before pop-up.
- **Argos Pop-Up position.** The tag will transmit as soon as released from the animal, providing a pop-up position. If the tag does not have a battery, transmissions will only occur when exposed to the sun and thus a delay and degraded pop-up position accuracy due to the drifting of the tag is possible if the tag surfaces at night or in low light conditions. If the tag includes a battery (-GEO optional, -3D standard), transmissions start immediately independent of light conditions. This results in fast pop-up positions and return of the first batch of priority archived packets.
- **Argos transmitted archival data for on-fish period.** Following pop-up either by the trigger of the kinetic release, or by tag shedding from the animal, S.A.M. tags will transmit the archived data.
- **Argos transmitted archival data for post pop-up ocean drifter period.** The tag continues observations and data archiving even after the kinetic release is fired. This data can be used to estimate the accuracy of on-fish position tracks by computing a post pop-up estimated tracks and comparing it to the 'actual track' as defined by the Argos position fixes for the ocean drifter.
- **Physical recovery of the tag.** If physically recovered, all archived data stored on the tag can be retrieved. In particular for SeaTag-3D, a large high-resolution data set is thus available.

3.1. Data Return by Argos Transmissions

The main factor in the design of the Argos data return schedule is to achieve a high probability match between the data that must be received for the tag deployment to be considered a success, and the amount of data that is likely to be available from a tag. The planning should consider that among a group of tags, the amount of data returned by each tag will likely vary considerably. Some tags may encounter a hazard such as beaching a very short time after tagging and just a few or tens of messages are returned. On the other end of the spectrum, some tags may report for over a year [6] and return many thousands of messages. An experiment design might anticipate three levels of data return:

1. **Minimally Reporting Tags (Pop-up position and less than 100 messages received):** Some tags might return primarily a pop-up position followed by few or tens of messages. Thus, the experiment is designed to use the pop-up position alone as a valid data point, such as to define the migratory range of the tagged animal. If an experiment is assured by the ST-GOLD tag replacement program, the anticipated count of tags falling into this category should be compensated for by 'over tagging', i.e. tagging more animals in anticipation of a percentage of non-reporting and minimally reporting tags that will be replaced under the ST-GOLD program.
2. **Tags reporting hundreds of messages:** This data return is sufficient to obtain the bulk of the priority data, i.e. daily summaries and histograms. Design the experiment so that this data answers the next level and perhaps the bulk of your questions. The information contained in the daily summaries provide the information needed for geo-positioning and a rough indication of vertical habitat utilization (minimum, average and maximum depth). The depth or depth and temperature histograms further illuminate vertical habitat utilization. Hundreds of messages are all that is needed for SeaTag-GEO and SeaTag-LOT, as these tags have a small memory and only archive and transmit daily summaries.
3. **Tags reporting thousands of messages:** Due to the tags use of solar power, there is no hard upper limit to the reporting endurance. You will probably receive many thousands of messages from some tags. For SeaTag-3D, this enables the reception of a significant time series data set, including depth, temperature and light exposure profiles and 3-axis magnetic measurements that with the right tagging procedure can be used to re-construct the body orientation of the tagged animal or estimate its momentary speed. A robust experiment design is one that makes use of such time series data for tags from which it is available, but does not rely on it for the tagging success of each tag. The Argos data delivery cost should be considered for long reporting tags, and we recommend purchasing Track&Loc with unlimited data delivery to limit these costs.

If your experiment routinely requires several thousand messages returned to be considered a success, methods of physical tag recovery should be considered.

SeaTag-S.A.M. Argos Message Return Statistics

Table 7 lists the observed daily message return for two sets of SeaTag-LOT. Six tags reporting after release from tuna on the U.S. Atlantic continental shelf yielded from 12 to 32.3 mean return, with the highest means associated with the two tags popping up in August (four months from the winter solstice), as compared to two months for the remainder. The highest daily return observed from any of the six tags was 52 messages received. The mean of the mean return of all tags was 17.6 messages per day. Twelve SeaTag-LOT tags popping up in the tropical Pacific yielded only about half as many messages per day, 9.2 mean. While counterintuitive, lower returns from the tropical regions can be explained by an often high angle of the sun, not broadside to the solar panel of a floating tag and clear water, lacking the particulates that can illuminate the shaded side of the tag through backscatter.

These two experiments were not suitable for total message count determination because the two sets of tags were programmed to stop transmitting 30 days following pop-up. Kyle Van Houtan [6] conducted ocean drifter tests using six SeaTag-GEO set for unlimited transmissions. The observed reporting period ranged from 3.3 to 14.3 months, with the longest three reporters still reporting at the time of analysis (6.6-14.3 months), while three tags had stopped reporting (3.3-5.8 months). As a first order of approximation for message return potential, combining the shortest reporting endurance (3.3 months) with the lowest message return per day (3.5 messages/day) yields 346 messages returned. Combining the longest reporting endurance (14.3 months) with the highest mean return per day (32.3 messages/day) yields 13856 messages.

Description	Area	Msg Received per Day	Error free reception
6 ea SeaTag-LOT Reporting after 30 days on bluefin tuna (30-day mortality study)	U.S. Atlantic Continental Shelf, 35° N - 43°N August-November	Mean of all tags: 17.6 Lowest mean: 12.0 Highest mean: 32.3 Max per day: 52	75.0 % of all messages
12 ea SeaTag-LOT reporting after 34-142 days on reef sharks	Tropical Pacific, 7° N - 15° N	Mean of all tags: 9.2 Lowest Mean: 3.5 Highest Mean: 20 Max per day: 33	65.3% of all messages

Table 7: Argos message return statistics

3.2. Data Return by Physical Tag Recovery

Physical recovery of tags is particularly useful for SeaTag-3D, as it provides access to the full raw dataset stored in the tags archival memory. This dataset can be far larger (up to 425984 data packets) than what can realistically be received via Argos transmissions (roughly 4000-12000 data packets for a year of post pop-up monitoring and subject to the various reporting ending or diminishing hazards a tag encounters while drifting at the surface)

Physical recovery of a tag is promoted by the S.A.M. tags long reporting endurance. The long transmissions provide sufficient opportunity to locate tags at sea through radio homing. In another approach, a tag might be Argos tracked until it beaches. In one case, social media was then successfully

employed to encourage beach combers to search for (and ultimately find) the tag. The long reporting endurance has made physical recovery increasingly common for SeaTag devices. For example, Seider *et al.* [9] have refined the technique of radio homing to tags, although in a large inland water (Lake Superior, U.S.), achieving the recovery of 88% of tags (58 out of 66) by radio homing. Frederick Goetz *et al.* [11] are using these high recovery rates to make physical recovery a part of the experiment design. At this time, at least one other SeaTag user is employing targeted physical recovery as well.

One practiced method and inexpensive yet effective equipment set for radio homing to recover SeaTag devices is described [here](#).

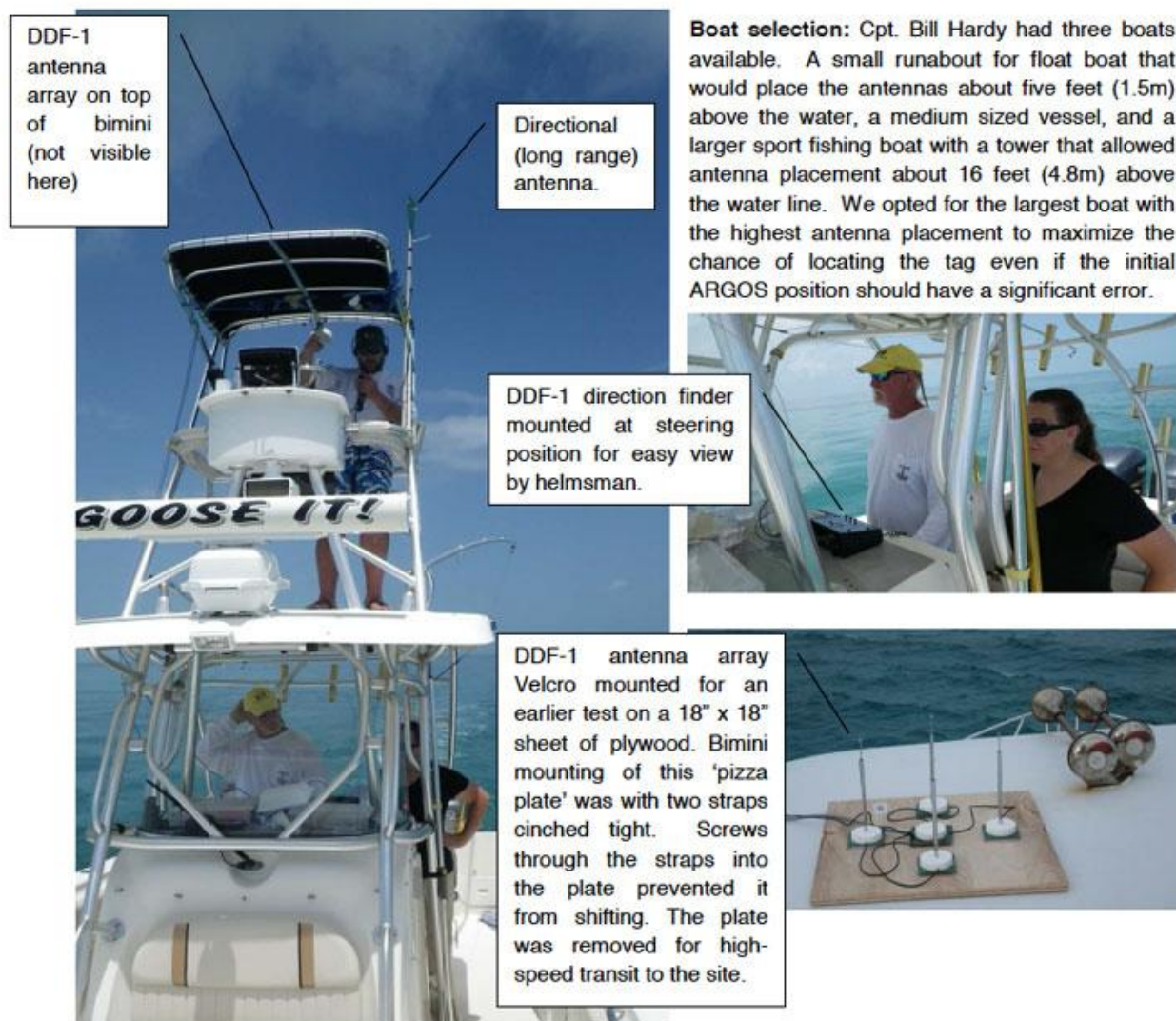


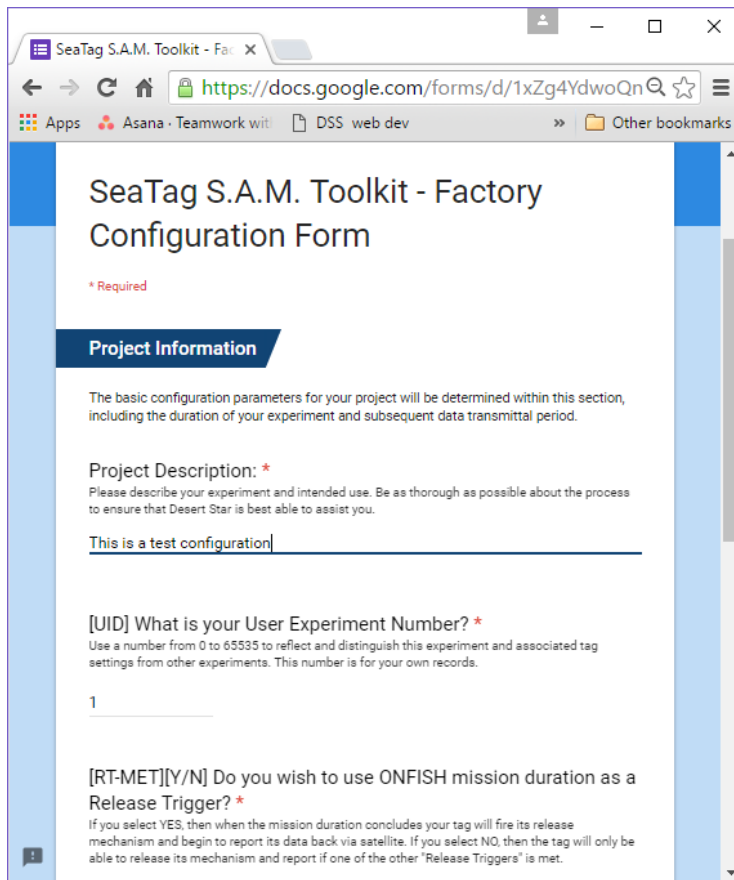
Figure 2: Radio Homing Technique for Physical Recovery of SeaTag at Sea

Tag Acquisition and Preparation for Tagging

4. Tag Purchasing and Argos Account Setup

Once you have decided to use SeaTag S.A.M. devices and made your selection of the tag types to be used, it's time to order the tags and set up your Argos account. While we are working at Desert Star to keep the tags in stock at least for smaller quantities, expect that there could be a delay and contact Desert Star early. One of the advantages of the S.A.M. PSAT is that solar power means you can test and experiment as much as you like with the tags without wearing out a battery. If you purchased Track&Loc with unlimited data delivery, such testing also does not add any Argos charges. Allow for enough time to conduct such tests; validating a part of your experiment design.

4.1. S.A.M. Factory Configuration Form



The screenshot shows a web browser window displaying a Google Form titled "SeaTag S.A.M. Toolkit - Factory Configuration Form". The form is divided into sections. The first section is "Project Information", which includes a description of the form's purpose. The second section is "Project Description", which asks for a description of the experiment and intended use. The third section is "[UID] What is your User Experiment Number?", which asks for a number from 0 to 65535. The fourth section is "[RT-MET][Y/N] Do you wish to use ONFISH mission duration as a Release Trigger?", which asks for a yes/no answer.

SeaTag S.A.M. devices are factory configured, based on a Google form that you complete. This process allows Desert Star to review your configuration and discuss any danger points we might spot. Such a review is also a requirement for the ST-GOLD tag replacement program. Further, factory configuration means that we can test your tags on your Argos ID before shipping, providing a pre-shipping quality control record in the form of these transmissions including their sensor readings, transmit activity (solar panel performance) etc.

Note for RFMO and tagging umbrella organizations: Self configuration is an available option for RFMO and other umbrella organizations that might stock an inventory of tags for use in a variety of experiments. Self configuration requires the [SDOCK-1 docking station](#) and the

[SeaDock software](#). The method is part of the training course for tagging umbrella organizations.

Complete the [S.A.M. Factory Configuration Form](#). Once completed, Google will send the form to Desert Star and you will receive a copy for your records. You can also edit the form at a later time, up to the point of factory configuration at Desert Star. At that time, Desert Star will lock the form to record the definitive settings of your tags.

4.1.1. S.A.M. Configuration Parameter Summary

A single Google form is used to cover all S.A.M. tag varieties: SeaTag-LOT, SeaTag-GEO and SeaTag-3D. Even if you are using a mix of these tags, you need to complete only one form. However, there are some fields that apply only to the -LOT and -GEO, and others that apply only to -3D. Non-applicable fields are ignored by the respective tag.

The data entry fields include a detailed description. Here is an overview of the categories:

- **General Fields:** This includes the project description and User ID. The project description is important for Desert Star's review of your settings. If we see a setting that looks problematic in view of the project description, we will let you know. The User ID is for your own convenience. Use it perhaps as an experiment or researcher designator. If a tag is found and returned, it may help you route the tag to the correct person or group.
- **Mission Duration:** This field defines after how many days at liberty the tag will trigger its release. It will thus set an upper limit for time-on-animal. Be aware that it is common for tags to shed early. The [SeaTag Performance Reports](#) lists the tag retention achieved for various species by other researchers. The tagging hardware that was used is listed for some studies. Review prior to defining your mission.
- **Temperature and Light Based Early Release Conditions (for -LOT and -GEO):** SeaTag-LOT and SeaTag-GEO do not include a depth sensor. Instead, the temperature sensor is used as a proxy for depth to trigger the release mechanism in case of a mortality or tag shedding.
 - The **minimum temperature** exposure release triggers if the tag has been below the defined temperature threshold for the specified amount of time. This is to release if the fish is dead or sinking. Select the temperature threshold such that it is below what the animal will normally experience, but above the temperature at the service limit depth of the tag (2000m for tags produced starting in 2016, and 1200m for older tags). The [NOAA World Ocean Atlas](#) is helpful to determine the temperature at depth in your tagging region.
 - The **minimum temperature gradient** release will trigger the release if the tag no longer experiences significant temperature variations. An actively diving fish will transition between colder and warmer water, for tuna experiencing a maximum gradient of at least 0.2 °C/minute when viewed over four-minute intervals. A tag at the bottom or floating however will generally not see more than 0.2 °C/minute. Thus, the temperature gradient trigger indicates either a dead fish or a tag floating at the surface.
 - The **darkness release** will trigger if the tag experiences continuous darkness for the specified duration. For fish that visit the proximity of the surface each day, this indicates mortality.
- **Depth Sensor based Early Release Conditions (for -3D only):** SeaTag-3D provides two depth sensor dependent conditions for early release:
 - The **Constant Depth Release (CDR)** triggers if the tag experiences a depth change of less than 10m for the four daily 6-hour averages for the specified number of days. For some

animals a constant depth implies mortality, but be careful. For demersal and benthic animals, holding a constant depth for an experienced period may be common and CDR should be switched off. The 10m threshold is selected to be beyond any tidal changes or sensor drift that for a lower threshold might prevent a release. Make sure that the animal definitely can be expected to experience diurnal changes of average depth of at least 10m. If that cannot be guaranteed, leave CDR off.

- **Crush Depth Release** triggers at the latest if the tag reaches its design limit. That is 2000m for S.A.M. tags manufactured in 2016 and later, and 1200m for tags up to 2015. You can set the crush depth release to a shallower depth, for example to release if a depth is reached that is beyond the known diving capability of the tagged animal.
- **Sensor Scan Rate (-3D):** This setting defines how frequently SeaTag-3D scans the sensors and archives a sensor scan packet (SDPT_3DSN2). The best power efficiency is once every four minutes, and the highest available speed is once every 16 seconds. Sensor scan packets may be Argos transmitted or physically recovered. They are considered non-priority packets in the Argos transmission scheme, but can be selectively elevated to priority status.
- **Priority Data (-3D):** Sensor scan packets can be elevated to priority transmission status based on satisfying a minimum depth and falling within a specified period from mission start. This can be used to selectively obtain time series data on extraordinary deep dives, or monitor the immediate post-tagging period. Consider how many packets will be elevated to priority status, and assure they will not dominate the Argos transmissions, preventing effective reception of the daily summaries and histograms.
- **Depth&Temperature Histogram Period (-3D):** Used to enable the histogram collection and archiving, and define the length of the observation period from 1 to 24 hours. Histograms are priority transmission data.

4.2. Attachment Hardware Selection

We are partnering with [Hallprint](#) in Australia to provide attachment hardware (tethers and heads). The tether is imprinted with your contact information. Please follow the [SeaTag Label Information Request](#) instructions to specify the information to be imprinted for your tags. Hallprint offers three head types as shown below. Please specify the head type and size desired in your order. This will depend on prior your experience. The [SeaTag Performance Report](#) also provides insights on retention achieved by other SeaTag taggers and in some cases details the attachment hardware or method they used. The order part numbers and pricing for the Hallprint Attachment System are specified on the [SeaTag S.A.M. Price List](#).

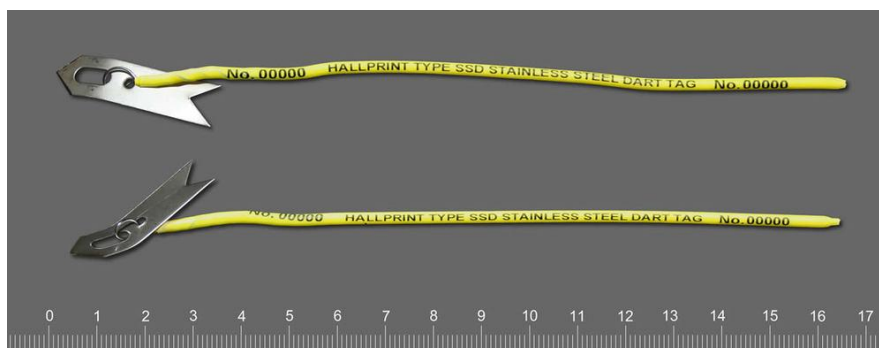


Figure 3A: Stainless Steel Dart (type SSD)

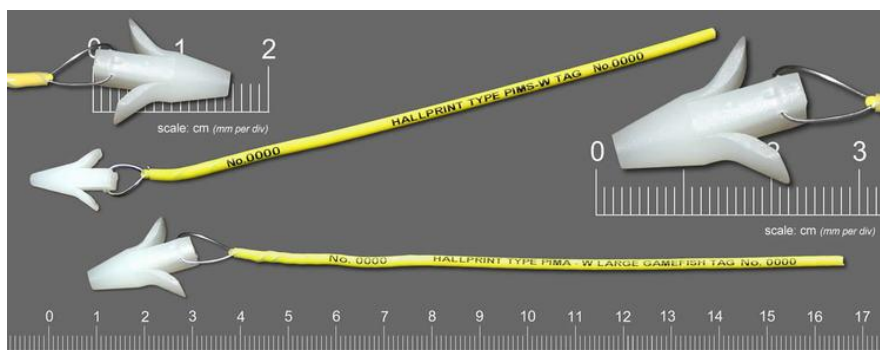


Figure 3B: US NMFS / Billfish Foundation Head. PIMS-W small and PIMA-W large

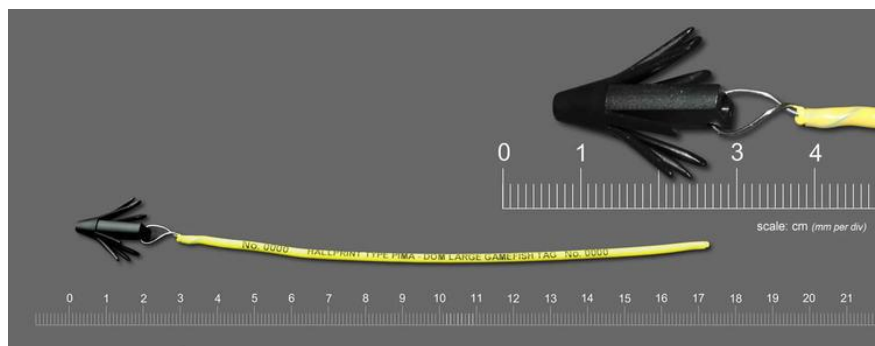


Figure 3C: Domeier Head (Developed by Dr. Michael Domeier)

4.3. Argos Account Setup and Tag ID Request

Prior to using SeaTag devices, you must [set up an Argos account](#) through CLS, the satellite service provider. There are two forms to be completed. The System Use Agreement (SUA) describes your tagging program. Complete as instructed. The ID Number Request Form contains some information that is specific to SeaTag devices. Please download the partially completed form from [here](#) and complete entirely. The number of ID you request should match the number of tags you are purchasing from Desert Star. Return the completed forms (both SUA and ID requests) by e-mail to the CLS user office.

4.4. The ST-GOLD Tag Replacement Program and the Standard Warranty

The terms of ST-GOLD, the Standard Warranty and Terms of Sale for SeaTag devices are available here:

- [Terms of the ST-GOLD Tag Replacement Program](#)
- [Terms of the Standard Warranty](#)
- [SeaTag Terms of Sale](#)

Tags in the ocean are at risk. That is clear both from Mike Musyl's PSAT Tag Performance Study [2] and from the SeaTag Performance Report that Desert Star is now publishing. While the typical reporting rate is around 80%, there is also a large variability. Further, consider that the 'reporting' criteria is satisfied if at least one valid Argos position fix of any class is received (a single or a few messages without a position fix won't meet the criteria - obtaining a position fix requires some minimal robustness of transmission). Yet, a tag reporting minimally may also only minimally satisfy your experiment requirements.

For this reason, Desert Star has instituted the ST-GOLD tag replacement program. Under this program, any tag that does not report, minimally reports (less than 100 messages received) or suffers a defect of its sensors or memory will be replaced free of charge.

Note that specifically not covered is tag shedding. While shedding is in part a function of tag design, it significantly involves species specific biological factors and the particular tagging method and attachment hardware selected. These are largely beyond our ability to control as a tag manufacturer [3][12]. Instead, we are collecting and publishing information on such events to provide reference points and improve future outcomes. See the [SeaTag Performance Report](#).

Replacement covers the tag and data delivery and processing if you have purchased Track&Loc. The cost of the program is 20% of the total tag price, including attachments or accessories and Track&Loc.

We recommend purchasing ST-GOLD as a means to secure your experiment and investment. For a multi-season tagging program, 'over tag' by a percentage roughly mirroring expected tag losses, and then use the replacement tags to rebuild your tag inventory for the next season.

SeaTag are also covered by a standard warranty for one year against defects in parts and manufacturing. However, standard warranty claims do require the return of each claimed tag for inspection. Our advice is to always purchase ST-GOLD, except in cases such as one-time experiments where a tag replacement is not useful.

4.5. Argos Data Delivery and Processing Options

There are [two options](#) for Argos data delivery and processing:

- You may order Track&Loc processing in combination with fixed rate Argos data delivery. The combined cost, per a contract negotiated between CLS and Desert Star Systems, is 30% of the cost of the tag including attachment hardware and ST-GOLD coverage.
- You may pay Argos transmission charges on a monthly basis based on tag activity, and rely on data processing and position track generation using the SeaTag software suite (SeaWatch, SeaConvert and SeaTrack).

We recommend the purchase of Track&Loc, and the following general data collection and processing strategy:

1. **Prior to tagging**, transmit test each tag, a requirement for both the ST-GOLD tag replacement program and the tag deployment methodology proposed by Mike Musyl. The Track&Loc contract will cover these transmission charges.
2. **Following tag deployment**, monitor the tags including shedding, opportunistic transmissions by the tags, preliminary tracks of shed or opportunistically reporting tags, and sensor data review. This 'real-time monitoring' is done using the SeaTag software suite. SeaWatch will automatically retrieve data from the CLS server. SeaConvert is available to decode the data. SeaTrack produces geo-position tracks based on the geomagnetic method for SeaTag-GEO and SeaTag-3D, and to a limited extent, i.e. with significant latitude uncertainty, using light measurements alone for SeaTag-LOT. The monitoring provides an early opportunity to review results, and adjust the tagging protocol in response to any deficiencies.
3. **After tag pop-up** and a subsequent data collection period that you specify, CLS will process the tracks and deliver a presentation ready data package. The comparison of Track&Loc tracks to those generated by SeaTrack here provides an important track verification opportunity: The statistically estimated tracks of Track&Loc produce a smooth, 'most probable track'. But the constraints applied including forcing the track to start and end at the known tagging and pop-up locations, limiting track progress to animal migratory capabilities, avoiding inland locations etc. can also present what are in reality measurement disturbances or model errors as plausible track excursions. The SeaTrack track, resulting from plotting the intersection of the magnetic field intensity and the light based longitude determination, demonstrates the precision of the underlying observations. Measurement disturbances manifest immediately in the track, and can be used to cross-check the Track&Loc results.

Please review [this table](#) comparing the cost, method and data merits of using standard monthly Argos billing and self-processing of the data vs. the use of Track&Loc with flat rate Argos data delivery. A review of citation [5] is recommended. The paper explores the performance differences between the geomagnetic method and light & SST method of geo-positioning, and compares the track measurement vs. statistical track estimation approaches.

See chapter six for tag data returns, comparing Track&Loc and SeaTrack

4.6. Validating your Experiment through a Controlled Environment Tests



After receiving the tags, we recommend some basic controlled environment tests in order to familiarize yourself with the tag and validate aspects of your experiment. Within the prescribed limits (see CAUTION below), tests will not shorten the tag's subsequent endurance because solar power is used for its operation and transmissions. Detailed operating instructions are available in chapter five, and data processing instructions in chapter six.

The following tests are recommended:

1. **Switching the Tag State:** SeaTag S.A.M. tags are always active. This helps diagnose any problems; i.e. the tag will always transmit independent of its state. As long as it is exposed to daylight. The tag however must be switched to **On-Fish** state before deployment in order to collect data. Learn how to switch the tag state using the light sleeve, and the alternative method of placing it in **Armed** mode and then putting it in a dark box to auto-transition to **On-Fish** mode as soon as it is removed from the box. Chapter five provides details.

2. **Transmission Test:** Switch the tags to on-fish state, and place in a water filled white or clear bucket or jar. The tag must be exposed to the sky and, for accurate magnetometer readings, at least

50m from buildings, vehicles, power lines and other metal containing infrastructure or objects. Transmission tests may be a few hours just to test Argos transmissions up to a few weeks to observe

fluctuations of data delivery rates with weather, collect and check sensor data and obtain a position scatter plot based on the collected daily summaries.

3. Check the Data Return Rate and Type: Use SeaWatch to retrieve the Argos data and see if the volume and type of data return is sufficient for your experiment. Note the changes in data delivery (number of packets received per day) with weather conditions. If you are transmitting sensor scan packets elevated to priority status, check that the return of daily summaries and histograms remains sufficient. See chapter six.

4. Test Observation Data Decoding: Use the SeaConvert utility to decode the data retrieved by SeaWatch and stored in the .DRL 'Desertstar Raw Log' files. Inspect this observational data. See chapter six.

5. Test the Geopositioning Accuracy: Leave the tag in place at one location for a week or longer. Each day will result in a daily summary including the observations for geo-position estimation. Process the data through SeaTrack to obtain a scatter plot of positions, indicating the accuracy of the position fixes.

Overall, the experiments should sufficiently familiarize you with the tag performance and tests aspects of your experiment so that the subsequent tag deployment is eased and the risk of insufficient or unsuitable data return reduced.

6. Match a batch of kinetic release powder and test its vitality: Match a batch of powder as explained in chapter five. Take one measurement spoon of powder, place on a non-flammable surface and ignite with a match. This tests your mixing procedure. See the next section details.

4.7. Prepare for Tagging: Charge the Kinetic Release Mechanism

SeaTag S.A.M. devices use a kinetic pop-up release mechanism. The mechanism offers certain advantages compared to the corrodible burn pin commonly used by other manufacturers. This includes imperviousness to marine fouling, instant trigger for an effective crush depth release, trigger with a minute amount of capacitor or battery power, and reliable operation in sea and fresh water alike.

It does however also require some special care: The release powder must be mixed (activated) and the mechanism armed after air transportation and before use. If a tag is not used, the powder must be emptied before air transportation. While the kinetic mechanism includes safeties, including requiring 10 minutes of darkness before triggering and cancelling the trigger if a release condition is present at the time of mission start, there is also some hazard and proper care must be exercised. The hazard of a tag end-cap ejected in air is roughly comparable to that of a paint ball gun projectile.

Release arming should be done by a person trained in the procedure. If you are working with tagging partners of opportunity such as fishermen, arm the release mechanism before delivering the tag. Advise the partners of the hazards as stated in chapter five.



Figure 4: Release kit contents

Materials

1. Silicon Grease
2. End Cap with O-ring
3. H-3 compound
4. Oxidizer
5. Measuring Spoon (0.05g)
6. Popsicle Stick
7. O-ring Remover
8. Silica Gel Pouch (to ensure freshness)

CAUTION: This release kit contains flammable substances once mixed. To avoid any hazards, prepare the compound in a non-flammable environment with the appropriate workspace and safety glasses.

Note: Be aware to keep total time of atmospheric exposure under one hour. If the substances absorb moisture, they can become ineffective and fail the release.

Step 1

Gently grind oxidizer bag using the Popsicle stick to break up compacted powder. Continue until oxidizer becomes fine-grained.

Step 2

Pour the full amount of oxidizer into the H-3 compound (container of charcoal). Close the lid and shake the container for 30 seconds to mix.

Step 3

Unscrew the nose cone from the tag. Take the measuring spoon and scoop one leveled spoonful of powder. Do not heap the scoop.

Step 4

Locate the circular ignition chip inside the burn chamber. Pour powder into the burn chamber. Distribute the powder evenly over the ignition chip by slightly tapping the tag.

Step 5

Remove excess powder on the burn chamber (i.e. inner walls and the top lip of the cap). Inspect the nose cone and O-ring groove. Make sure that it is clean for a secure seal. If the O-ring is dry, lube O-ring with a small amount of silicon grease (remember excessive grease can affect the seal). Snap O-ring on the groove of the nose cone.

Step 6

Screw nose cone on the burn chamber until finger snug. Do not over tighten to prevent shearing of the bolt.

Note: Once the substance is mixed you can no longer air transport or ship the tag or container of mixed powder legally without compliance with HAZMAT regulations. Empty the burn chamber of powder before air transport.

[Video Tutorial: Release Mechanism Arming](#)

Note: This video demonstrates arming for SeaTag-MOD with a modular release & power section. S.A.M. devices have a tag integrated release section, and only the basic powder mixing and chamber closing procedure applies (the o-ring does not need to be removed).

Tag Handling and Tagging

WARNING:

Kinetic Release Hazards

SeaTag devices include a kinetic release mechanism. Upon release trigger, the end-cap will be ejected. The hazard if hit is comparable to that of a paint ball gun projectile. The tag incorporates safety mechanisms: The tag will not trigger the release if in **Safe-Shipping** mode. The tag requires ten minutes of darkness before allowing a release trigger. The tag will cancel any release that results from a condition present within 8 minutes after transitioning to **On-Fish** state (such as a faulty depth sensor indicating crush depth). The tag will not trigger the release within the first eight minutes of **On-Fish** state. Nonetheless, always practice safety when handling an armed tag:

- Wear safety glasses when arming the kinetic release mechanism.
- Work at a clean work space free of flammable materials when arming the mechanism.
- Do not arm the release next to an open flame or hot surface and do not smoke.
- Do not point the release end of the tag at yourself or anyone else.
- Float armed tags in a bucket of water or store in a case or bag to avoid a projectile hazard if a trigger should occur.
- Always return unused tags back to **Safe Shipping** state before transportation.
- Open the release chamber and empty out the powder before air transporting an unused tag.

Avoid Accidental Trigger of the Kinetic Release Mechanism During Testing or Pre-Deployment

Once a tag is in **On-Fish** state, the kinetic release mechanism will trigger if one of the release conditions is met. This may result in an accidental release during your tests. If a tag is not used, always transition it back to the **Safe-Shipping** state. This prevents a release trigger. Review your tag's configuration settings to be aware of the trigger conditions:

- Trigger due to constant depth release time period having been reached and the tag is not on a diving animal. (-3D)
- Trigger due to the tag being placed in darkness (a box, bag, cabinet, dark room or light sleeve applied), and the darkness release time period expiring. (-LOT,-GEO)
- Trigger due to tag experiencing a low temperature below the low temperature release threshold. (-LOT,-GEO)
- Trigger due to the tag not experiencing minimum defined temperature gradients. (-LOT, -GEO)
- Trigger due to the release time at liberty being reached (all models)

5. Tag Handling and Tagging

Tagging with SeaTag S.A.M. devices follow these three steps:

1. **Charging the tag and pre-tagging test transmissions:** At least a few daylight hours before tagging starts (or the day before tagging), place the tags in a water filled white or clear bucket on deck with clear view of the sky. For tag versions without a battery, the capacitor will now charge. Tag transmissions will proceed, satisfying the pre-tagging test required by ST-GOLD and the *Musyl* tag reporting protocol.
2. **Transitioning the tag to the on-fish state:** Before tagging starts, switch the tags to the **On-Fish** state. This will start data collection. If the tag was stored in a dark container or bag in the **Armed** state, transition to **On-Fish** will be automatic as soon as the tag detects light. If previously in the **Safe Shipping** state, light signals are required to transition the tag.
3. **Tagging:** Verify the tag is in **On-Fish** mode as indicated by a green LED blink once every 32 seconds. Then, tag the fish.

Tags that are not used are transitioned back to **Safe Shipping** state using the light switch method, ready for use at the next opportunity.

5.1. Identifying and Transitioning between the S.A.M. Tag Operating States

S.A.M. tags are always active, but may be in one of four states, identified by the color of the status LED blink once every 32 seconds:

Safe Shipping: The tag is not collecting data and will not fire its release. Always place tags in this state for transportation and return to this state if a tag is not used. Identified by a **Red Blink** to indicate the tag is not ready to be put on fish.

Armed: Armed tags will auto-transition to **On Fish** if experiencing at least two hours of darkness followed by light any time thereafter. Armed tags do not collect data until transitioned to **On Fish**. Armed state may be used for these purposes:

- Tags may be delivered to a tagging vessel in a box in **Armed** state for use when a tagging opportunity arises (days, months or even years later). To ready for tagging, simply remove from the box and float in a bucket to start the pre-tagging test transmissions. The tag will automatically transit to **On Fish** state.
- You may place a tag in **Armed** state and float in a bucket on deck the night before tagging. The next morning it will auto-transition to **On Fish** at first light. If not use that day, simply transition back to **Armed** state in the evening and return to the bucket. The tag will be ready in **On Fish** with a cleared memory the next morning for another day of fishing.

The Armed state is identified by an **Orange Blink**. Tags in Armed state should not be placed on fish except in an emergency (tag not ready when fish is caught). If you tag the fish, you will not get observations for the first day, but the tag will transition to **On Fish** on the second day.

On Fish: Tags in On Fish state collect and store data. The tag memory is cleared every time On Fish state is entered, and the mission timer starts when transitioning to On Fish. To obtain a precise time on animal, transition the tag to On Fish on the day of tagging, either automatically at first light from **Armed** or using the light signaling. On Fish state is indicated by a **Green Blink** to show the tag is ready for tagging. A tag in On Fish state will transmit the loop or archived priority data when reaching the surface (opportunistic transmissions) or when shedding from the animal.

Reporting: Reporting state is automatically entered after the tag triggers its release for any of the configured release conditions. Once in Reporting mode, the tag will use both battery (if equipped) and solar power to transmit. This will transmit the pop-up position and the first set of data rapidly. It will transmit all archived priority data 14 times or as otherwise specified, and then transition to transmitting all archived data. The Reporting state is identified by a **Red Blink** to indicate the release has fired. If you find a tag in reporting state, you can transition it back to other states with the light signals and deploy again. However, re-arming the release mechanism may or may not be possible depending on any marine fouling or contact degradation.

5.1.1. Transitioning between the S.A.M. Operating States

S.A.M. tags use light sleeve signals and automatic action to transition between the operating states. Unlike other manufacturers PSAT tags, a magnet cannot be used for this purpose because it might de-calibrate the tags precision magnetometer.

Safe Shipping → Armed: Transition by light signal only to arm the tag.

Armed → On Fish: Transition automatically at first light following 2h+ darkness, or by light signal to get ready immediately for tagging.

Armed → Safe Shipping: Transition by light signal only to prepare unused tags for shipping or later use.

On Fish → Reporting: Transition automatically only, after a release condition has been met and the release has fired.

On Fish → Armed: Transition by light signal to cancel today's tagging and get ready for tomorrow's tagging opportunity.

Reporting → Safe Shipping: Transition by light signal to prepare a recovered tag for another deployment.

A tutorial and video explaining the light switch method in detail is available here:

[Tutorial: Light State-Switch Method](#)

5.2. Tagging Procedure

The tagging procedure for Seatag S.A.M. is similar to that for other PSAT and fish tags. If you have worked with other PSAT before, then the method you used should also be compatible with the S.A.M. tags. Otherwise, research and consult with other researchers to learn what methods are applicable for your species of interest. Here are a few examples.

Over-the-side tagging of Bluefin Tuna with Applicator Needle (VIMS, Willy Goldsmith, SeaTag-LOT)







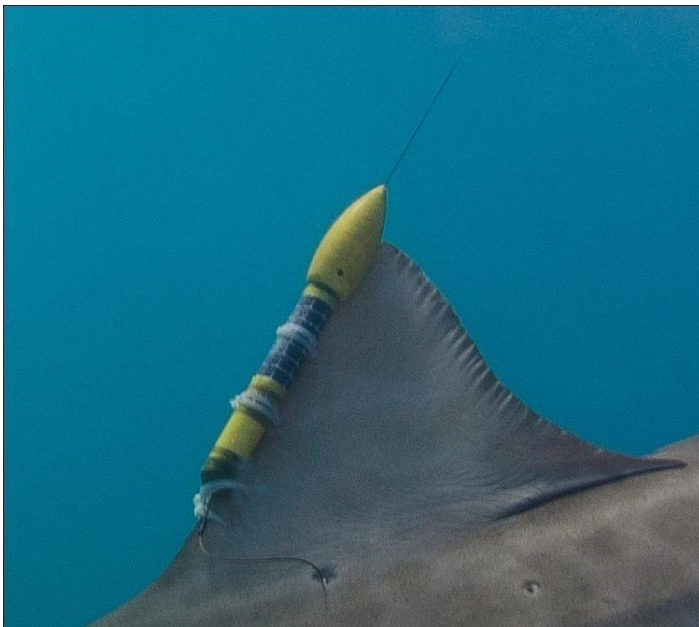
Bluefin Tagging with applicator needle while out of the water (VIMS, Willy Goldsmith, SeaTag-LOT)







Tiger Shark Tagged on Dorsal Fin Using Zip-Ties (Dr.Neil Hammerschlag, U Miami, SeaTag-MOD)



This tagging method consists of two loosely fitting zip ties forming a 'cup holder' for the tag, plus a single point loop and zip-tie attachment between the release end-cap and the leading edge of the dorsal fin. When the release triggers, the tag can slide out of the cup holder. This method has proven to provide long attachment up to over 1 year repeatedly. The approximately constant alignment of the tag with the shark body provides an opportunity to track shark body position using the three-axis accelerometer of SeaTag-MOD.

Bullshark Tagging by Speargun (Juerg Brunnschweiler ETH, Mike Neumann BAD Divers, SeaTag-LOT)



Speargun tagging does not require removing the animal from the water and is thus in particular suitable for larger animals.

[Bullshark Tagging Video \(SeaTag-LOT\)](#)

Lobster Tagging using Carapace Glued Tag Holder (Bryan Morse, UNB, SeaTag-MOD)



Tag mounting using a custom manufactured holder glued to the carapace of a lobster is one example of a specialty technique. Consider non-traditional attachment methods and their potential for longer tag retention or suitability for a particular species.

[American Lobster Tagging Project](#)

Manta Ray and Whale Shark Tagging (Dr. Alistair Dove, Georgia Aquarium, SeaTag-GEO, SeaTag-MOD)

These two videos show how the SeaTag-MOD and SeaTag-GEO ride on a whale shark and a manta ray respectively. The tags have a streamlined float to reduce drag [8].

[Whale Shark with SeaTag-MOD at St.Helena](#)

[Manta Ray double-tagged with two SeaTag-GEO in Quintana Roo \(Mexico\)](#)

Tagging Method, Retention and Wound Infection in Sablefish (KB Echave, NOAA/NMFS, SeaTag-GEO and SeaTag-MOD)



Katy Echave is tagging sable fish for stock assessment. Here, attachment of a SeaTag-GEO prototype is shown. Echave has published a [study](#) on her tagging method [12], showing that tagging wound infection is a factor and can lead to loss of retention. Two tagging methods are tested and evaluated. Detailed tagging instructions for both methods are provided.

6. Experiment Real-Time Monitoring

Real-time monitoring of your tagging study provides you with ongoing quality control and early feedback of unusual tagging outcomes or problems. It thus offers an opportunity for responsive action or correction.

The real-time monitoring capability results from the combination of the tags opportunistic Argos transmission capabilities powered by renewable solar energy and the real-time monitoring optimized SeaTag software suite.

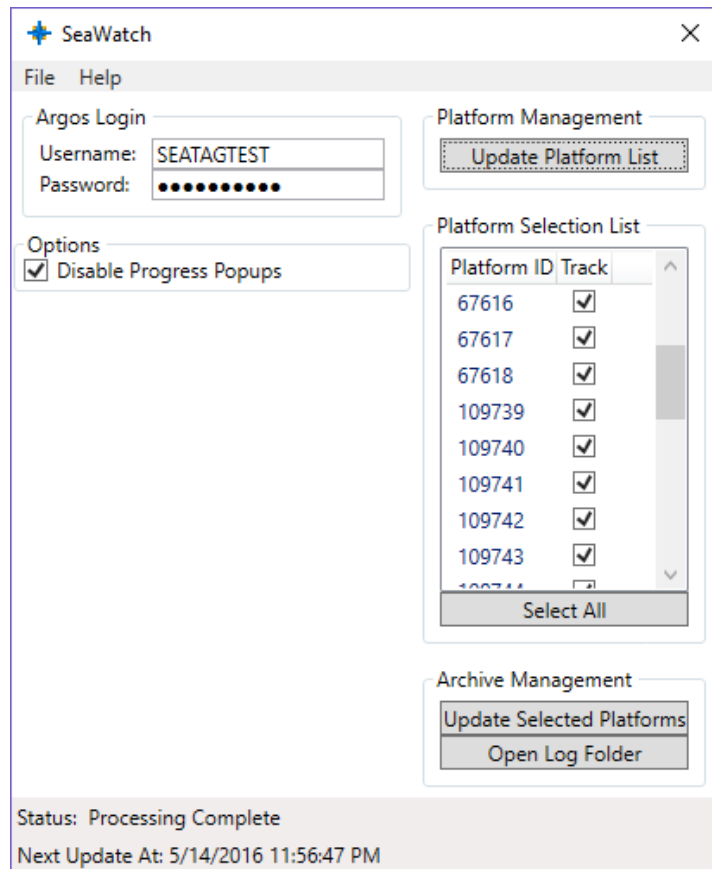
The real-time monitoring opportunities are as follows:

1. Prior to tag deployment, monitor the test transmissions of the tags, verifying their functionality and clearing for deployment.
2. If the animal surfaces, an Argos position fix and some of the priority archival data packets may be received. These work anchor points to verify track accuracy.
3. If the tag is caught in fishing and has an opportunity to transmit, the event location may be available.
4. Shed tags will transmit right away. If excessive shedding is detected, a review and change of the tagging procedure may be called for.
5. Following pop-up, the tag will first transmit the priority data loop (daily summaries, histograms, priority elevated time series data) 14 times or as specified and then follow up with the complete loop or archived priority and non-priority (time series) packets. Engineering packets verify the tag performance and provide calibration data to SeaTrack and Track&Loc. Observation archiving continues, and combined ocean drifter geo-position and Argos 'true' tracks provide verification of the tags accuracy of geo-positioning accuracy.
6. Tag drift can be monitored for extensive locations, providing opportunities for recovery by radio homing or when run ashore [9]. This enables access of the full archived dataset; which for SeaTag-3D can greatly exceed the density of the transmitted data set.

Real-time monitoring is via the SeaTag software suite of SeaWatch, SeaConvert and SeaTrack.

The installers for the software suite are available on-line on the [SeaTag S.A.M. resources page at desertstar.com/SAM](http://desertstar.com/SAM).

6.1. SeaWatch: Automated Retrieval of Tag Messages from the CLS Server



Argos data retrieval for your tags from the CLS is via the SeaWatch utility. SeaWatch runs in the background on your machine, contacting the CLS server via web services once per hour. It will retrieve the data from all selected tags (Platform ID) in your program and will work for Desert Star manufactured tags as well as those of other manufacturers.

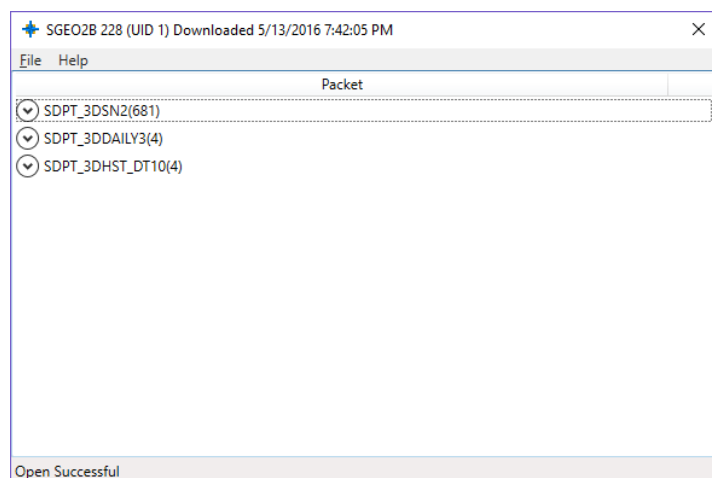
SeaWatch generates a .DRL 'Desertstar Raw Log' file (JSON format) for each tag. This serves as the data exchange standard for the SeaTag software suite, that is both SeaConvert and SeaTrack as the input data set.

See the [SeaWatch Tutorial](#) for operating instructions.

If SeaWatch does not work with your account, the reason may be that web

services is not enabled for the account by CLS. Contact CLS customer service for support.

6.2. SeaConvert: Tag Data Decoding

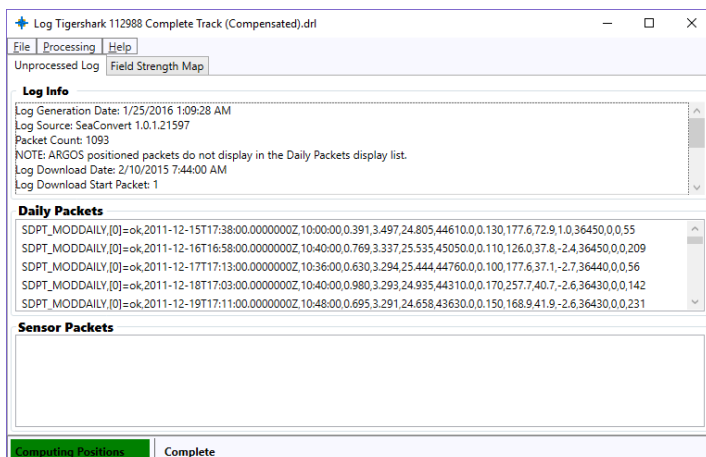


SeaConvert decodes .DRL files retrieved from the CLS server by SeaWatch and creates a bundle of .CSV files, each file containing the sorted data of one packet type. The conversion process may be done for one tag dataset at a time, or using bulk conversion for all datasets stored in one folder.

SeaWatch also identifies any Argos messages with corrupted checksum (Argos transmission errors, a common result typically affecting 20% - 50% of the received messages depending on sea state

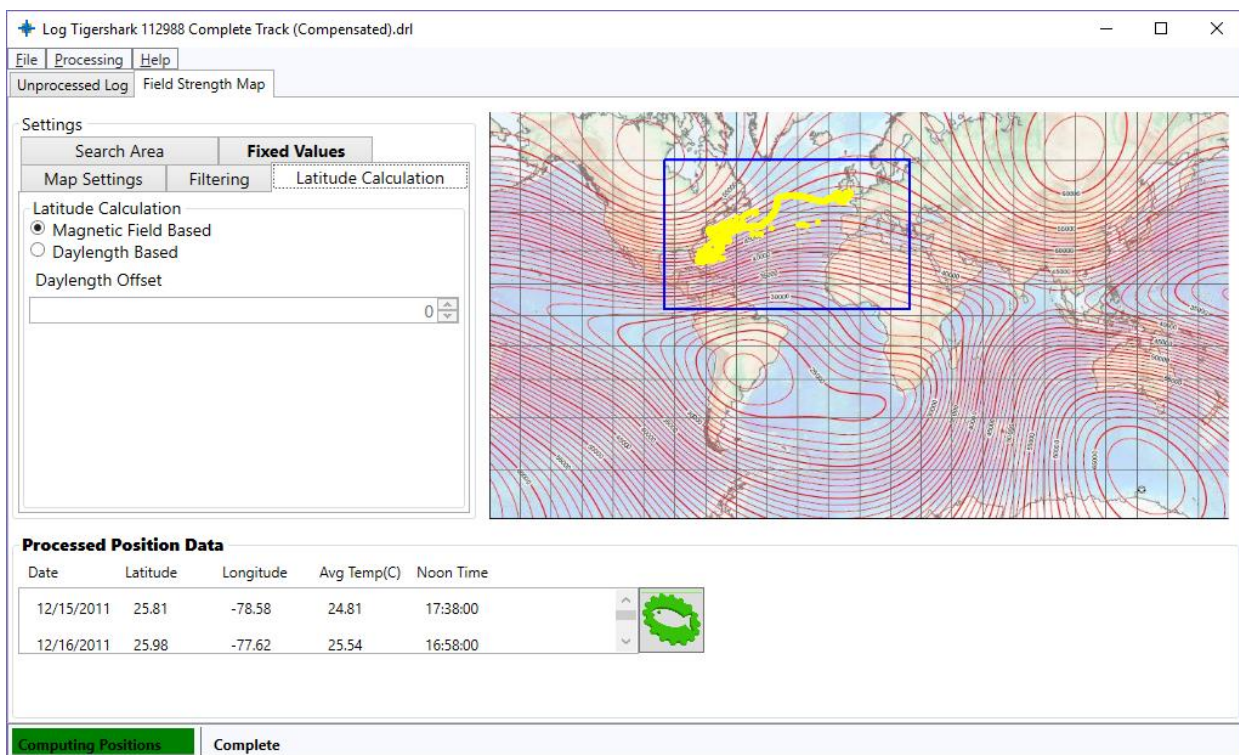
and location). They are stored and available in an INVALID file. Summary statistics for the data set are available in the SUMMARY file. See the [SeaConvert Tutorial](#) for operating instructions.

6.3. SeaTrack: Geo-Position Track Processing



SeaTrack uses the data in the .DRL file, specifically the daily summary packets, to process a geo-position track for the tag. The method is one of the intersection of two measured properties: Either the intersection of the light observation based noon time (the tag determines and transmits the local apparent noon time), with the observed average magnetic field intensity for the day (marked as red lines on the SeaTrack map below). Or, for the

SeaTag-LOT which does not have a magnetometer, the intersection of the local apparent noon based longitude with the daylength based latitude. SeaTrack exports .KML (Google Earth) tracks including the daily observations available in the properties of each position estimate, and a .CSV latitude/longitude file. The tracks are produced rapidly (within seconds).



A few basic filtering options include track smoothing (running average over specified number of day), a longitude confidence filter (longitude measurements are removed if the associated observed day length is short, allowing potential bias in the measurement), and outlier rejection based on speed filtering. This track measurement approach relies on the quality of the underlying observations, and thus works best for the SeaTag-GEO and SeaTag-3D tags equipped with a magnetometer. Here, the processed tracks are generally suitable for publication. But, for best results a two-track approach use is recommended: Use SeaTrack for monitoring while tagging is in process and during the data collection

phase following pop-up when Track&Loc results are not yet available. The intersection of measurements method of SeaTrack directly indicates the quality of the position data and points out any measurement disturbances such as for example due to crustal magnetic anomalies or artificial anomalies that are not captured by the model. Then, use the Track&Loc dataset for publication, cross-checking its tracks against SeaTrack results to detect any erroneous but plausible looking track excursions that can result in the statistic track estimation if the model is incorrect or the measurements are disturbed. For SeaTag-LOT without a magnetometer, the light based latitude measurements (day length observations) tend to exhibit substantial uncertainties [5]. Thus, SeaTrack results for SeaTag-LOT are coarse and the statistical track estimations of Track&Loc incorporating the tags Sea Surface Temperature (SST) are generally needed to obtain a useful track. Nonetheless, longitude will be accurate and thus even here SeaTrack is well suited for monitoring of a tagging campaign before the Track&Loc data set is received.

See the [SeaTrack Tutorial](#) for operating instructions.

7. S.A.M. Data Product Review

S.A.M. data products are available via the SeaTag software suite, and through the CLS Track&Loc service. The two methods are alternative ways to obtain the decoded observation data and position tracks, but they may be used in combination to serve real-time monitoring and publication needs, and to cross-check tracks generated with one method against the other method.

This chapter provides data product samples to illuminate the data analysis options available to you.

7.1. SeaTag Software Suite Data Products

Data products are available at any time by converting the SeaWatch produced raw log files (.DRL files) either through SeaConvert to decode and sort the observations or SeaTrack to generate position tracks.

7.1.1.SeaConvert Data Products

SeaConvert creates a bundle of .CSV files, each representing one packet type. The data is cleaned, that is corrupted transmissions (i.e. messages with a checksum error) are sorted out into an INVALID file. Further duplicate data packets are removed. Duplicates occur because and Argos satellite is in view on average only 10%-20% of the time, requiring the tag to send each priority data packet multiple times in order obtain a high percentage of packets received. In addition, a summary file provides statistics for the data set.

Packet Statistics				
Packet Type	Total	Valid	Invalid	Valid Unique
SDPT_SAMDAILY2	533	374	159	68
SDPT_SAMEN2	174	120	54	119
SDPT_TTSN	1	1	0	1
SDPT_SAMDAILY	3	0	3	0
SDPT_SAMENG	1	0	1	0
Final Statistics				
Statistic	Count	Valid	Invalid	Valid Unique
Full Packet Totals	787	495	292	232
Processed Packet Totals	712	495	217	188
Non-Spurious Packet Totals	708	495	213	188

Table 8: Dataset summary statistics for SeaTag-LOT 141323 (Willy Goldsmith, VIMS)

Table 8 shows the summary statistics of a SeaTag-LOT used for a 31-day post-release mortality study. SeaTag-LOT transmits only daily summaries and engineering packets. Note that while the total number of daily summaries received is 533, there are only 68 valid unique daily summaries. That is because daily summaries are nominally created once per day based on light observations. Here the dataset contains daily summaries for the time on animal and the post pop-up period. The high ratio of total received vs. valid unique indicates that probably most of the daily summaries were received. In fact, in this case 100% of all daily summaries were received.

Figures 5 plots some of the data reported in the daily summary packet; in this case the temperature observations. SeaTag-LOT detects mortality by reporting the maximum temperature change rate (deg C / minute) observed each day. As the fish dives through the vertical temperature gradient, it experiences rapid temperature changes. If dead on the sea floor or the the tag has shed, the gradient declines. Here we see the behavior of a healthy fish, with temperature gradients around 2 °C / minute, and minimum temperatures dropping over 10 °C below the mean. Then on day 27, the max. temperature change rate suddenly declines, the minimum temperature approximates the mean temperature and transmissions were received from the tag. The status byte was still indicates **On Fish** state, meaning the tag shed. A few days later, the status byte indicated Reporting state, with the release condition being Low Δ Temp. Thus, it can be inferred that the fish was healthy for the 27 days until the tag shed.

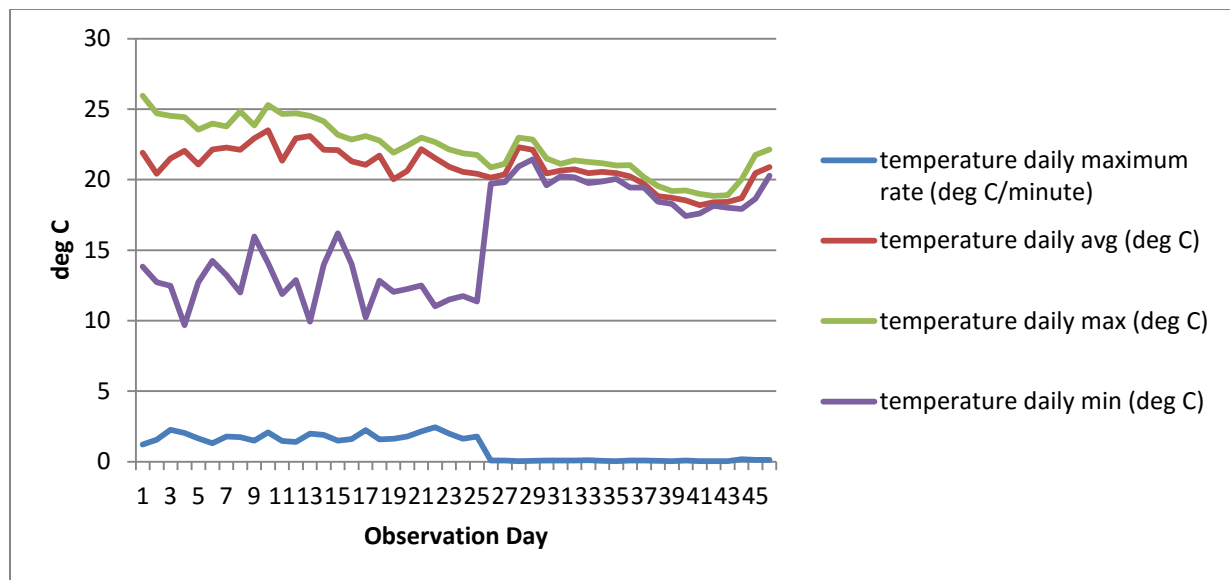


Figure 5: Temperature observations of the same SeaTag-LOT as reported in the daily summaries show the fish was healthy for 27 days after release, at which point the tag shed.

7.1.2. SeaTrack Data Products

Figure 6A-6D provides several perspectives of a track of a SeaTag-MOD, all processed with a seven day running average filter. This track is of a tiger shark, tagged in the Bahamas. The tag was on the animal for one year, then popped up and drifted across the Atlantic to Wales for two more years, where it was found on a beach and returned. Figure 6A is the one year migration of the tiger shark. Notice the tight cluster of position fixes in the Bahamas. Figure 6B zooms in on the Bahamas to inspect the residency cluster, which occurred from start of tagging in December until April, and from the sharks return to the Bahamas in October until tag pop-up in December. Figure 6C is the same track as 6A, here processed using not the magnetic observations but the day length observation to determine latitude. The reduced precision of light based latitude is clear. Figure 6D shows the drifter track across the Atlantic.

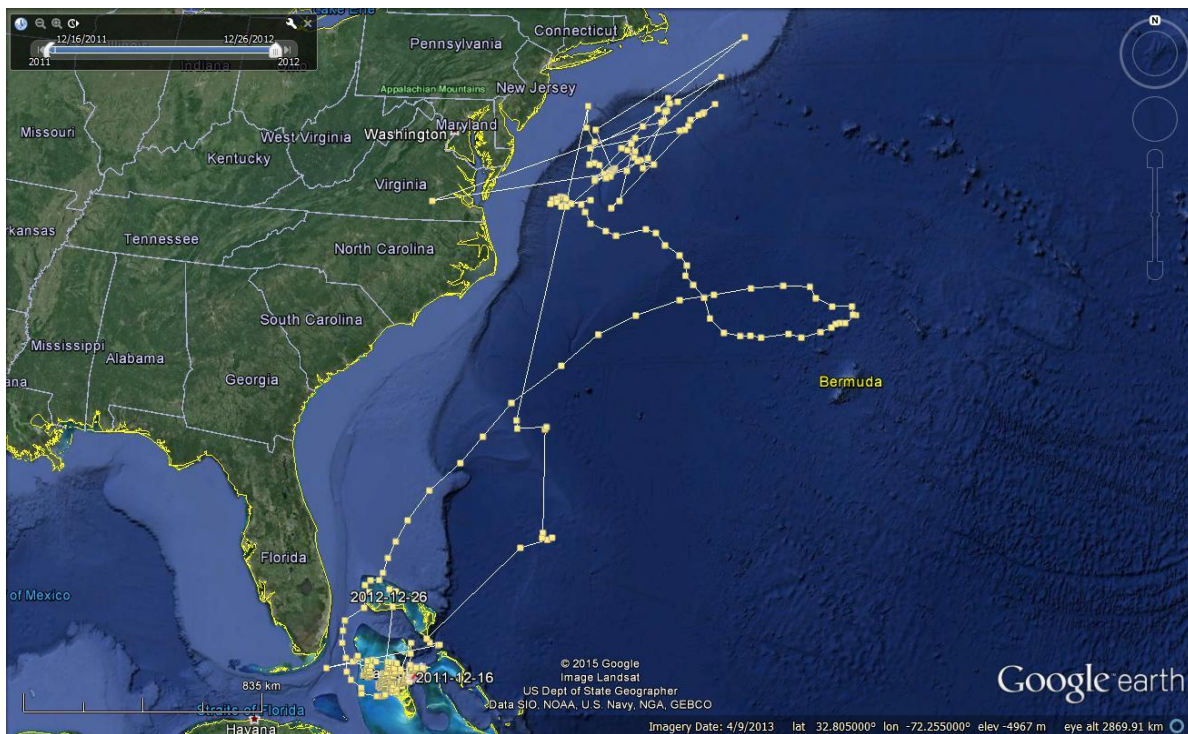


Figure 6A: One year track of a tiger shark tagged in and returning to the Bahamas (Neil Hammerschlag, U Miami RSMAS, SeaTag-MOD)

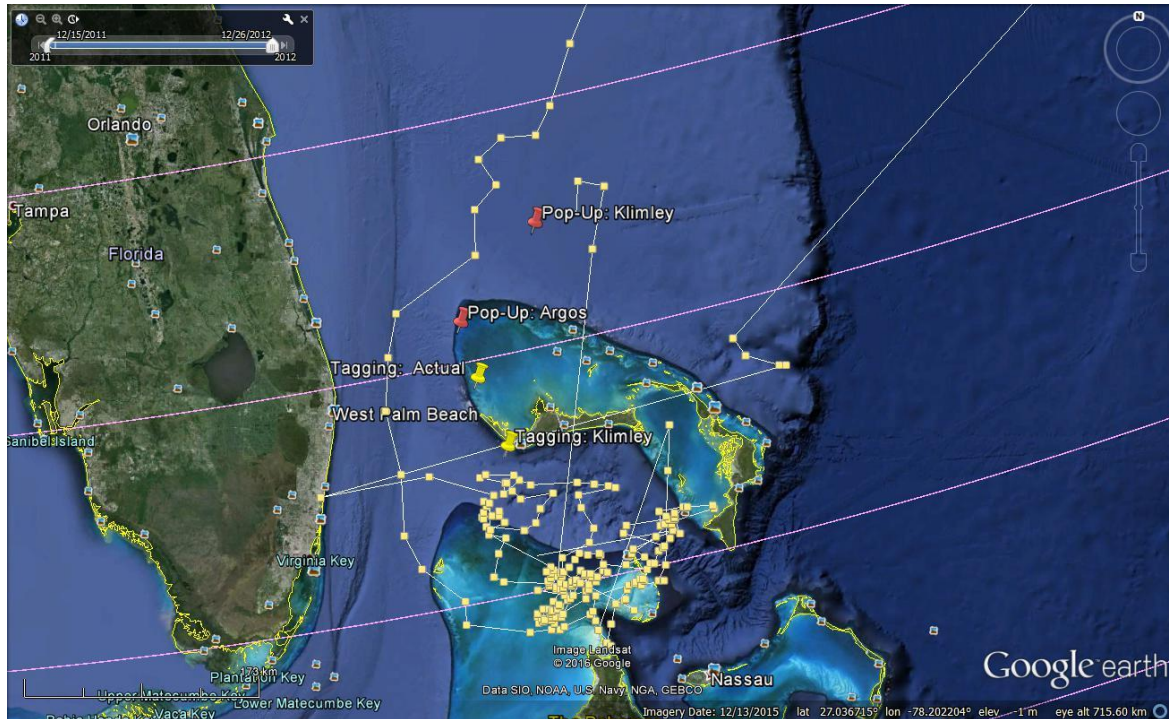


Figure 6B: Bahamas Detail showing tight residency cluster from October-April and good match between actual and geomagnetic measured tagging and pop-up positions

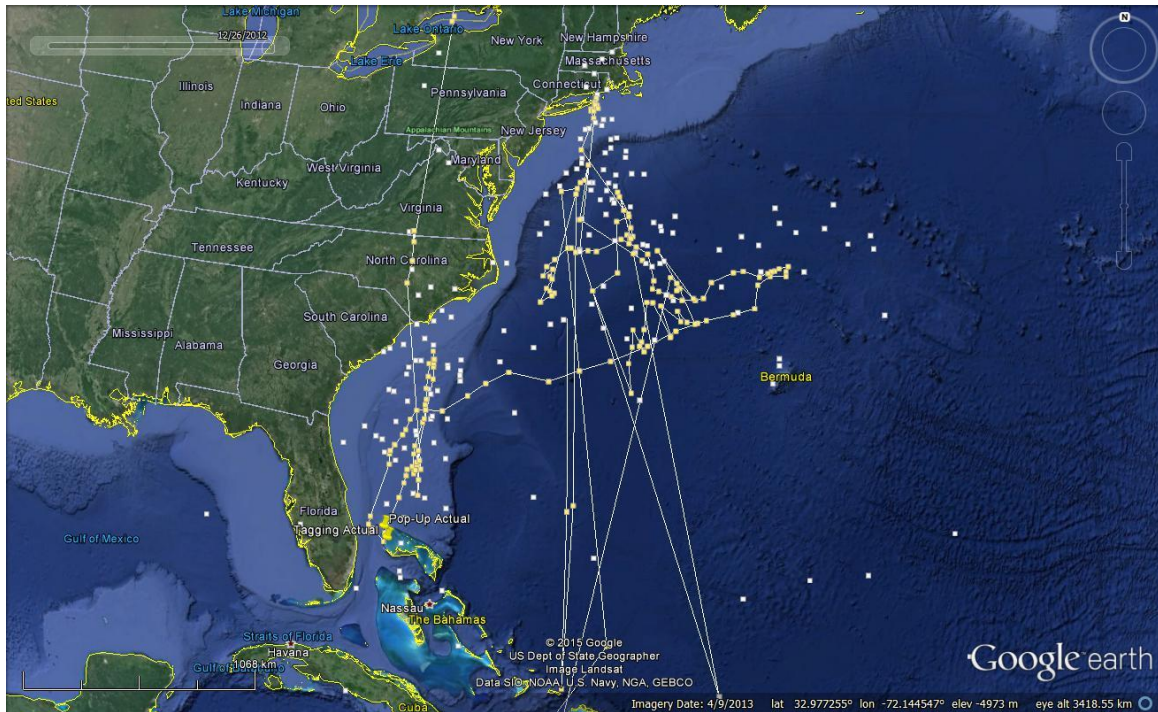


Figure 6C: Same track as figure 6A, but using the tags day length light observations instead of the magnetic field intensity measurements to determine latitude. Precision is reduced, the Bahamas residency is not apparent but the general larger scale track features persist.

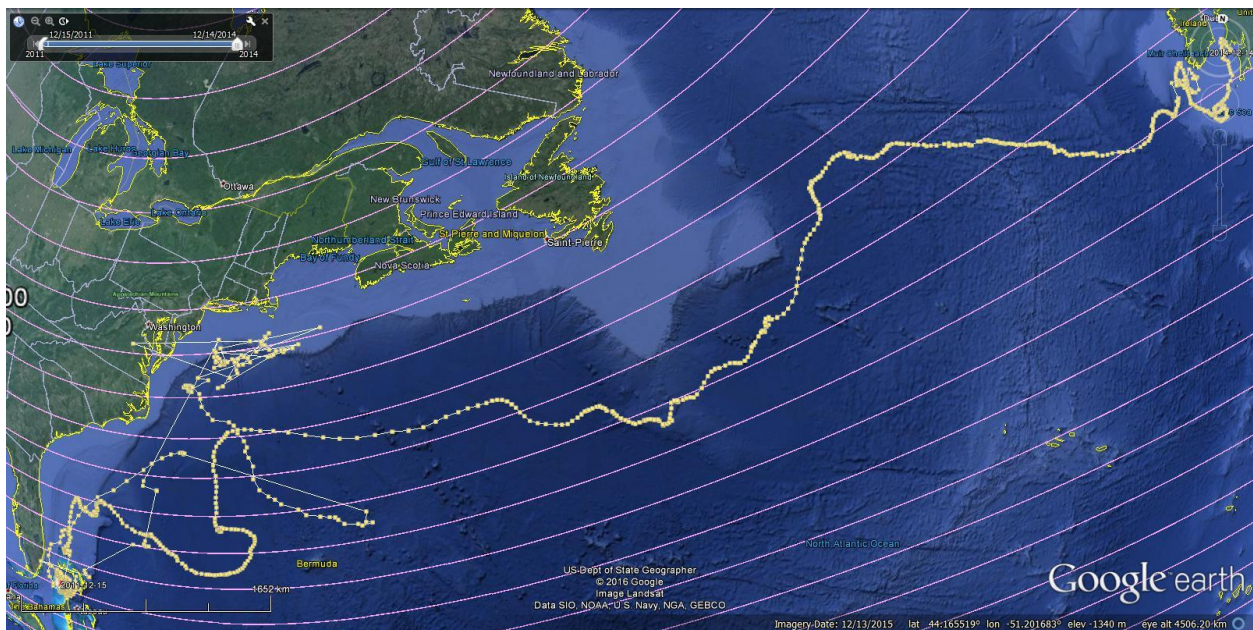


Figure 6D: 1-year tiger shark and subsequent two year post pop-up drift across the Atlantic. Areas of strong and weak ocean currents are apparent in the daily progress of the track.

7.2.Track&Loc Data Products

Here is a review of Track&Loc data products, both an ocean drifter and the dataset from a bluefin tuna. Both datasets are from SeaTag-LOT.

7.2.1.SeaTag-LOT 67610: Ocean Drifter

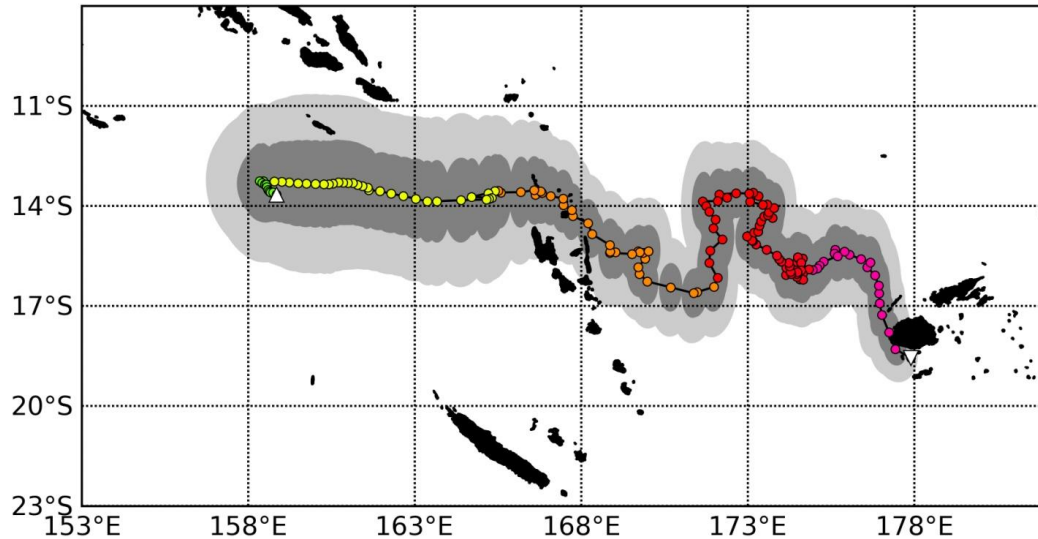


Figure 7A: Track of SeaTag-LOT Ocean Drifter 67610 with 50% and 90% confidence intervals. Track coloration reflects monthly progress

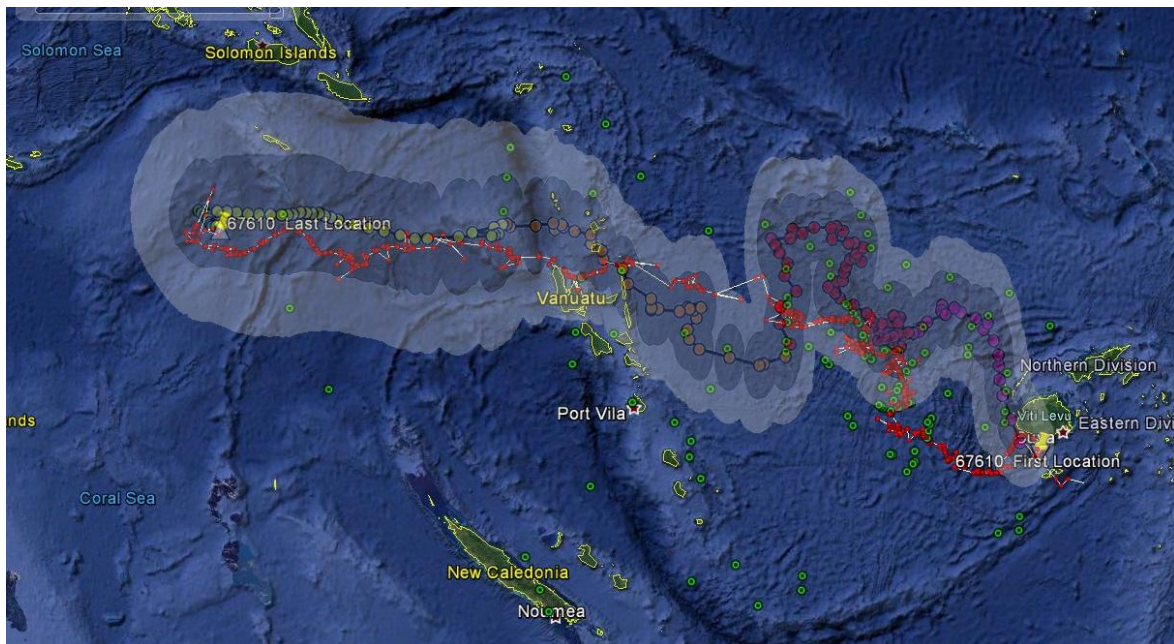


Figure 7B: Same estimated track overlaid on Argos position track (red dots) to illustrate actual estimation errors.

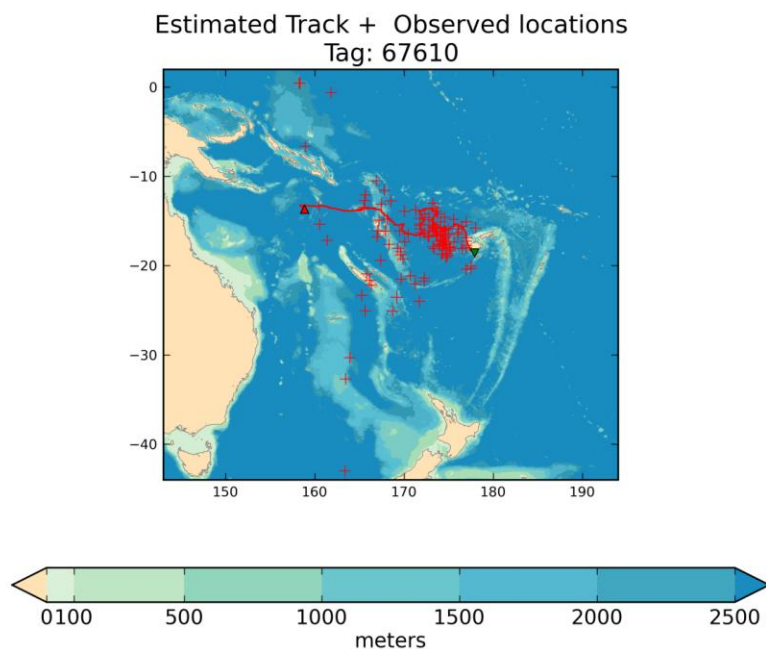


Figure 7C: Bathymetry plot with start and end positions (green and red triangle), estimated track (red line) and the raw light-based position fixes (red dots)

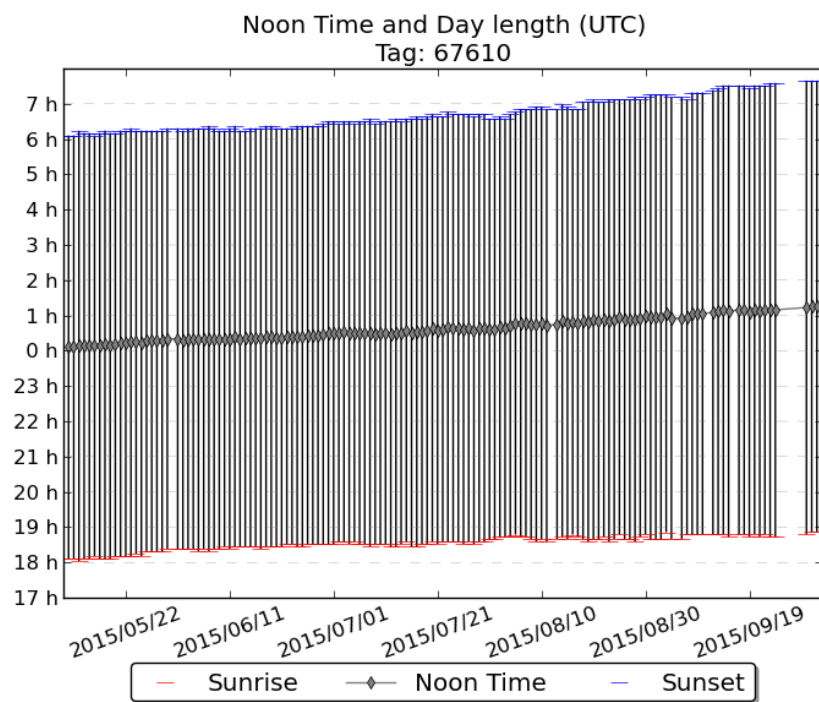


Figure 7D: Day length and local apparent noon observations (center line). The progressively later local apparent noon observation shows the tag is drifting to the west

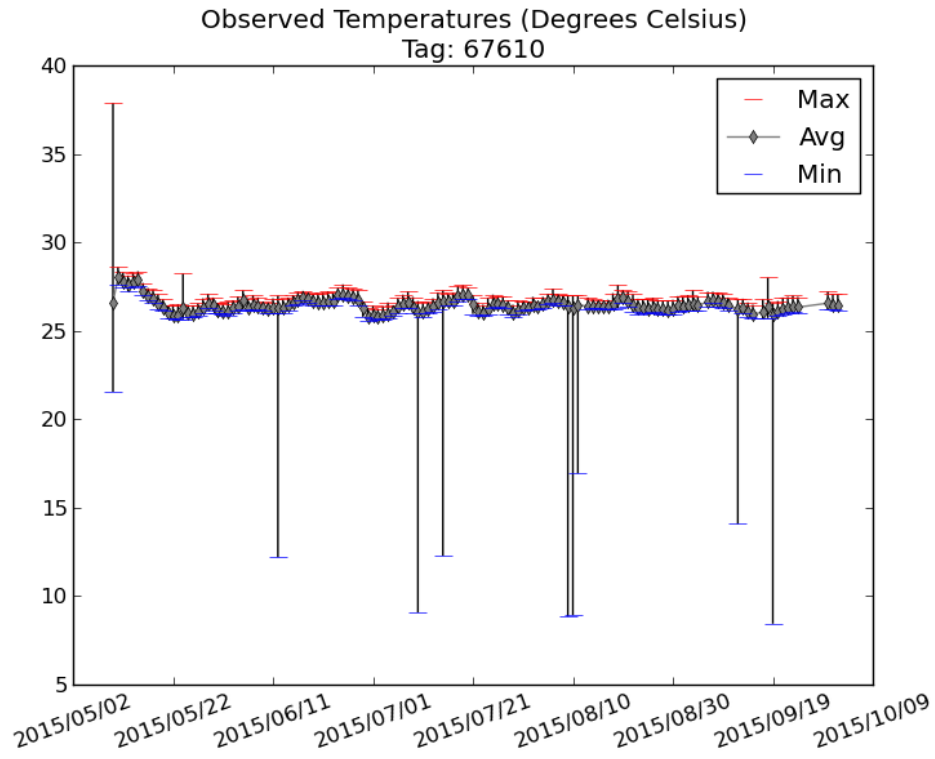


Figure 7E: Minimum, average and maximum daily temperature. The occasional strong dips of the minimum temperature may be predation on the floating tag

7.2.2. SeaTag-LOT 141316: Bluefin Tuna 31-Day Post Release Mortality Study

The data credit for the following plots is William Goldsmith, VIMS. The plots reflect results from one animal in a n=20 post release mortality study (study in progress as of May 2016).

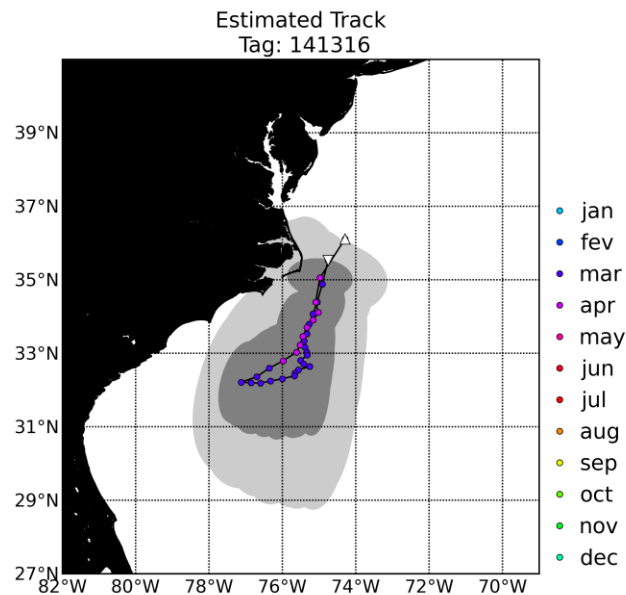


Figure 8A: 31 day track based on light based local apparent noon observation, day length observation and SST. 50% and 90% confidence intervals. This is one of the tracks used in citation [5], discussing the accuracy and confidence of light based and geomagnetic tracks

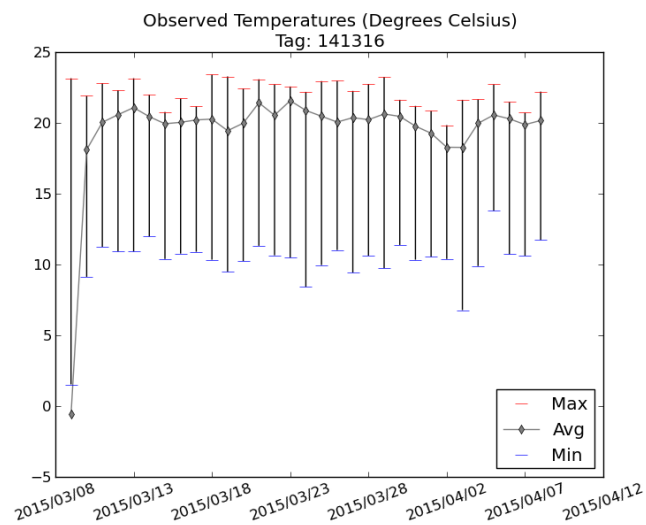


Figure 8B: Temperature plot. Compare to figure 5. This fish was healthy for the 31-day post release period until commanded tag pop-up

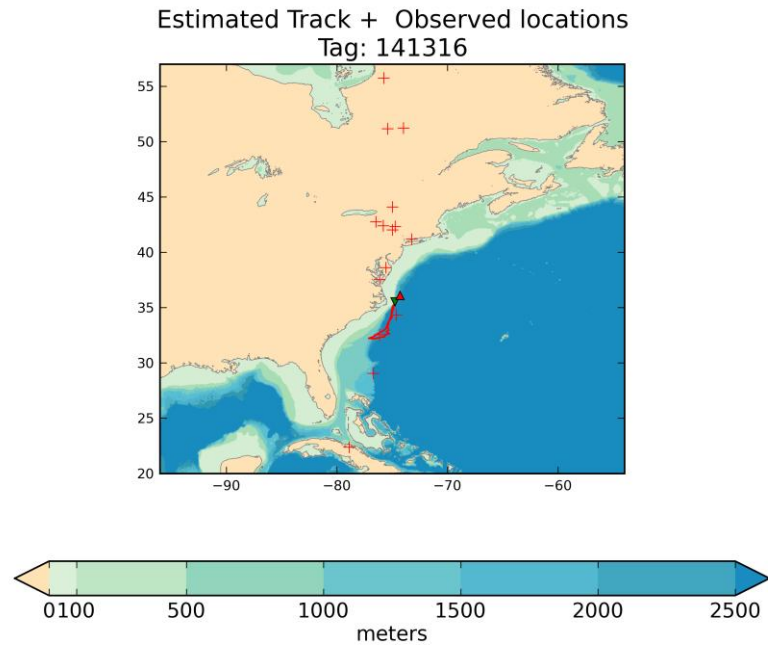


Figure 8C: Bathymetry plot including estimated track and raw light positions (red crosses)

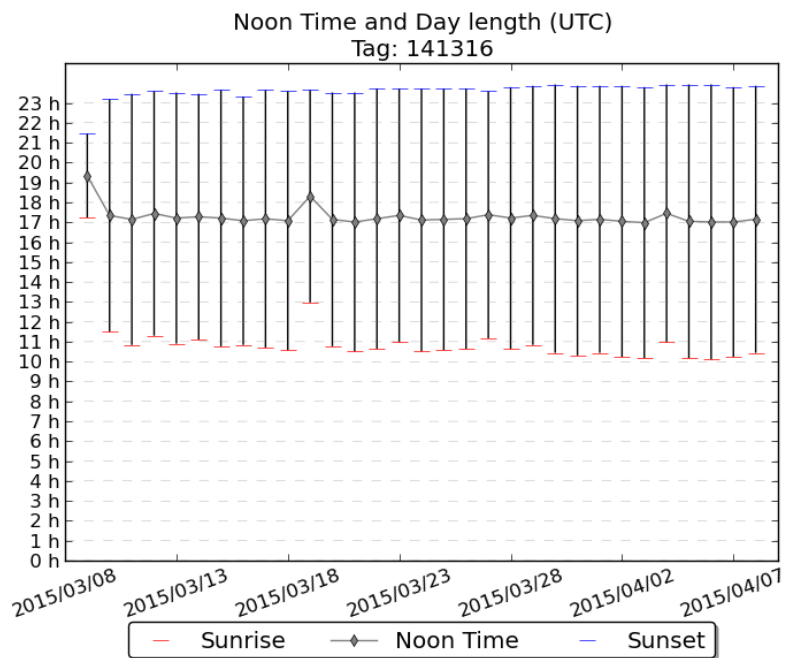


Figure 8D: The local apparent noon and day length observations. Note the generally greater precision (consistency) of the noon measurement as compared to the day length measurements. Thus, light based longitude is measured with greater precision and accuracy than latitude.

8. Citations

- [1] Forty Years of Conventional Billfish Tagging: Successes, Failures and Lessons Learned. Julian Pepperell, 5th International Billfish Symposium, 2013, Taipei
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