Conceptual Tag Report: The Trophic Sentinel System

Project Context: SharkSight AI Model Validation

The Trophic Sentinel Tag (TST) is a conceptual, advanced fin-mounted telemetry system designed to provide real-time, high-resolution, in-situ biological and environmental data. Its primary objective is to serve as a mobile ecological sampling platform to overcome the limitations of traditional archival tags (PSAT) and surface-dependent tags (SPOT) and provide the ground-truth data essential for training and validating the next generation of predictive ecological models, specifically the **SharkSight** human-shark encounter risk model.

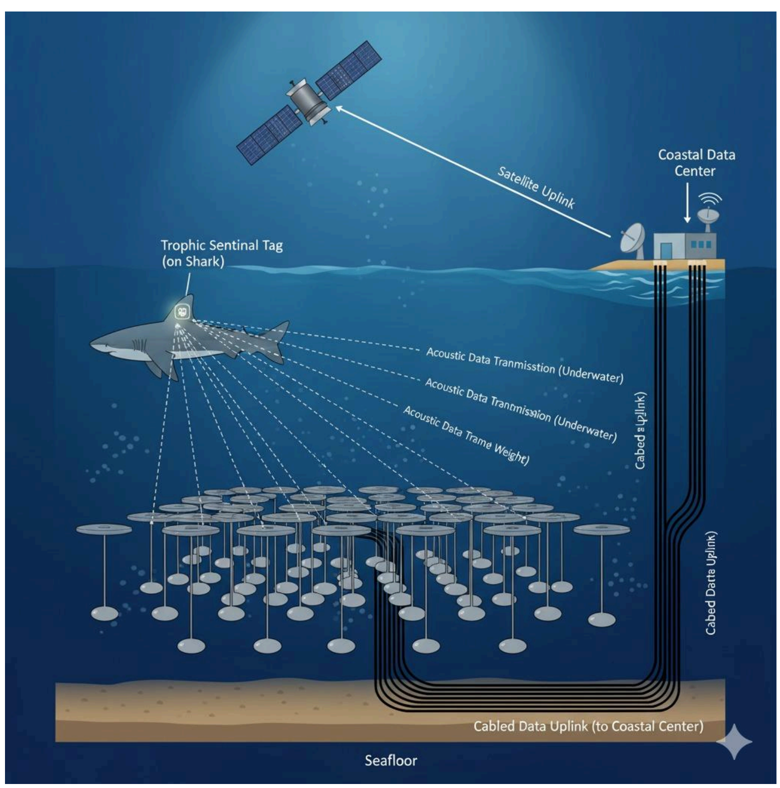
The current challenge for SharkSight, as outlined in the project plan, is to correlate broad-scale NASA satellite features (Xi: SST, Chlorophyll-a, EKE) with historical shark presence/absence points (Y). The TST is engineered to provide the high-fidelity, instantaneous Y=1 (Foraging Event) data points and localized in-situ X data necessary to establish a robust trophic link, which is currently a weakness in oceanographic correlation models.

1. Trophic Sentinel Tag: Conceptual Design Overview

The TST is envisioned as a ruggedized, fin-mounted unit (similar in form factor to a fin-mounted SPOT tag) secured via bio-degradable or dissolving bolts, ensuring non-recovery-dependent release, a known advantage over physical recovery methods noted in existing research.

The key innovation is the fusion of high-precision movement sensors, direct water chemistry analysis, and a novel foraging detection system with an advanced, low-latency, two-step communication architecture.

Concept Image



2. Key Features and Data Contribution

The TST integrates five distinct component groups, directly addressing the data requirements for advanced AI training and real-time risk assessment:

Feature/System	Sensor/Component	Purpose & Data Output	AI Model Contribution (X or Y)
I. High-Resolution Location	Fastloc®-GPS + Enhanced Argos Transmitter	Provides high-accuracy latitude and longitude when surfaced. Enhances the low-resolution position data often associated with PSAT geolocation (as discussed in Braun et al., 2018).	X **(Feature/Location)**: High-resolution Lat/Lon for precise correlation.
II. Vertical & Behavioral Data	High-Resolution Pressure Sensor (Depth) + Tri-axial Accelerometer	Records precise depth, fine-scale behavior (tail beats, speed), and time spent at the surface (PSurface) and in vertical profiles (PVertical), replacing static assumptions with live behavior data for future models.	X **(Feature/Behavior)**: Depth, Speed, PVertical (as noted in the conceptual plan).
III. Water Chemistry & Habitat	Micro-CTD (Conductivity, Temperature, Depth) + Fluorometer/Spectrometer	Measures in-situ Temperature and Salinity (from conductivity). Critically, it measures Chlorophyll-a and Turbidity at the shark's exact depth, providing **ground-truth validation for NASA PACE satellite data.**	X **(Feature/Environment)**: In-situ SST, Chlorophyll-a (Ground-Truth).
IV. Trophic/Foraging Link	Bio-Acoustic Recorder (Hydrophone) + Stomach-pH-Probe (Dissolvable Tether)	The "Trophic Sentinel" component. Hydrophone records feeding sounds. The pH probe generates an immediate, high-confidence signal for a **Feeding Event** by detecting rapid changes in stomach acidity following ingestion.	Y **(Target/Label)**: Instantaneous **"Feeding Event"** (Y=1) at a specific time/location.

V. Real-Time Data Relay	Low-Power Acoustic Transducer + Relay Buoy Uplink (Iridium/GSM)	Bypasses the traditional latency of satellite tags that rely on the animal surfacing. Data is broadcast to nearby floating Relay Buoys which use an Iridium/GSM satellite link to transmit data to the SharkSight backend in near-real-time.	**System Enabler**: Low-latency data stream for **Real-Time Predictive Models** and **Instant Alerts**.

3. Support for Hackathon Objectives

The Trophic Sentinel Tag concept directly addresses the core technical and ecological goals of the SharkSight project:

3.1. Quantifying the Trophic Ecological Link

The TST overcomes the limitations of inferring trophic ecology solely from movement or environmental correlation by generating a robust, primary data point: the **Feeding Event (**$Y=1$**)**.

- **Ground-Truthing PACE Data:** The internal fluorometer measures Chlorophyll-a at the shark's precise depth and location, allowing for direct comparison and validation of the regional Chlorophyll-a data provided by the NASA PACE satellite. This links the macro-scale satellite feature to the micro-scale environment.
- **Defining Foraging Hotspots:** By coupling the instantaneous $Y=1$ (Feeding Event) point with the concurrently measured local environmental features (Temperature, Chlorophyll-a) and large-scale NASA data (SST, EKE), the AI model can be trained on definitive foraging locations rather than inferred presence. This will significantly increase the fidelity and predictive power of the Logistic Regression model's β_i coefficients.

3.2. Enabling Real-Time Risk Prediction

The current state of satellite telemetry (SPOT and PSAT) is generally limited by data volume and latency. The TST's two-step communication architecture is purpose-built to enable the "Instant Alert System" required by the SharkSight Risk Dial.

- **Low-Latency Transmission:** The Relay Buoy network ensures that high-priority data, such as a Feeding Event trigger, is transmitted immediately via satellite (Iridium/GSM).
- **Instant Alert System:** A confirmed Feeding Event is treated as a critical, high-priority flag. This enables the **SharkSight Risk Dial** to update instantly based on a validated foraging event in a specific area, leading to an immediate, science-backed shift to a **RED (HIGH)** risk status ($RE \geq 0.65$). This capability transforms the model from a historical correlator into a genuine, real-time risk mitigation tool.

4. Operational Comparison to Existing Tags

The TST is a hybrid evolution of existing technologies, selectively borrowing deployment characteristics while eliminating their inherent data constraints:

Tag Type	Primary Limitation Overcome by TST	TST Parallel Component
PSAT (Pop-off Satellite Archival Tag)	High latency, often poor geolocation accuracy (60-80 km error) when light levels are inadequate, and reliance on post-deployment retrieval for full dataset.	Fastloc-GPS for high accuracy; Acoustic Relay for real-time, low-latency transmission.
SPOT (Smart Position and Temperature Tag)	Only records/transmits data when the fin/antenna is above the water surface, resulting in significant data gaps for diving species. No in-situ environmental or trophic sensing.	Acoustic Relay transmits continuously regardless of surfacing. Integrated CTD and Fluorometer provide continuous in-situ environmental data at depth.
Acoustic Transmitter (Vemco/Lotek)	Limited spatial coverage; requires costly, fixed array of receivers (AU$2,000-3,000 per receiver) and physical recovery of receivers to obtain data.	Relay Buoy network is a mobile, satellite-linked version of the receiver array, enabling vast spatial coverage and instant data uplink.

Conclusion

The Trophic Sentinel Tag (TST) represents the ideal conceptual technology for validating and enhancing the SharkSight AI model. It is designed to provide the specific trophic-link and high-fidelity environmental data (Y=1 Feeding Event, in-situ Chlorophyll-a) that will allow the Logistic Regression model to move beyond correlation and into robust, explainable, and real-time prediction of potential human-shark encounter risk.