



TurtleGuard: An Edge-Based Sensor-Fusion and Risk-Scoring System for Hatchling Disorientation and Thermal Reproductive Risk at Olive Ridley Rookeries

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Abstract

Seven sea turtle species exist worldwide, but synchronized mass nesting, or arribada, is chiefly associated with olive and Kemp's ridleys. Odisha hosts globally important olive ridley (*Lepidochelys olivacea*) arribadas; the Government of India reported more than **6.98 lakh** nesting turtles at the Rushikulya river mouth (Odisha) in February 2025 (Press Information Bureau, 2025). Olive ridleys contribute to marine food webs by consuming jellyfish, crustaceans and other prey, while a persistent temperature-driven imbalance in hatchling sexes could affect future breeding dynamics. At beaches where nesting occurs at this scale, artificial lighting can disrupt hatchlings' seaward orientation, while elevated incubation temperatures can alter sex ratios and affect developmental outcomes. These risks operate at different stages of the turtle's life but require timely, site-specific environmental monitoring.

TurtleGuard, an **edge-based sensor-fusion and risk-scoring system**, is designed to assess both risks without disturbing turtles or nests. Its optical module combines directional horizon brightness, light-source visibility, spectral measurements, and weather conditions to identify settings associated with hatchling disorientation. Where authorised passive footage is available, movement trajectories provide a behavioural indicator for evaluating the optical score. A separate thermal module analyses sand-temperature proxies and historical records to flag elevated incubation risk. Each score includes its contributing measurements and data-quality status for review by conservation personnel.

TurtleGuard treats the first **0–48 hours** after emergence as an operational priority window, rather than a fixed biological energy limit. Its thermal score does not directly determine hatchling

sex; that inference requires local calibration. The present contribution is a transparent monitoring framework and a protocol for validating it. A screened, longitudinal dataset spanning nesting, emergence, and later life stages could enable future tests of unresolved questions about **arribada timing, hatchling orientation, thermal resilience, and recruitment**.

KEYWORDS

Olive ridley; arribada; hatchling orientation; artificial light at night; temperature-dependent sex determination; sensor fusion; edge computing and risk scoring.

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1 | PROBLEM STATEMENT

1.1 | Artificial-light-induced disorientation

Hatchling sea turtles rely on visual cues from the terrestrial landscape and horizon to navigate toward the ocean during the seafinding phase. Empirical evidence indicates that light wavelength, intensity, directionality, and background contrast influence hatchling phototaxis and seaward orientation (Witherington and Bjørndal, 1991a,b; Karnad et al., 2009). A light source that appears moderate on a clear, moonlit night can become more disruptive when cloud cover reflects skyglow, when the source is directly visible from the beach, or when its position generates a strong landward horizon cue. The project does not categorize “amber light” as inherently safe; intensity, geometry, shielding, duration, and beach visibility remain essential variables (Florida Fish and Wildlife Conservation Commission, n.d.).

1.2 | Thermal reproductive risk

Sea turtles exhibit temperature-dependent sex determination. Cooler incubation conditions tend to favor males and warmer conditions tend to favor females, but the relationship is not governed by a simple universal rule. A single measurement of sand-surface temperature at noon does not independently characterize the thermal conditions experienced by embryos during incubation. Moisture, depth, shading, rainfall, grain size, metabolic heat, and developmental stage can alter the actual thermal environment. Rushikulya monitoring reported approximately 71% female hatchlings on average in monitored arribada samples, with substantial interannual variability (Shanker et al., 2024). A nearby temperature probe does not directly quantify embryo sex or hatchling survival.

2 | RESEARCH GAP AND AIM

Beach managers require a method to determine whether an observed risk is driven by direct glare, landward brightness, spectral composition, cloud-amplified skyglow, poor data quality, local thermal conditions, or a combination of these factors. TurtleGuard aims to develop a transparent, cost-effective, edge-capable monitoring architecture that synthesizes multi-source environmental observations into explainable risk assessments. Its objectives are to quantify the seaward–landward light relationship, record environmental conditions that alter artificial-light risks, generate

permission-dependent behavioural indicators, monitor thermal context without claiming direct sex determination, and establish a screened, governed long-term dataset.

3 | STUDY DESIGN AND DATA

This synopsis outlines a step-by-step environmental monitoring study. Published monitoring reports offer context while the equations below set out the measurements and validation steps for a future authorized deployment. The examples in this paper use made-up data just to show how the calculations work, they are not actual field measurements or hatchling observations. A real field record would need a site, a sector, a timestamp, instrument calibration details and provenance, for each observation. Camera brightness would stay a measure without photometric calibration and any missing thermal data would be marked as gaps.



FIGURE 1 Adult sea turtle photographed on the beach during the authors' Rushikulya field visit. The photograph documents the coastal setting and an adult turtle observed there. Photograph: authors.

4 | MEASUREMENTS AND QUALITY GATES

The horizon contrast ratio (HCR) is an engineering index, not a universal biological law:

$$HCR_t = \frac{L_{sea,t} - L_{land,t}}{L_{sea,t} + L_{land,t} + \varepsilon}. \quad (1)$$

A negative HCR indicates that the landward sector is brighter in the measured geometry. HCR is combined with direct-source visibility, spectral distribution, and weather. The proposed optical-risk score is

$$\begin{aligned} z_t &= \beta_0 + \beta_1 X_{HCR,t} + \beta_2 X_{source,t} \\ &\quad + \beta_3 X_{spectral,t} + \beta_4 X_{weather,t}, \\ R_{opt,t} &= \frac{100}{1 + \exp(-z_t)}. \end{aligned} \quad (2)$$

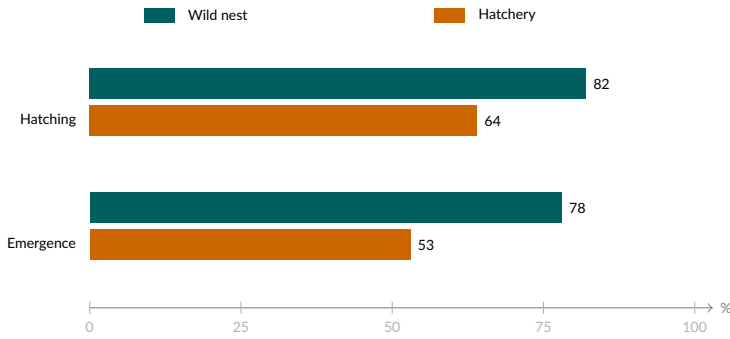


FIGURE 2 Reported hatching and emergence success in wild and relocated hatchery nests at Rushikulya: 82/64% and 78/53%, respectively (Shanker et al., 2024).

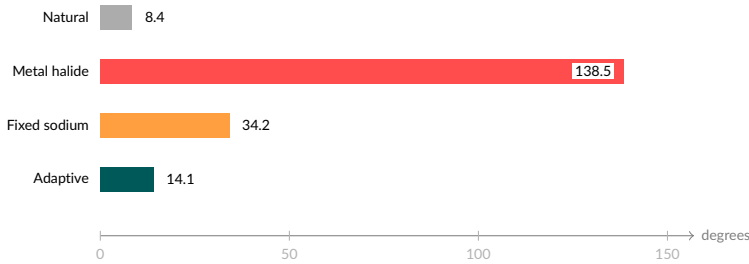


FIGURE 3 Mean orientation errors (degrees) transcribed for lighting conditions.

Coefficients are model parameters, not established biological constants. Hatchling movement is excluded from predictive inputs so that subsequent trajectories can independently evaluate the score.

Thermal data are recorded as continuous time series. A cumulative heat-exposure index compares proxy temperatures across sectors and periods:

$$E_{\text{heat}} = \sum_{t=1}^n \max(0, T_t - T_{\text{ref}}) \Delta t. \quad (3)$$

The index does not demonstrate embryo mortality or female proportion without calibration against authorised biological outcome data. Optical alerts describe a particular night; thermal assessments summarise exposure over days or weeks. A combined priority is calculated only after both component scores pass their separate quality checks. Otherwise, the interface reports “insufficient data” rather than a numerical priority score.

5 | EVIDENCE, WORKED EXAMPLES, AND VALIDATION

Published monitoring provides context rather than TurtleGuard performance results. The Government of India reported more than 6.98 lakh olive ridleys nesting at Rushikulya in February 2025 (Press Information Bureau, 2025). Long-term monitoring reported hatching success of 82% in wild nests and 64% in hatchery nests, and emergence success of 78% and 53%, respectively (Shanker et al., 2024). These observational aggregates do not measure the

TABLE 1 Constructed inputs and calculated horizon contrast.

Scenario	L_{sea}	L_{land}	HCR
Seaward brighter	0.80	0.20	+0.594
Landward brighter	0.20	0.80	−0.594
Small seaward contrast	0.60	0.40	+0.198

performance of TurtleGuard.

Table 1 is a deterministic calculation check for Equation 1. We constructed three pairs of relative brightness inputs and set $\varepsilon = 0.01$ in the same arbitrary units. None of the inputs was measured at Rushikulya. The calculations show how a brighter landward sector changes the sign of the index; they do not establish a biological risk threshold.

As a separate calculation check for Equation 3, consider constructed proxy temperatures of 28, 29, 30, and 31 °C at four successive six-hour intervals. With the illustrative reference $T_{\text{ref}} = 29.5^\circ\text{C}$, the calculated cumulative excess is $0 + 0 + 3 + 9 = 12^\circ\text{C h}$. These are not logged sand temperatures; the reference value is used here only to demonstrate the arithmetic. The result does not estimate embryo mortality or sex ratio.

The earlier project reports list mean orientation errors of $8.4^\circ \pm 2.1^\circ$, $138.5^\circ \pm 15.2^\circ$, $34.2^\circ \pm 5.8^\circ$, and $14.1^\circ \pm 3.2^\circ$ for four lighting regimes. Their executive summary instead uses 114.6° as the unshielded baseline. Raw trajectories, sample sizes, the meaning of the $\pm$ values, and comparable test procedures are not supplied. Consequently, those numbers are source-reported and unaudited; no percentage reduction or treatment effect is claimed here.

Future validation would calibrate the instruments, independently review authorised movement trajectories, and test whether optical scores fixed before emergence predict independent orientation outcomes. Complete videos, nights, or sectors should remain in one training or test partition (Roberts et al., 2017). A resulting report should disclose sample sizes, dates, sectors, environmental covariates, missing records, calibration drift, false-alert rates, and insufficient-data behaviour.

6 | LIMITATIONS AND CONCLUSION

This remains a framework and prototype-oriented investigation, not a completed longitudinal field trial. It lacks an audited Odisha-labelled trajectory dataset, a locally calibrated thermal-to-sex-ratio model, and evidence from randomised interventions. Non-nesting sand proxies do not substitute for active-nest temperatures. The first 0–48 hours after emergence is an operational priority window rather than a fixed biological energy reserve.

TurtleGuard separates directional light, spectrum, weather, behaviour, thermal context, data quality, and human operational constraints in an explainable monitoring framework. Students do not handle turtles or instrument active nests. Equipment placement, imagery collection, and data access require prior approval; an automated score does not trigger wildlife or lighting intervention. Future work depends on a screened, governed, life-stage-aligned dataset and authorised validation.

references

Florida Fish and Wildlife Conservation Commission. Sea Turtles and Lights, n.d. URL <https://myfwc.com/wildlifehabitats/wildlife/sea-turtle/lighting/>. Undated official guidance; accessed 26 September 2026.

D. Karnad, K. Isvaran, C. S. Kar, and K. Shanker. Lighting the way: Towards reducing misorientation of olive ridley hatchlings

due to artificial lighting at Rushikulya, India. *Biological Conservation*, 142(10):2083–2088, 2009. doi: 10.1016/j.biocon.2009.04.004. URL <https://doi.org/10.1016/j.biocon.2009.04.004>.

Press Information Bureau. Operation Olivia: ICG protects over 6.98 lakh Olive Ridley Turtles along the Odisha coastline, 2025. URL <https://pib.gov.in/PressReleasePage.aspx?PRID=2129578>. Published 19 May 2025.

D. R. Roberts, V. Bahn, S. Ciuti, M. S. Boyce, J. Elith, G. Guillera-Arroita, S. Hauenstein, J. J. Lahoz-Monfort, B. Schröder, W. Thuiller, D. I. Warton, B. A. Wintle, F. Hartig, and C. F. Dormann. Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. *Ecography*, 40(8):913–929, 2017. doi: 10.1111/ecog.02881. URL <https://doi.org/10.1111/ecog.02881>.

K. Shanker, A. Swaminathan, C. Pusapati, H. Ramesh, R. George, and M. Manoharakrishnan. Monitoring Sea Turtles in India, 2008–2024. Dakshin Foundation, Bengaluru, India, 2024. URL https://dakshin.org/wp-content/uploads/2025/08/Dakshin-Turtle-Report-2024_revised.pdf.

B. E. Witherington and K. A. Bjørndal. Influences of artificial lighting on the seaward orientation of hatchling loggerhead turtles *Caretta caretta*. *Biological Conservation*, 55(2):139–149, 1991a. doi: 10.1016/0006-3207(91)90053-C. URL [https://doi.org/10.1016/0006-3207\(91\)90053-c](https://doi.org/10.1016/0006-3207(91)90053-c).

B. E. Witherington and K. A. Bjørndal. Influences of wavelength and intensity on hatchling sea turtle phototaxis: implications for sea-finding behavior. *Copeia*, 1991(4):1060–1069, 1991b. doi: 10.2307/1446101. URL <https://doi.org/10.2307/1446101>.