

Quantifying the Sim-to-Real Domain Gap in Drone-to-Satellite Wildlife Detection:

Paired Acquisition at Año Nuevo Island, California, March 2026

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Summary

Automated wildlife detection from satellite imagery could transform ecological monitoring, but no study has quantified the domain gap between drone-trained detectors and real satellite data at matched resolution. We present results from a same-day paired acquisition at Año Nuevo Island, California (March 19, 2026): a drone orthomosaic at 2 cm ground sample distance (GSD) processed through Oikonos production pinniped and seabird detectors, paired with a Maxar WorldView Legion scene at 36 cm GSD acquired the same day over the same site. We find that drone-trained detectors applied to synthetically degraded imagery retain partial detection through 36 cm, but the same detectors applied to real satellite imagery at matched resolution produce zero detections. This sim-to-real gap confirms that naive resolution transfer fails and that sensor-aware domain adaptation is required for satellite-scale wildlife census.

Study Site and Acquisition

Año Nuevo Island (37.108°N, 122.338°W) is a 10-acre marine reserve within the UC Natural Reserve System at Año Nuevo State Park supporting breeding colonies of northern elephant seals (*Mirounga angustirostris*), California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina*), Brandt's cormorants (*Urile penicillatus*), western gulls (*Larus occidentalis*), brown pelicans (*Pelecanus occidentalis*), Cassin's auklets (*Ptychoramphus aleuticus*), rhinoceros auklets (*Cerorhinca monocerata*), and black oystercatchers (*Haematopus bachmani*). On March 19, 2026, Oikonos conducted a routine drone survey producing a georeferenced orthomosaic at approximately 2 cm GSD. The same day, a Maxar WorldView Legion scene was acquired at 36 cm GSD (Map-Ready Pansharpened, 0% cloud cover) through the UP42 commercial satellite platform.

Detection Pipeline

The Oikonos production detection pipeline uses Cascade Mask R-CNN for pinniped detection (64.8% recall, 82.9% precision, reproducible within 1% F1 across four model versions) and a separate seabird detector (AP50 approximately 75%). Both models were trained exclusively on drone-resolution imagery (2–3 cm GSD) from the Año Nuevo Spatiotemporal Benchmark, a continuous 2016–2026 drone archive comprising approximately 360,000 pinniped annotations (UCSC Costa Lab, machine-generated via Picterra, systematically validated against 5,000 hand-drawn ground-truth annotations by Oikonos) and approximately 50,000 seabird annotations (Oikonos).

Synthetic Degradation

To simulate satellite-scale imagery, the drone orthomosaic was degraded to target ground sample distances of 10 cm, 30 cm, and 36 cm via area averaging and re-upsampling. This naive downsampling approach does not model atmospheric modulation transfer function (MTF) loss, pansharpening fusion artifacts, sensor-specific noise characteristics, or off-nadir viewing geometry. Developing a sensor-aware degradation pipeline that models these effects and closing the resulting domain gap is the subject of ongoing work under

the SCOPE (Scalable Cross-resolution Observation Pipeline for Ecology) project.

Results

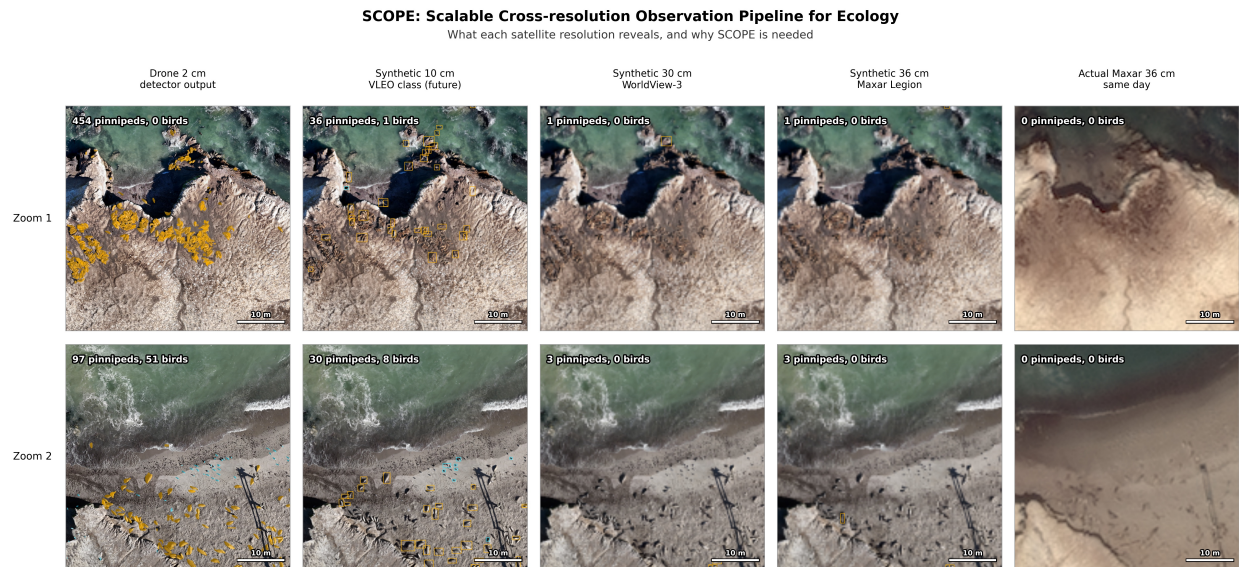


Figure 2. Detection of pinnipeds and seabirds across simulated satellite resolutions at two zoom regions on Año Nuevo Island, California (2026-03-19). Left column: Oikonos drone orthomosaic at 2 cm native resolution with Oikonos pinniped and seabird detector output (orange = pinniped, cyan = bird). Columns 2 through 4: same imagery degraded to target ground sample distance via area averaging and re-upsampled; detector boxes shown in orange and cyan. Column 5: paired Maxar WorldView Legion scene acquired the same day at 36 cm native resolution. Zoom 1 contains 454 detected pinnipeds across a dense haul-out; Zoom 2 contains 97 pinnipeds and 51 birds on a mixed beach. Detector recall collapses beyond 10 cm GSD; the paired real-Maxar scene exhibits additional sensor effects (atmospheric MTF loss, pansharpening artifacts, off-nadir geometry) not captured by synthetic degradation alone. SCOPE (Scalable Cross-resolution Observation Pipeline for Ecology) proposes resolution-native training and sensor-specific degradation modeling to close this gap.

Figure 1. Detection of pinnipeds and seabirds across simulated satellite resolutions at two zoom regions on Año Nuevo Island, California (2026-03-19). Left column: Oikonos drone orthomosaic at 2 cm native resolution with production pinniped (orange) and seabird (cyan) detector output. Columns 2–4: same imagery degraded to target ground sample distance via area averaging and re-upsampled; detector boxes shown in orange and cyan. Column 5: paired Maxar WorldView Legion scene acquired the same day at 36 cm native resolution. Detector recall collapses beyond 10 cm GSD; the paired real-Maxar scene exhibits additional sensor effects (atmospheric MTF loss, pansharpening artifacts, off-nadir geometry) not captured by synthetic degradation alone.

At drone resolution, the detector identifies 454 pinnipeds and 51 birds across the two zoom regions. Detections decline progressively through synthetic degradation and collapse to zero on real satellite imagery at matched resolution. This is the sim-to-real domain gap: naive downsampling retains partial detection where real satellite data produces none. The sensor-specific characteristics described above are not captured by synthetic degradation, and closing this gap is what makes satellite-scale wildlife detection possible.

Significance

Manual satellite census has been demonstrated for emperor penguins (LaRue et al. 2024, *Proc. Royal Society B*), Weddell seals (LaRue et al. 2021, *Science Advances*), and albatross (Dolliver 2019), but each required years of expert effort for a single taxon. Automating detection from satellite imagery is the critical step toward scalable, continuous wildlife monitoring. Our result shows that the path from drone-scale ML to satellite-scale detection cannot rely on naive resolution transfer. Sensor-aware degradation modeling, domain-adaptive training, and paired drone-satellite validation are required. The SCOPE project is designed to close this gap through sensor-aware degradation modeling, resolution-native training at both drone and satellite scales, and an open benchmark for cross-resolution ecological computer vision.

Acknowledgments

Drone imagery was collected under Oikonos - Ecosystem Knowledge operations at Año Nuevo Island within the UC Natural Reserve System. Satellite imagery acquired through UP42 (Maxar WorldView Legion, Map-Ready Pansharpened). The pinniped annotation dataset was contributed by the UCSC Costa Lab (Dr. Rachel Holser, Dr. Daniel Costa) through an ongoing research partnership. The seabird annotation dataset and hand-drawn pinniped ground-truth

set were produced by Oikonos. We thank Dr. Michelle LaRue (University of Canterbury) for methodological guidance on satellite-based wildlife detection and Michelle Hester (Oikonos) for project support.

Data and Code Availability

The detection pipeline and annotation tools (AniNet) will be released as open-source software on GitHub under Apache 2.0 license. The Año Nuevo Spatiotemporal Benchmark, including pretrained detection models and annotations, will be released on Zenodo and HuggingFace under CC-BY 4.0 and OpenRAIL licenses. Drone imagery is openly shared by the UC Natural Reserve System.

References

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