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Enhancing Arctic Resilience through Citizen Science and AI-based Mapping for Marine Pollution Control

Apostolos Papakonstantinou[a,b,*], Victor Lion[c], Arnab Muhuri[c], Élise Lépy[d], Thora Herrmann[d], Natascha Oppelt[c]

[a] Civil Engineering & Geomatics Dpt., Cyprus University of Technology, [b] SciDrones PC Spin-Off, Greece, Apostolos Papakonstantinou - a.papakonstantinou@cut.ac.cy
[c] Kiel University, Department of Geography, Germany, Victor Lion - lion@geographie.uni-kiel.de, Arnab Muhuri - muhuri@geographie.uni-kiel.de, Natascha Oppelt - oppelt@geographie.uni-kiel.de
[d] University of Oulu, Faculty of Humanities, Finland, Élise Lépy - elise.lepy@oulu.fi, Thora Herrmann - thora.herrmann@oulu.fi

* Corresponding author

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Abstract:

The escalating presence of marine litter (ML) is a critical global concern that profoundly impacts marine ecosystems, coastal economies, and local communities. Reliable monitoring and mapping of marine litter accumulation along Arctic coastlines is particularly challenging because many shorelines are remote, logistically demanding, and only intermittently observed. To bridge these data gaps, the ICEBERG project—funded under Horizon Europe—is developing an integrated monitoring framework tailored for data-sparse Arctic regions. This development aligns with the objective to improve scientific understanding of pollution sources and distributions while supporting pollution-control governance in the context of climate change.

The integrated mapping framework is specifically designed to map and monitor marine litter pollution by merging data sources—including time-lapse cameras, drones, and Citizen Science—to co-design local pollution-control strategies and governance. While the project encompasses three primary case study sites—western Svalbard, southern Greenland, and northern Iceland—recent efforts focus heavily on the north-eastern coast of Iceland. This study area extends from the Eyjafjörður region and Akureyri, moving past Húsavík to Raufarhöfn at the country's north-eastern tip. The environmental conditions in this region present unique challenges for cartographic data acquisition and machine learning model reliability: a) Dynamic Environmental Constraints: The area is defined by extreme seasonal shifts, ranging from near-continuous summer daylight to limited winter light, frequently accompanied by snow, ice, and strong winds. b) Geographical Diversity: The coastline transitions from sheltered fjords to exposed areas influenced by the North Atlantic, featuring long, wide black sandy beaches, rocky shores, and cliffs. c) Biological and Vegetative Complexity: The supratidal zones are often covered with Arctic lupines (Lupinus arcticus), reed beds, and grass, while both beach and cliff environments serve as critical breeding grounds for seabirds like Arctic terns.

The proposed mapping framework revolutionizes traditional, labor-intensive in situ campaigns by combining state-of-the-art GeoAI with diverse data streams. It integrates time-lapse cameras for temporally continuous observations at fixed coastal sites with UAV surveys that provide broader spatial coverage through intermittent acquisitions. Together, these complementary data sources are used within a machine-learning-based object-detection model to support scalable, comparable litter assessment across sites. A cornerstone of this framework is the Coastal Marine Litter Observatory (CMLO), which automates the detection and classification of beach macrolitter through deep learning algorithms. The CMLO pipeline utilizes very high-resolution drone data and a citizen science-based acquisition protocol designed for non-experienced pilots using consumer-grade UAS. Once data is uploaded, the system automatically checks metadata and uses a specially trained algorithm to detect and classify marine litter into seven categories according to OSPAR guidelines. This automated mapping process can process a 500m beach in less than 20 minutes, producing harmonized density maps and geovisualizations that provide a scalable, objective alternative to manual monitoring.

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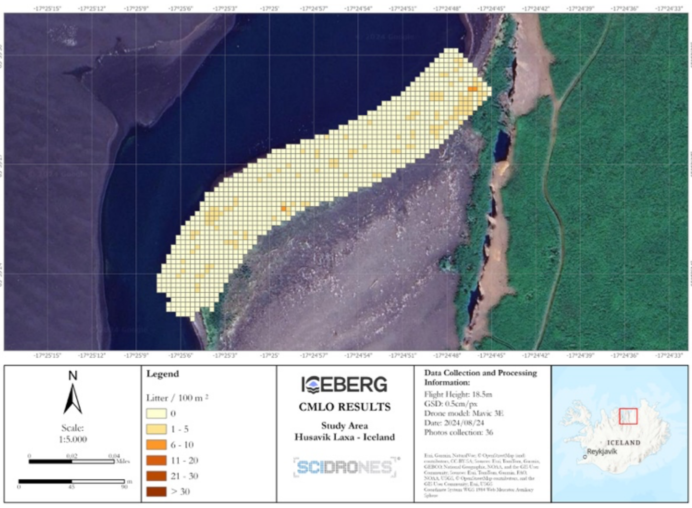

Figure 1. Marine Litter Density map from Laxa Beach Húsavík area.

By linking drone remote sensing, laboratory simulations, and local community-led monitoring, the framework improves workflow transferability and harmonizes monitoring practices. Ultimately, this approach strengthens community resilience and provides locally actionable evidence for long-term coastal assessment and Arctic Ocean pollution-control planning based on spatiotemporal mapping. This integrated mapping approach provides a scalable, objective alternative to manual monitoring, empowering local communities to maintain and refine their own pollution-control efforts. This mapping strategy supports robust near-real-time monitoring and mapping of marine pollution, facilitating standardized data collection and harmonized results to drive efforts and actions crucial to supporting SDG 14.1.1 and EU-MSFD D10C1 indicators. Furthermore, it provides locally actionable evidence for long-term Arctic Ocean pollution-control governance.

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