

AQUA-QUANT: Hybrid Neutral-Atom Quantum Optimization and Deep Learning for Marine Habitat Protection

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Abstract: AQUA-QUANT, a top-15 finalist in the Blaise Pascal Quantum Challenge 2025, is a hybrid quantum-AI framework for coral reef conservation. It combines Pasqal's neutral-atom quantum optimisation with deep learning to optimise marine habitat protection strategies.

Marine ecosystems face unprecedented degradation: coral reefs, despite covering less than 1% of the ocean floor, support roughly 25% of marine biodiversity and have suffered an estimated 50% decline in cover since 1950 [1]. Addressing this crisis demands novel computational approaches for ecological monitoring and large-scale conservation planning. We designed AQUA-QUANT within the Blaise Pascal Quantum Challenge 2025 [2], a global hackathon organised by Pasqal combining quantum computing and AI for sustainable innovation. The framework is currently at architectural-design stage; no component has been validated on real marine data. Our interdisciplinary team was selected among 15 finalists from 137 submitted projects in a rigorous multi-stage review by an international jury. The project targets SDG 13 (Climate Action) and SDG 14 (Life Below Water).

AQUA-QUANT integrates two core components and identifies a third for future development. First, a deep learning pipeline based on convolutional neural networks processes underwater imagery and IoT sensor data (sea-surface temperature, dissolved oxygen, pH) to detect early signs of coral bleaching [3]. Second, a quantum optimisation module formulates the spatial resource-allocation problem as a Quadratic Unconstrained Binary Optimisation (QUBO) instance: binary decision variables encode whether each candidate reef sector receives a conservation intervention (coral transplanting, larval seeding, or shading structures), while coupling terms capture spatial adjacency constraints and ecological synergies. The Rydberg blockade mechanism intrinsic to neutral-atom platforms provides a hardware-native encoding that replaces explicit penalty terms for unit-disk-graph-structured problems, though careful parameter tuning and classical post-processing remain necessary [4,5]. As a planned extension, a quantum-enhanced kernel method based on the Quantum Evolution Kernel (QEK) [6] would map coral-health graph representations into a high-dimensional Hilbert space via parameterised pulse sequences, potentially improving bleaching-signature detection over classical feature extraction.

Our QUBO formulation targets near-term neutral-atom hardware. Notably, such platforms offer a sustainability advantage: neutral-atom QPUs operate at room temperature with a reported power consumption of approximately 3 kW, compared to the tens of kilowatts typical of classical HPC rack-level deployments, suggesting a significant energy reduction that remains to be validated at application scale [7]. Future work will focus on benchmarking against classical solvers on real marine protected-area instances and extending the quantum-enhanced kernel pipeline to multi-temporal satellite imagery.

References

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