PhD CANDIDATE:

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PROJECT TITLE

Ecological Effects of Fish Farms and FADs in a Hotspot of Change: A Mediterranean Case Study

SCIENTIFIC BACKGROUND

Due to the growing demand for fish, the use of Fish Farms (FFs) and Fish Aggregating Devices (FADs) increased in the last years worldwide [1,2]. However, these installations raise ecological concerns as they may alter trophic dynamics and ecosystem food webs in the areas where they are deployed [3]. For instance, aggregation around FFs and FADs may influence predator foraging strategies [4] lead to behavioural and dietary shifts, even in top predators like the common bottlenose dolphin, *Tursiops truncatus* (BD) [5].
These ecological alterations can lead to habitat degradation, reduced resilience of native communities, and increased dependence on anthropogenic structures, ultimately threatening biodiversity [6]. Additionally, FFs and FADs may pose entanglement, disturbance, and injury risks to vulnerable species attracted to them, raising further conservation concern, while some wild species may damage human structures or affect their functioning [7].
Historically, research on these structures relied on visual census, which has limitations related to visibility, observer bias, and restricted spatio-temporal coverage [4]. New approaches - such as environmental DNA metabarcoding (eDNA) and Passive Acoustic Monitoring (PAM) - are emerging as powerful non -invasive tools to survey marine biodiversity and detect community changes near these structures [8,9].
eDNA is, nowadays, an acknowledged approach to assess biodiversity, including the presence of cryptic or elusive taxa [10]. PAM uses hydrophones to record underwater sounds, capturing vocalisations and ambient noise to monitor the presence and behaviour of soniferous species over time, and to assess the overall acoustic environment (soundscape, i.e. the total acoustic energy in an area, shaped by biological, geological, and human sources of an area [11]. While eDNA reveals which species are present, PAM provides insights into their behaviour and activity through acoustic cues, making their integration high-potential option to improve knowledge on the ecological impacts of FFs and FADs.
Malta offers an ideal setting due to its island geography, which creates a relatively confined and well-defined marine environment, facilitating targeted ecological monitoring [12]. In addition, long-standing regulations for both FFs and FAD fisheries offer a stable context for investigation.

AIMS AND METHODOLOGY

This PhD project aims to investigate the ecological impacts of FFs and FADs by combining PAM and eDNA metabarcoding in the Mediterranean waters around Malta. The project will:

1) assess biodiversity and community structure associated with such facilities;
2) characterise their soundscape;
3) use the BD as a model species to understand potential impacts on sensitive species.

To achieve this, the project will:

- develop and deploy an experimental "scientific" FAD equipped with eDNA and PAM sensors;
- Monitor biodiversity and soundscapes at three sites: the scientific FAD (Karraba Bay), a FF (St. Paul's Bay), and a control site (CS) without structures (Salina Bay);

- Develop Artificial Intelligence (AI) tools to simplify soundscape analysis (in collaboration with University of Malta's AI department, ECHO AI project).

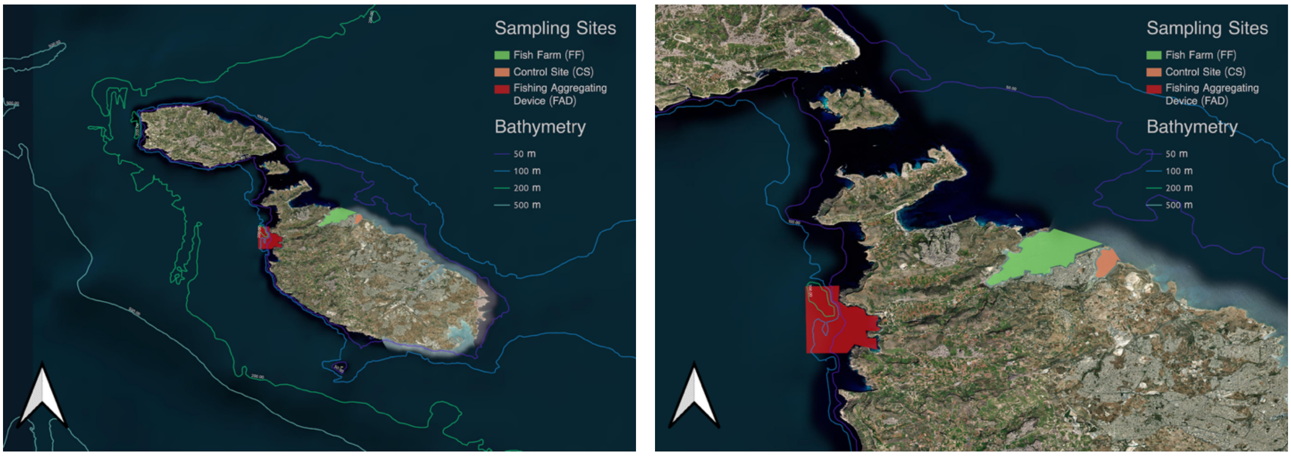


Figure 1: Sampling areas – Fish Farm in Saint Paul's Bay, FAD in Karraba Bay, Control in Salina Bay

This integrated and simultaneous approach will provide a fuller picture of marine ecosystems dynamics: eDNA reveals species presence and potential community dynamics, PAM detects acoustic patterns, allowing (for species such as BD) to infer activity and behaviour. Together, they offer complementary insights into the impacts of human-made structures on biodiversity and ecological processes.

The following hypotheses will be tested:

1) Biodiversity composition and community structure differ significantly across the sites (FADs, FFs, and CS), due to the influence of artificial marine structures;
2) Soundscape characteristics vary across sites, reflecting differences in biological activity and anthropogenic noise linked to the presence/absence of human infrastructures;
3) Target species presence and acoustic activity follow identifiable temporal patterns, potentially driven by diel, lunar, or seasonal cycles.

Sampling will be performed using a custom-built probe able of simultaneously collecting:

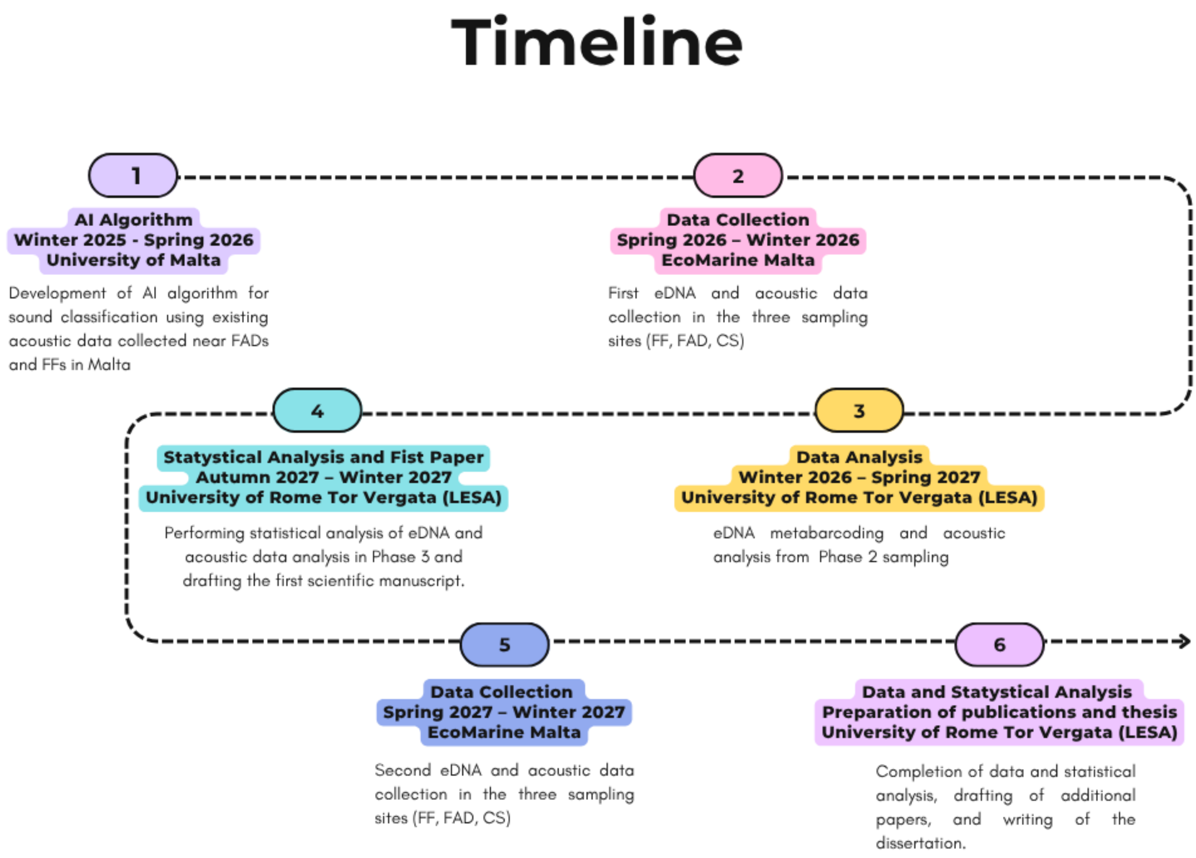
- eDNA samples, through the "metaprobes" [8];
- Underwater acoustic data, via integrated hydrophones.

Analytical methods will include:

- Metabarcoding analysis of eDNA using mitochondrial COI and 12S rRNA markers to identify community composition. These analyses will be carried out at the University of Rome Tor Vergata, with proven expertise and publications in marine eDNA metabarcoding [8,13,14].
- Soundscape analysis using Raven Pro software, for characterizing the acoustic environment and identifying biological/anthropogenic sources, under the CoNISMa (https://www.conisma.it/en/) agreement;
- AI-assisted analysis of acoustic data to improve detection efficiency and streamline processing, in collaboration with the University of Malta which has signed a formal commitment in this regard.

Scientific partner of the project, EcoMarine Malta (https://www.ecomarinemalta.com.mt/) and the University of Malta, will support logistics and part of data collection/analysis for at least 6 months.

The following charts summarize the timeline of the project, and outline eventual problems and possible solutions.



PROBLEM & SOLUTION TABLE

Problem	Description	Solution
Integration challenges between PAM and eDNA systems	Technical difficulties in integrating PAM and eDNA systems without compromising data quality, due to differences in sampling protocols, timing, and environmental requirements.	Conduct iterative prototyping and extensive lab/field testing.
Environmental and operational constraints during deployment	Challenges related to weather conditions, sea state, and logistical limitations that impacted the efficiency and consistency of marine data collection during fieldwork.	Refine deployment protocols using operational insights from other projects. Enhance mounting systems and platform durability.
Delays in sample collection and analysis	Delays in the collection of eDNA and PAM samples, or in laboratory analyses, caused by adverse weather, equipment availability, or logistical constraints, resulting in a potential shift in the project timeline.	Flexible scheduling, backup sampling days, and prioritised lab workflows to minimise timeline disruptions.
Risk of platform damage or removal by fishers	Possible damage or unauthorized removal of the monitoring platform due to misidentification or lack of trust by local fishers.	Leverage established relationships with fishers from other projects from EcoMarine Malta. Reinforce engagement via workshops and co-design activities.

Problem	Description	Solution
Data synchronisation or integration failures between PAM and eDNA systems.	Failures in synchronising or integrating PAM and eDNA datasets due to differing temporal and spatial resolution or metadata formats.	Develop robust data integration protocols. Conduct time-synchronised pilot tests.
Battery limitations for long-term deployment	Insufficient battery capacity reducing the duration of autonomous PAM system operations in the field.	Conduct power stress-testing under simulated conditions, use energy-efficient components and explore external power solutions such as scheduled battery replacement.
Permitting and regulatory delays	Delays in obtaining necessary permits for offshore deployment due to complex regulatory procedures.	Initiate early dialogue with regulatory bodies. Leverage previous EcoMarine permits for other projects permits and institutional relations for faster approval.
Weather-related deployment interruptions	Adverse sea and weather conditions causing delays or interruptions in offshore operations.	Plan deployments Using weather forecasting tools and with flexible field windows.

Bibliography

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Note: For the full list of references in APA format, please refer to **Annex 1**.