REMEDIES: Co-Creating a Plastic Litter Free Future

DELIVERABLE: D1.4

TITLE: BUOYS WITH GPS

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Abbreviations

Acronym	**Title**
AIS	Automatic Identification System
GPS	Global Positioning System
IPX7	Waterproofing standard
LDPE	Low-Density Polyethylene
UV	Ultraviolet
WP5	Work Package 5
UNEP	United Nations Environment Programme
PLOS	Public Library of Science
ID	Identifier
URL	Uniform Resource Locator
TV	Television

Executive Summary

This project undertook the large-scale deployment of 200 GPS-tracked floating devices (buoys) across the Aegean Sea, including key river mouths in Northern Greece, to monitor the drift and accumulation patterns of floating litter—primarily plastics. The overarching goal was to identify marine litter hotspots and better understand the seasonal and spatial dynamics that drive their formation.

Deployments were conducted across all major sectors of the Aegean, from northern inflow points to southern exit corridors, and were strategically timed to account for seasonal weather patterns such as the Etesian winds (meltemia) in summer and variable southerlies in winter. The research also considered the geomorphology of islands and straits, which significantly affects floating litter retention and redirection.

The project placed strong emphasis on citizen participation, with over 100 individuals contributing—from local volunteers and fishermen to representatives of municipalities, ministries, and national media. Public involvement was key not only in the retrieval and reporting of devices, but also in raising awareness about the issue of marine plastic pollution.

Key findings include:

- Confirmation that seasonality and wind direction play critical roles in floating litter transport.
- Identification of natural retention zones, especially near island clusters and narrow straits (e.g., Kavo Doro, Mykonos–Ikaria corridor)
- Demonstration that northern Aegean rivers can act both as sources and traps for plastic, depending on flow intensity and vegetation.
- Recognition that no fixed hotspots exist year-round; rather, dynamic conditions shape where and when pollution accumulates.
- Mapping of key accumulation areas, such as Chania (Crete), Oinousses, Kea, and northern Cycladic coasts.

The outcomes of this project form a scientific basis for future interventions aimed at reducing plastic pollution, including preventive policies, targeted cleanup efforts, and cross-sectoral collaborations across the Aegean region and beyond.

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1. Introduction

Marine plastic pollution represents a pressing environmental issue of the 21st century, particularly in semi-enclosed basins such as the Mediterranean Sea. These regions are especially vulnerable due to their limited water exchange, high coastal population densities, and intense maritime activity (Cózar et al., 2015; Suaria et al., 2016). Within this context, the Aegean Sea is considered a hotspot for the accumulation and retention of floating litter. Its complex geomorphology, stratified hydrodynamics, and seasonal wind patterns—such as the northern Etesian winds (Meltemia)—facilitate the trapping and prolonged residence of plastic waste (Liubartseva et al., 2018; Ioakeimidis et al., 2020).

Scientific studies have identified rivers as major conduits for plastic waste transfer from terrestrial to marine environments, with over 80% of marine litter originating from land-based sources (UNEP, 2014; Jambeck et al., 2015). The northern Aegean, receiving inputs from rivers such as Axios, Strymonas, Aliakmonas, and Evros, functions as a primary entry point for such pollutants. Moreover, the interplay between Black Sea outflow, local wind regimes, and intricate island formations enhances litter retention and leads to the formation of plastic "hotspots" (Cózar et al., 2015; Politikos et al., 2017).

Given the dynamic and spatially heterogeneous nature of plastic distribution in the marine environment, there is an urgent need for high-resolution, temporally explicit monitoring tools that can capture the movement and accumulation of floating waste. Conventional sampling methods (e.g., net tows, visual surveys) provide only snapshot data and are often inadequate for tracking long-range dispersal or identifying source-to-sink pathways.

To address this limitation, the REMEDIES project introduces an innovative methodology combining low-cost, eco-designed buoys equipped with GPS tracking devices. These buoys simulate the behavior of floating plastic waste and allow for the continuous monitoring of their drift trajectories across different marine regions and seasons.

This deliverable (D1.4) presents the design, deployment, and preliminary analysis of GPS-enabled buoys launched across the Aegean Sea and major river outflows. The study aims to (i) map plastic transport pathways, (ii) identify accumulation zones, and (iii) explore seasonal and spatial variability in plastic movement. The approach integrates geospatial data with environmental forcing (e.g., wind, currents) and engages local communities for buoy recovery and awareness campaigns, thereby bridging technological innovation with citizen science and circular economy principles.

The structure of the present deliverable is described in the following Chapters:

● Chapter 1 – Introduction
Provides the scientific background of marine plastic pollution in the Aegean Sea, underscoring the limitations of conventional monitoring approaches. It introduces the use of GPS-tracked buoys as a novel method to map plastic drift, identify accumulation zones, and promote citizen engagement in environmental observation.

● Chapter 2 – Movement of Plastics & Microplastics: Emphasis on the Aegean
Explores the interplay of physical oceanography, wind systems, geomorphology, and anthropogenic pressures shaping the transport of plastic litter in the Aegean Sea. It synthesizes prior research and in-situ observations to highlight key mechanisms and temporal variability in plastic accumulation.

● Chapter 3 – Location Description
Details the rationale behind selecting specific monitoring locations—including river mouths, straits, and island regions—and describes their hydrodynamic, ecological, and topographic characteristics that influence plastic retention and dispersal.

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● Chapter 4 – Technology Description and Preliminary Testing
Describes the design, materials, and testing of the GPS-enabled buoys used in the study. It includes comparative assessments of wooden and plastic casings, evaluations of GPS performance, and integration with the REMEDIES digital portal.

● Chapter 5 – Activities (Round 1)
Outlines the initial deployment phase of buoys across river systems and key maritime corridors during peak seasonal conditions. The chapter reports on buoy behaviour, drift trajectories, citizen-supported deployments, and data acquisition challenges.

● Chapter 6 – Activities (Round 2)
Presents the second phase of deployments, emphasizing methodological refinements, new geographic areas, and enhanced GPS technology. It demonstrates the evolution of the tracking strategy based on insights gained from earlier trials.

● Chapter 7 – Research and Findings
Synthesizes data from both deployment rounds to identify plastic transport patterns, accumulation hotspots, and key source-to-sink pathways. It includes river-specific analyses, seasonal comparisons, and regional case studies of floating litter behaviour.

● Chapter 8 – Public Engagement and Awareness
Highlights the integration of citizen science in the REMEDIES project, including community-driven recovery of GPS buoys, educational initiatives, and media outreach. The chapter emphasizes the role of public awareness in enhancing environmental stewardship and data reliability.

● Chapter 9 – Conclusion Summary
Summarizes the main outcomes of the project, reaffirming the effectiveness of GPS-based monitoring for marine litter tracking. It distils key scientific insights, outlines the broader implications for policy and management, and suggests directions for future research and replication across the Mediterranean and beyond.

2. Movement of Plastics – Emphasis on the Aegean

In order to better understand the movement of marine floating litter, it is essential to first identify their sources, the factors influencing their motion, and the variables involved.

Within this framework, we examine how plastics are transported and accumulated in the Mediterranean—and specifically in the Aegean Sea, based on scientific studies. The analysis focuses on the main transport factors, seasonal variations, concentration "hotspots," and presents maps/data that document the trajectories of waste and the most vulnerable areas.

The primary factors of marine litter transport in Greek waters include ocean currents, seasonal wind patterns—particularly the Etesian winds (Meltemia)—the complex coastal and insular geomorphology, riverine discharges, and land-based anthropogenic activities along the coastline. These factors will be further analyzed in the following sections, with emphasis on their individual and combined influence on the transport and accumulation of marine litter in the Aegean Sea.

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2.1 Marine Currents

Ocean currents constitute the primary mechanism for the horizontal transport of floating plastics. Litter entering the sea (either from land-based sources or from vessels) is carried by surface currents and influenced by wave action, often traversing long and complex routes before ending up in accumulation zones (van Sebille et al., 2020). In the Aegean Sea, the general surface circulation is highly intricate, being affected by geomorphological features (such as archipelagos and irregular coastlines) and the exchange of water with adjacent basins (Politikos et al., 2017; Nittis et al., 2003). Surface currents enter the southern Aegean via the straits of Crete and Rhodes (from the Levant), move northward along the western Turkish coast, and merge with the lighter waters of the Black Sea, which enter through the Dardanelles into the northern Aegean (Olson et al., 2007). The less saline waters from the Black Sea flow as a surface lens into the northern Aegean, generating a cyclonic (or anticyclonic) circulation cell that gradually mixes with the denser Mediterranean waters (Zodiatis et al., 2017). This system of cyclonic and anticyclonic dynamics, which varies spatially and temporally, contributes to the trapping of litter in certain areas. For example, models indicate that the northern Aegean (the Limnos plateau) acts as an accumulation basin as a result of these circulation characteristics (Politikos et al., 2017; Cózar et al., 2015). During MCG's research, many of the aforementioned aspects concerning marine currents were confirmed by the devices deployed as part of the REMEDIES project. These devices tracked the movement of floating litter in both the eastern and western Aegean, following the general current patterns reported in the international literature and as further illustrated in *Figure 1*.

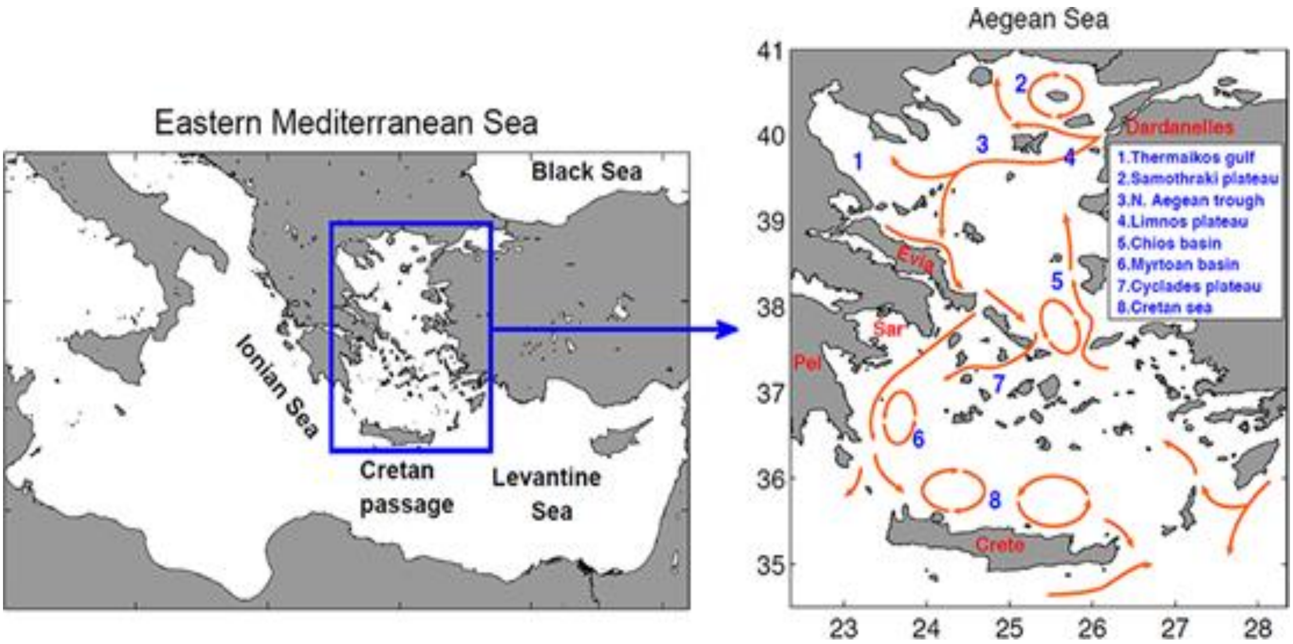

Figure 1. *Map of the Aegean Sea. Numbers 1 to 8 denote major basins, gulfs and plateaus, and abbreviations indicate place names: Peloponnese (Pel), Saronic Gulf (Sar), Evia Island, Dardanelles Strait, and Crete. (Map adapted from Nittis and Perivoliotis, 2002; Nittis et al., 2003; Olson et al., 2007)*

In Figure 2, one can observe the upward trajectory followed by the devices deployed in the eastern Aegean from south to north, whereas, in contrast, in the western Aegean in the Kavo dóro area, the devices are observed moving from north to south, heading toward the western Mediterranean or Crete. In the northern Aegean, currents driven by the influx of Black Sea water push floating litter toward the northern coasts—a process that will be discussed further below. However, as the photograph suggests, the movement of these devices is not as straightforward as it appears; the actual trajectory of the litter (in our case, GPS-tracked devices) is also influenced by additional factors discussed in the following sections.

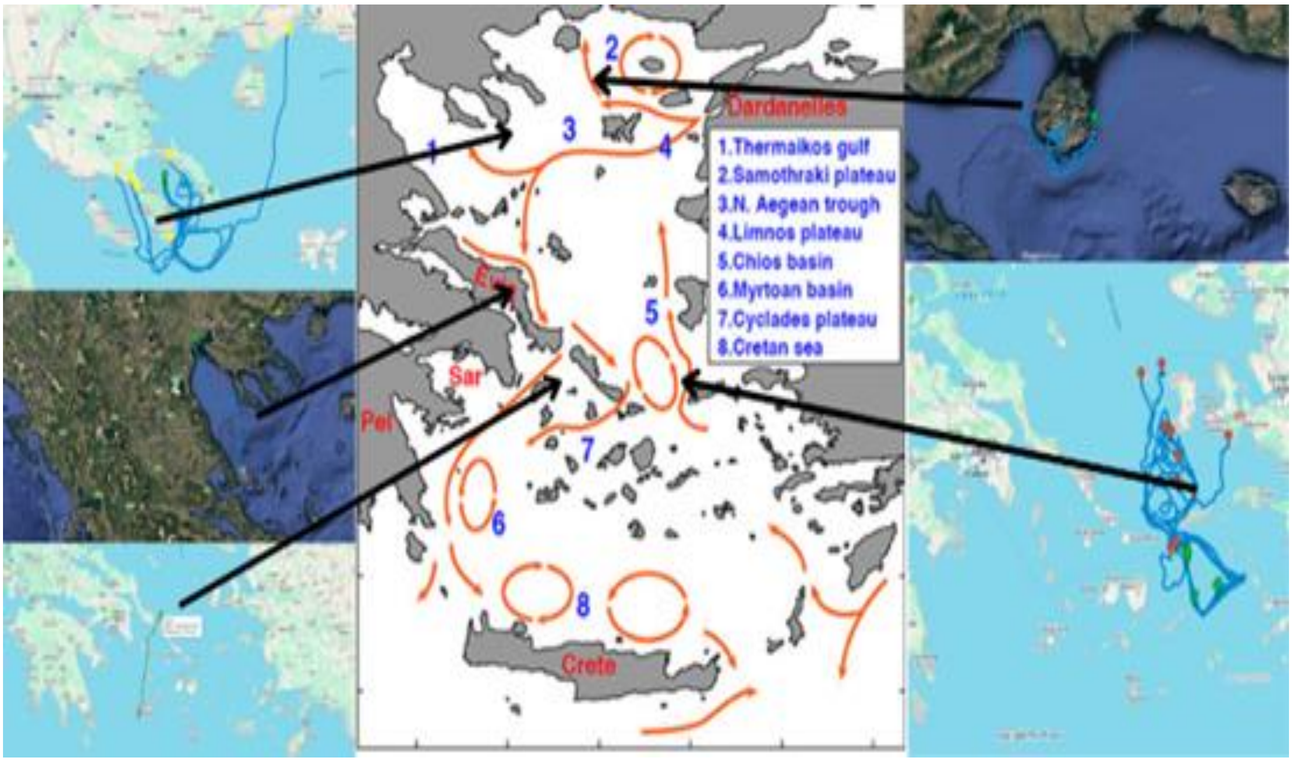

Figure 2. Prevailing Current Patterns in the Aegean Sea – Updated Based on Field Observations (Source: MCG)

2.2 Winds (Meltemia) & Wave Action

Another critical driver of plastic transport in the Aegean is wind forcing, which modulates surface currents through the Ekman drift mechanism (Figure 3). This phenomenon arises from the interaction of wind stress with the Coriolis force, causing surface waters—and the floating litter they carry—to be deflected at an angle relative to the wind direction (Gill, 1982; Cushman-Roisin and Beckers, 2011).

The Coriolis force is an apparent force that emerges in rotating reference frames such as the Earth. It acts perpendicular to the direction of motion and the axis of rotation, leading to a deflection of moving objects: to the right in the Northern Hemisphere and to the left in the Southern Hemisphere (Ekman, 1905; Pond and Pickard, 1983). Although it is not a physical force in the traditional sense, it is essential for accurately describing large-scale geophysical flows, including ocean currents and atmospheric winds.

As this deflection continues with depth, the current's velocity decreases and its direction shifts further, forming the so-called Ekman spiral. The vertical extent influenced by the wind is known as the Ekman layer, within which the net movement of water—called Ekman transport—is oriented approximately 90° to the wind direction (to the right in the Northern Hemisphere). This mechanism plays a vital role in shaping the drift and accumulation patterns of marine litter, especially under persistent wind systems such as the northerly Meltemia in the Aegean Sea.

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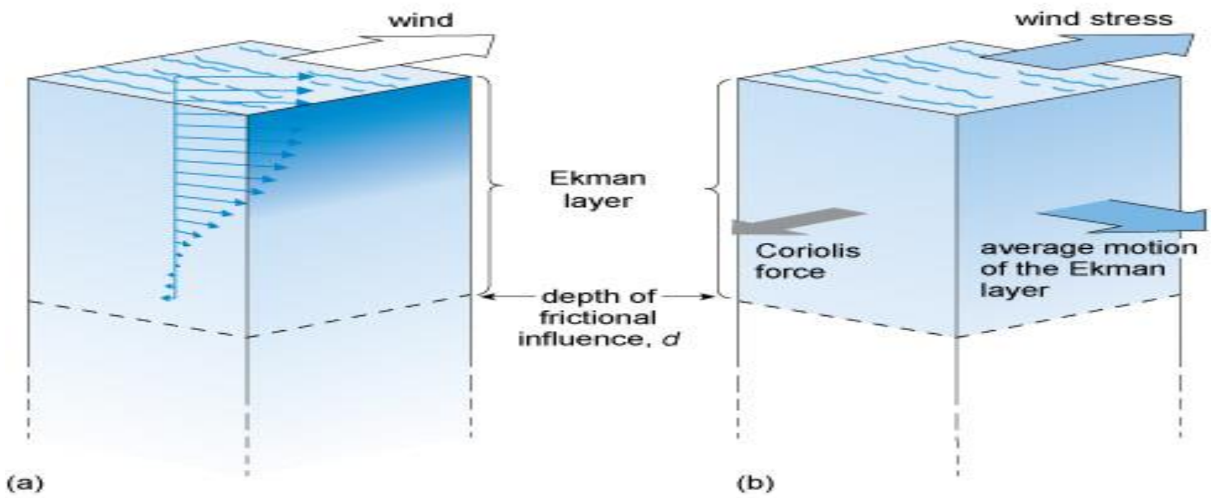

Figure 3. (a) The Ekman spiral pattern under ideal conditions in the Northern Hemisphere. Each successive water layer is deflected to the right, with arrow lengths corresponding to the strength and direction of the current. (b) The complete Ekman layer. The wind force is balanced by the Coriolis force. In the Southern Hemisphere, the spiral and average motion are reversed.

During the summer months in the Aegean Sea, strong northerly Meltemi winds exert a significant influence on the distribution of floating plastic litter. These persistent wind systems often push surplus plastics southward, temporarily clearing northern coastal areas from surface litter (Politikos et al., 2017; Zeri et al., 2018). Beyond their directional effect, wind and wave action contribute to the formation of slicks or windrows—elongated surface streaks composed of foam, organic material, and floating litter aligned parallel to the prevailing wind.

Field studies in the Aegean and Ionian Seas have shown that these windrows act as microplastic concentration zones. Sampling efforts have consistently recorded the highest microplastic densities within these structures compared to adjacent open waters (Zeri et al., 2020; Ruiz et al., 2022). Even under relatively mild storm conditions, floating microplastics are aggregated into these narrow, linear features, resulting in locally elevated concentrations that may persist for several days.

For example, during a device deployment carried out under the REMEDIES program in July–August 2023, when Meltemia were strong, intense northerly winds propelled the devices deployed in the eastern Aegean in a southeasterly direction toward the basin of Egypt–Israel–Cyprus. One of the devices (from Israel) travelled up to 1800 km in two months (Figure 4 and Figure 5), in contrast to devices deployed at the same location in early 2024 (March), which followed an upward course toward the northern Aegean, albeit covering smaller distances due to the absence of Meltemia and the prevalence of gentler southerly winds.

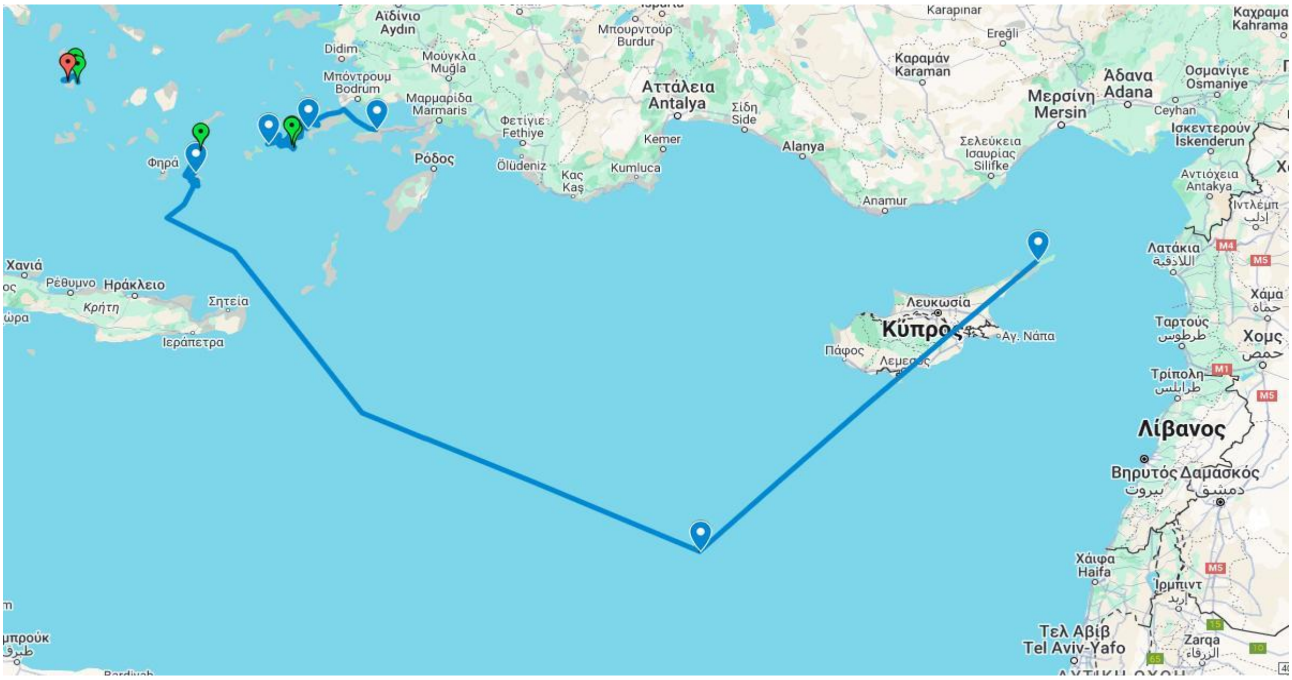

Figure 4. Movement of buoys during Summer Months June - July- August (Dodecanese region). (Source: MCG)

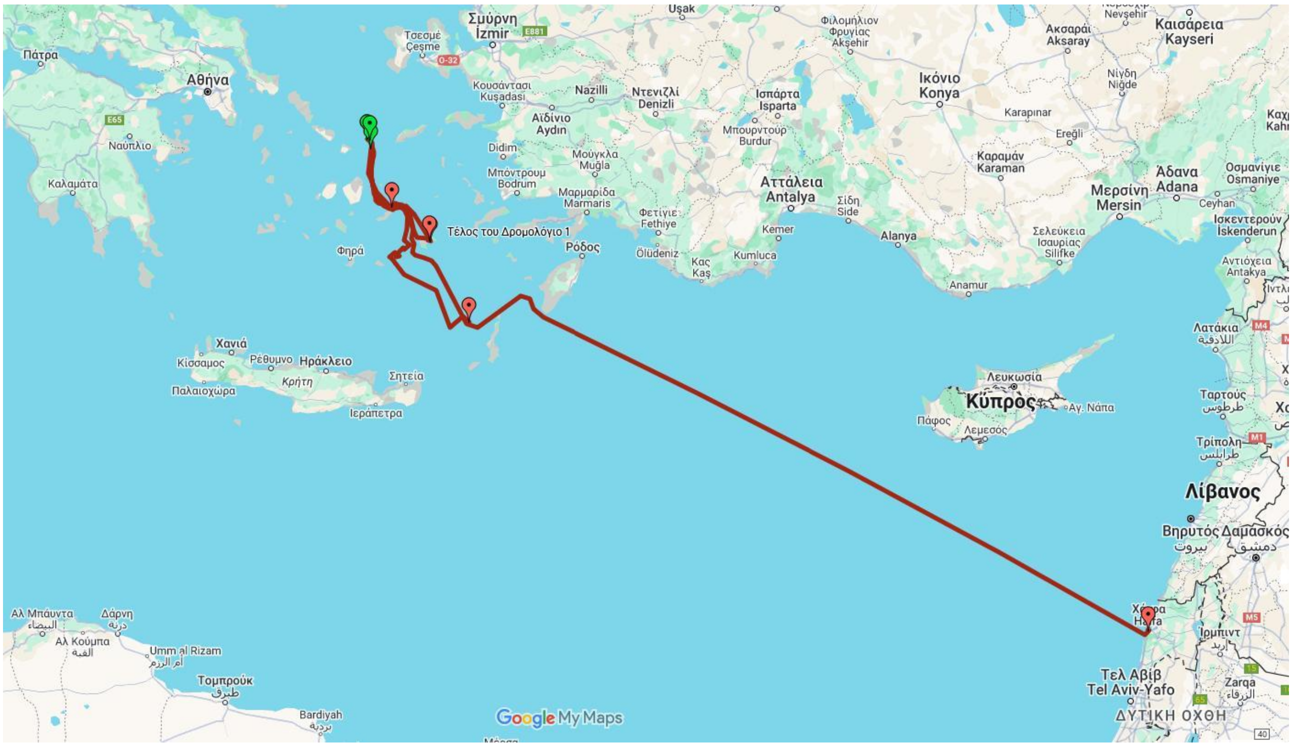

Figure 5. Movement of buoys during Summer Months June - July- August (Central Aegean region). (Source: MCG)

2.3 Geomorphology & Hydrodynamics

Another crucial factor influencing the movement and accumulation of marine floating litter in the Aegean is its geomorphology. The Mediterranean Sea, being a semi-enclosed basin, exhibits restricted water exchange with the Atlantic Ocean—limited to the Strait of Gibraltar—and is therefore prone to the retention of floating plastics (Suaria et al., 2016; Cózar et al., 2015). While the primary surface outflow consists of less saline waters directed westward, excess plastic litter tends to remain trapped due to the fact that the Mediterranean's outflow is derived primarily from deeper layers.

The Aegean Sea, in particular, presents a highly fragmented topography, with numerous islands (e.g., Cyclades, Dodecanese), semi-enclosed gulfs (e.g., the Saronic Gulf), and narrow straits. This complexity creates natural retention zones for floating litter. Narrow channels, curved coastlines, and small-scale gyres enhance the entrapment and deposition of plastics along the shoreline and the seafloor (Politikos et al., 2017; Ioakeimidis et al., 2020). Numerical simulations and field data have shown that significant quantities of floating litter accumulate along the western Greek mainland (e.g., Pelion, Pagasitikos Gulf) and on Cycladic islands, primarily due to this combined influence of geomorphology and regional currents.

In some cases, deep-sea depressions and submarine canyons may also act as microplastic sinks, particularly where current velocities are reduced, allowing particles to settle. For example, sediment surveys in the Tyrrhenian Sea revealed record-breaking microplastic concentrations exceeding 1.9 million particles per m^2 in deep accumulation zones (Pierdomenico et al., 2019). In contrast, regions with stronger bottom currents tend to exhibit lower seafloor plastic densities due to continuous resuspension and transport.

The interplay between geomorphology, currents, and wind forcing is therefore critical in determining the fate of floating litter. Even minor shifts in environmental parameters can lead to markedly different outcomes. For instance, two GPS buoys deployed in the Kavo Doro Strait (Figure 6) under near-identical conditions exhibited divergent drift patterns: one was entrapped near Kea Island due to local eddies, while the other was transported westward by the prevailing current. This example highlights how small variations in local forcing can interact with topography to create differential retention zones.

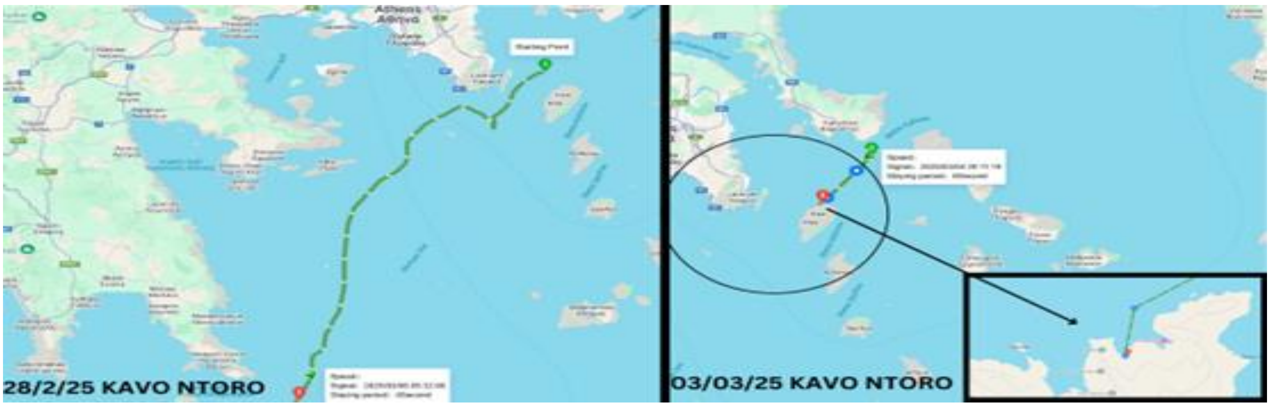

Figure 6. Wind and current influence on devices. (Source: MCG)

In addition to the factors affecting litter movement, it is important to consider the variables that determine their quantitative levels and periodicity. These variables include anthropogenic activities that dictate the geographic distribution of plastics (which is strongly influenced by where they are produced or enter the environment) and seasonal variations, since the dispersal of plastics is not constant throughout the year due to changes in meteorological and hydrological patterns.

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2.4 Anthropogenic Source, Activities and Climate

To understand the significance of anthropogenic sources, consider a study suggesting that the Aegean might overall serve as a "source" of plastics to the Eastern Mediterranean. In 20-year simulations, more litter exited the Aegean (via the 34th parallel in the Levantine) than entered from elsewhere. Specifically, approximately 35% of particles escaped southward (toward the Mediterranean), while only about 7% came from other Aegean basins. This indicates that the Aegean, due to its numerous local sources, "feeds" the Mediterranean with plastics and is not merely a receptor. The study also notes that roughly 10% of the litter settles or is stranded within the Aegean (mainly in its western parts), while the remainder circulates in the sea for longer periods (Politikos et al., 2017).

The geographical distribution of plastics is heavily influenced by where they are produced or enter the environment. In the Aegean, significant sources include:

- Rivers and runoff: Although smaller than the Nile or the Rhône, rivers such as the Axios, Nestos, Strymonas, Axios and Evros transport plastics from inland to the northern Aegean. In particular, the Evros, through the Marmara Sea, serves as a conduit for pollutants from the Balkans and the Black Sea into the Aegean. Studies indicate that large volumes of microplastics enter the northern Aegean via the influx of Black Sea waters (BSW).

- Urban Centres and Industry: Areas with high population density and industrial activity exhibit elevated local loads. The Saronic Gulf—the maritime gateway to metropolitan Athens—receives vast amounts of treated wastewater (~800,000 m^3/day), which contains microplastics (fibres from clothing, cosmetic particles, etc.). Additionally, numerous point sources such as ports (e.g., Piraeus), marinas, shipyards, fish farms, and coastal municipalities contribute to the local litter load. This helps explain why beaches in the Saronic area (e.g., Salamina) show higher microplastic levels compared to more isolated coastlines elsewhere. Similarly, the enclosed Gulf of Corfu in the Ionian is burdened by two ports, tourism, and the Kalamá river, functioning as a litter reservoir.

- Shipping and Fishing: The Aegean is a maritime hub with intense shipping activity (commercial vessels, cruise ships, fishing boats). Illegal or accidental discharges from ships contribute to the pollution. In addition, the loss of fishing gear (nets, ropes) adds macroplastics that eventually fragment into microplastics. In the northern Ionian, frequent shipping has been linked to increased plastic concentrations. Overall, maritime activities (shipping, oil platforms, fish farming) represent significant plastic sources in the Mediterranean, complementing land-based inputs. Finally, as mentioned, the dispersal of plastics is not uniform throughout the year but exhibits significant seasonal variations due to changes in meteorological and hydrological patterns. For example:

- Winter Period: From December to April, the most intense rainfall and storms increase riverine runoff, releasing more plastics into the sea. Simultaneously, winter winds and water column disturbances may disperse microplastics more evenly or direct them toward specific convergence zones. Simulations indicate that in winter, higher concentrations of microplastics occur in both the northern and southern Aegean (e.g., south of Crete), following a "trap-like" distribution pattern. This is possibly due to the convergent circulation established during winter—in the northern Aegean, the lighter Black Sea waters form an extensive lens that retains litter, while in the southern Aegean, cyclonic eddies trap material carried by southerly currents.

- Summer Period: Conversely, from May to September, strong northerly Meltemia and summer drought reduce riverine inputs. Persistent Meltemia creates a "cleansing" effect—pushing much of the Floating litter toward the open sea or more southerly regions, effectively clearing vulnerable areas. In addition, during summer the water column stratifies thermally (strong thermoclines), limiting vertical mixing. As a result, local surface microplastic concentrations are reduced (acting as a "cleaning" process) compared to winter. However, this does not necessarily imply a decrease in the overall plastic load—some microplastics may

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simply sink slightly deeper into calmer waters or be transported out of the Aegean via its southern outlets. Seasonal studies clearly record lower plastic densities in the Aegean during summer, particularly along coasts that receive substantial winter runoff. (It is worth noting that in the open ocean the opposite is often observed—for example, in the Pacific, the "Great Garbage Patch" becomes more pronounced in summer due to calmer conditions that facilitate surface accumulation, whereas winter turbulence submerges some litter.)

In the Mediterranean, however, riverine inputs and Meltemia dictate a different seasonal trend.

- Transitional Seasons: Spring and autumn function as transitional phases. In spring, as storms subside and Meltemia begin, there may be a brief period of high surface pollution before dispersal occurs. In autumn, early rains combined with weakening Meltemia might lead to local peaks—for example, after the first rains, plastics accumulated during summer in depressions may be flushed out, leading to spikes in the sea.

Overall, the seasonal variations are critical for planning, monitoring and cleanup operations.

- Winter/Spring: priority should be given to coastal river catchments and the northern Aegean.
- Summer: emphasis should shift to southern areas and marine accumulations (especially as tourist activities increase, while natural dispersion may carry litter further away).

3. Location Description

Monitoring marine litter in the Aegean Sea requires a strategic selection of locations that encompass the diverse environmental dynamics and anthropogenic influences affecting the dispersion of litter. The movement of marine litter in this region is determined by a complex interplay of natural and human-induced factors, including ocean currents, wind patterns, tourism, and salinity variations.

3.1 Study Areas

The selected monitoring sites represent key locations for marine litter accumulation and transport in the Aegean Sea in general (Figure 7):

1. Axios River
2. Aliakmon River
3. Strymonas River
4. Evros River
5. Kavo Doro (Central Aegean including Euboean Gulf)
6. Tinos - Mykonos- Ikaria Strait (Central Aegean)
7. Lesvos (Eastern Aegean)
8. Mykonos-Ikaria Strait (Central-Eastern Aegean)
9. Halkidiki (Northern Aegean)
10. Thasos (Northern Aegean)
11. Dodecanese Islands (Southern Aegean)
12. Skyros (Western Aegean)

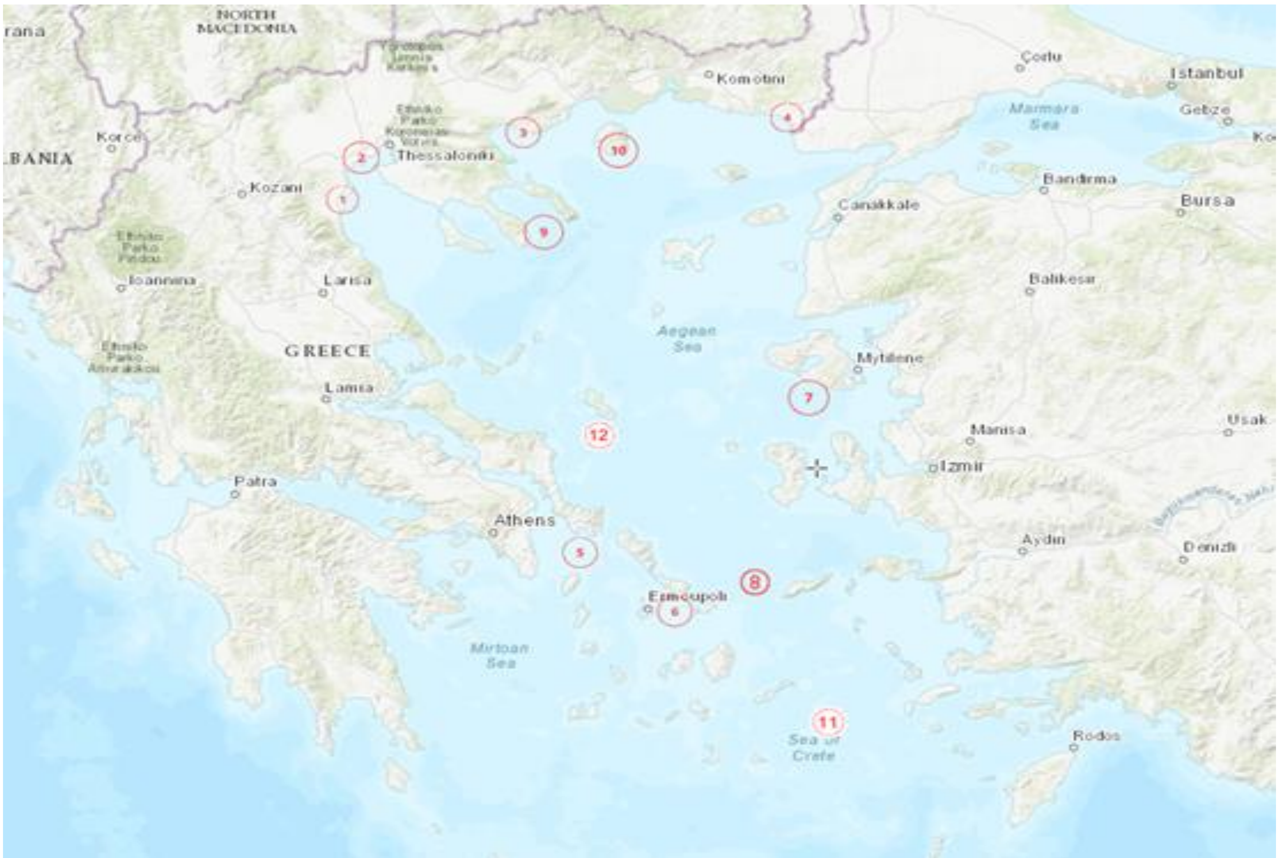

Figure 7. Locations of buoys in the Aegean (Source: MCG). Each location was selected based on its hydrodynamic properties, contribution to litter accumulation, and its significance in understanding the pathways of marine litter transport and are for each selected

3.2 Analysis of Key Monitoring Locations

Each location was selected based on its hydrodynamic properties, contribution to litter accumulation, and its significance in understanding the pathways of floating litter transport. Their main characteristics are presented below.

3.2.1 Axios River

The Axios River (Figure 8) discharges into the Thermaic Gulf and originates in North Macedonia. It carries industrial effluents, agricultural runoff, and urban waste as it traverses industrial and agricultural zones. High concentrations of microplastics and plastic-related pollutants are present due to agricultural activities, which contribute pesticides, fertilizers, and plastic residues. The river plays a crucial role in introducing plastic litter into the Thermaic Gulf, where prevailing currents concentrate litter along the coast. Its flow is highly variable, with flood events causing sudden increases in water volume, complicating continuous monitoring efforts.
The delta region of the Axios River features extensive wetlands, sandy stretches, and shallow coastal zones that trap significant volumes of litter. Ocean currents and seasonal winds influence the dispersion of litter, with the summer Meltemi winds transporting plastic litter toward the coasts of Halkidiki and central Macedonia, while winter southerly winds push litter toward Thessaloniki and the northern Thermaic Gulf.

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Hydrodynamic Properties:
The Axios River, flowing from North Macedonia into the Thermaic Gulf, displays pronounced seasonal variations in flow, primarily due to snowmelt and rainfall. These hydrodynamic dynamics enhance its ability to mobilize and transport suspended materials, including macroplastics (Ioakeimidis et al., 2014).

Contribution to Litter Accumulation:
Traversing urban centers and agricultural zones, the Axios receives significant loads of plastic litter from surface runoff, irrigation discharge, and urban waste inputs, which are carried downstream to the marine environment (Liubartseva et al., 2018).

Significance in Marine Litter Transport:
The Axios exemplifies how riverine systems serve as key vectors for terrestrial plastic litter into semi-enclosed seas like the Aegean, making it essential for modelling litter dispersal (Topouzelis et al., 2020).

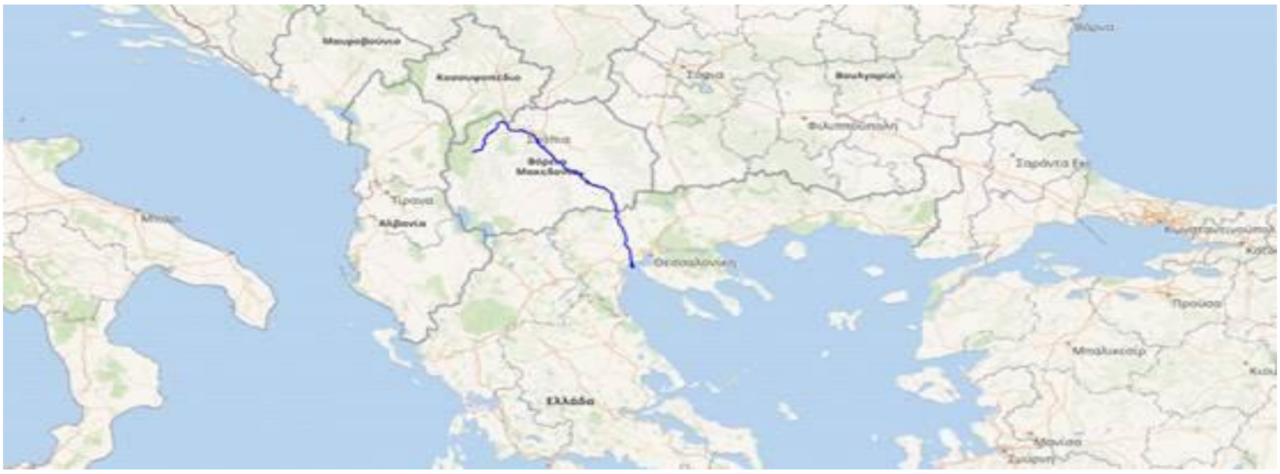

Figure 8. Axios location in Northern Greece (Source: Google Maps).

3.2.2 Aliakmonas River

The Aliakmon River (Figure 9) is the longest river in Greece and also discharges into the Thermaic Gulf. It traverses agricultural and semi-mountainous areas, with primary sources of pollution being agricultural and livestock-related plastic litter. Compared to the Axios, the Aliakmon carries a lower plastic load, but its delta acts as a receptor for litter transported by the Gulf's currents. Seasonal variations in river flow and potential GPS signal disruptions in open waters may present challenges for mapping the transport pathways of litter from land-based sources to the open sea.

Hydrodynamic Properties:
As the longest river in Greece, the Aliakmonas is regulated by multiple dams and reservoirs, which influence water retention and sediment transport. These features affect the timing and extent of litter movement (Blettler et al., 2018).

Contribution to Litter Accumulation:
Agricultural plastic litter (e.g., films, packaging) enters the river via runoff and is intermittently released downstream, particularly during high-flow events (Ioakeimidis et al., 2014).

Significance in Marine Litter Transport:
The Aliakmonas provides insight into how controlled hydrological systems with dams can delay but not prevent the transfer of plastics to marine environments, revealing key challenges for source-based mitigation strategies (van Emmerik & Schwarz, 2020).

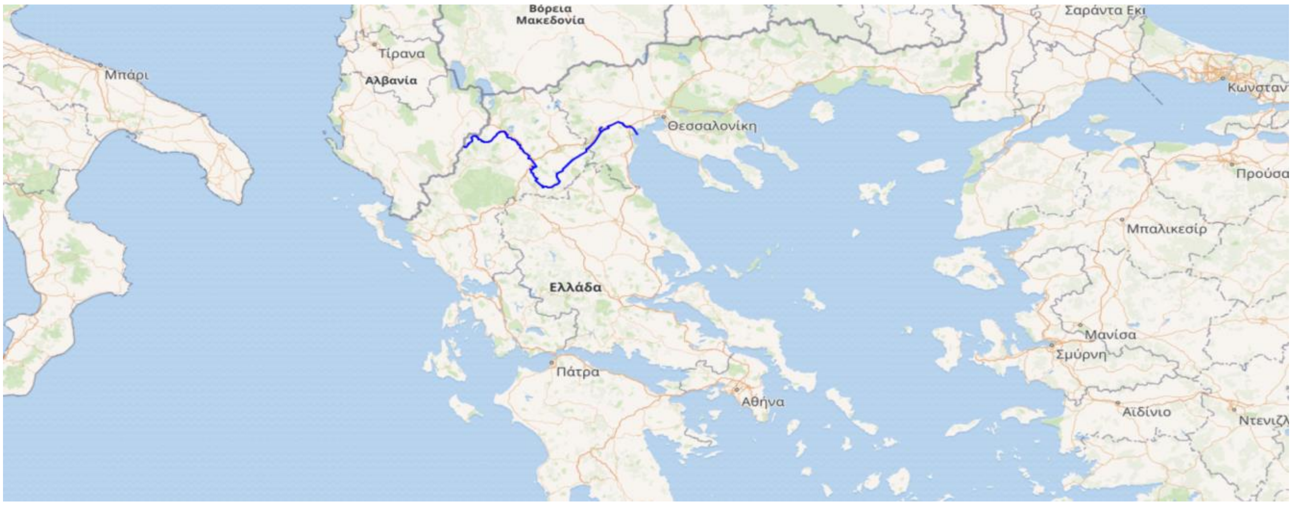

Figure 9. Aliakmonas location in North Greece (Source: Google Maps, 2025).

3.2.3 Evros River

The Evros River (Figure 10) is the largest river in Thrace and a transboundary river between Bulgaria, Greece, and Turkey. Major sources of pollution include uncontrolled litter dumps, illegal litter disposal sites along its course, agricultural runoff (such as plastic from greenhouses and irrigation systems), and industrial discharges from upstream regions. The river delivers significant volumes of plastic litter to the sea, where strong currents and low-salinity water at the estuary facilitate the widespread dispersion of litter into the northern Aegean (Black Sea Basin Programme, 2021).

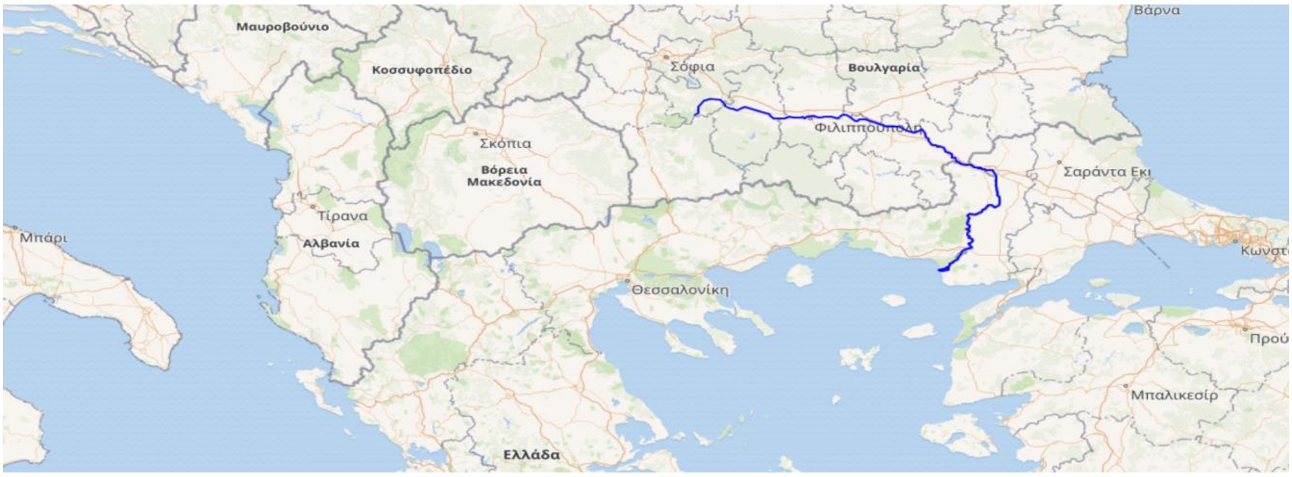

Figure 10. Evros location in North Greece (Source: Google Maps).

Hydrodynamic Properties:
With a broad floodplain and frequent flooding events, the Evros displays dynamic flow patterns, particularly during winter and spring. This promotes the mass mobilization of litter over wide areas (Blettler et al., 2018).

Contribution to Litter Accumulation:
The river drains agricultural, urban, and industrial landscapes across three countries, making it a conduit for complex mixtures of macro- and microplastics toward the Aegean Sea (Ioakeimidis et al., 2014).

Significance in Marine Litter Transport:
As a transboundary river, the Evros is key to understanding the international dimensions of marine litter transport and the need for joint monitoring frameworks (van Emmerik & Schwarz, 2020).

3.2.4 Strymonas River

The Strymonas River (Figure 11) discharges into the Strymonic Gulf, with its waters passing through Bulgaria and Eastern Macedonia. The primary sources of plastic pollution include industrial and agricultural waste from Bulgaria, runoff from Greek agricultural areas, and waste deposition from nearby communities and tourist activities. High concentrations of microplastics are observed at its estuary. The riverbed's natural morphology, including bends and variations in depth, can create localized zones where litter accumulates or is resuspended, adding complexity to monitoring efforts.

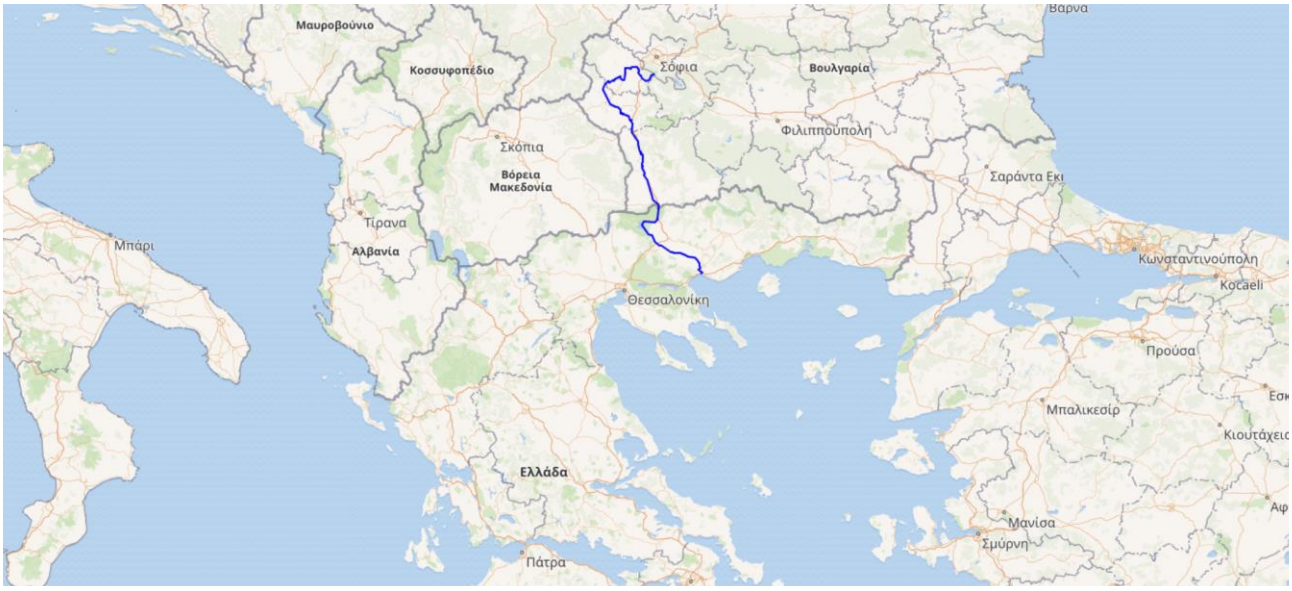

Figure 11. Strymonas location in North Greece (Source: Google Maps).

Hydrodynamic Properties:
Originating in Bulgaria, the Strymonas experiences strong seasonal variability driven by rainfall and snowmelt in the Rhodope Mountains. This variability affects sediment load and litter mobility (Blettler et al., 2018).

Contribution to Litter Accumulation:
The river collects litter from rural and semi-urban settlements. Sudden increases in discharge during storms or melting periods lead to litter flushes toward the Strymonian Gulf (Liubartseva et al., 2018).

Significance in Marine Litter Transport:
Its transboundary nature highlights the importance of coordinated regional efforts in monitoring riverine litter flux and identifying international sources of marine pollution (Topouzelis et al., 2020).

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3.3. Key Marine Straits and Hydrodynamic Corridors

3.3.1 Kavo Doro Strait

The Kavo Doro Strait (Figure 12), situated between southern Evia and Andros in the central Aegean, is characterized by intense marine currents that influence water circulation, salinity distribution, and pollutant transport. The narrow topography (~11 km wide) and complex bathymetry accelerate water flow, making it one of the most turbulent areas in the Aegean. Observational data indicate persistent southward currents that transport litter from the northern Aegean to the Myrtoan Sea and beyond.

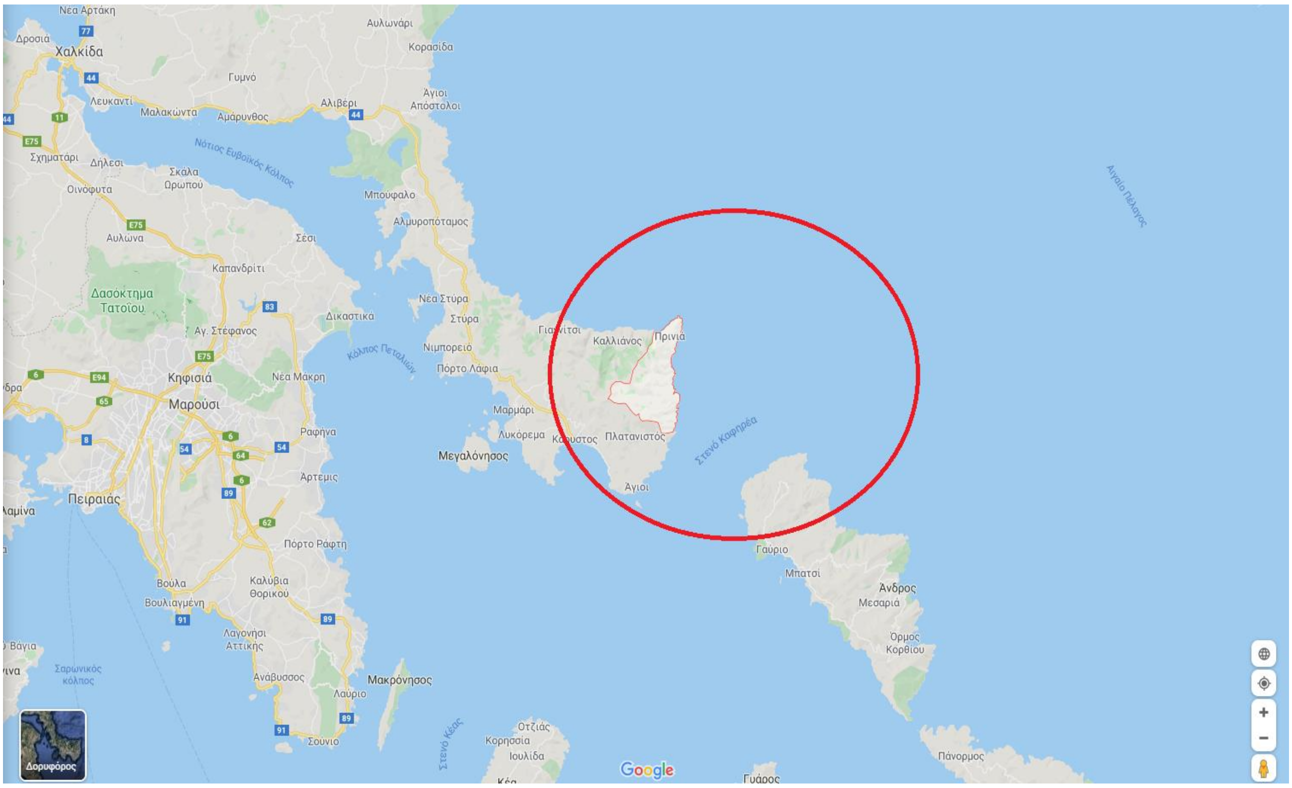

Figure 12. Kavo Doro location in Central Greece (Source: MCG)

3.3.2 Tinos-Mykonos-Ikaria Strait

This strait (Figure 13) is a critical corridor for maritime transport, plastic litter movement, and oceanographic processes. The interaction of the Meltemi winds, seabed morphology, and the "Venturi Effect" (fluid acceleration through narrow channels) results in dynamic currents that enhance the transport and concentration of floating litter. The presence of seasonal eddies influences litter accumulation in certain areas.

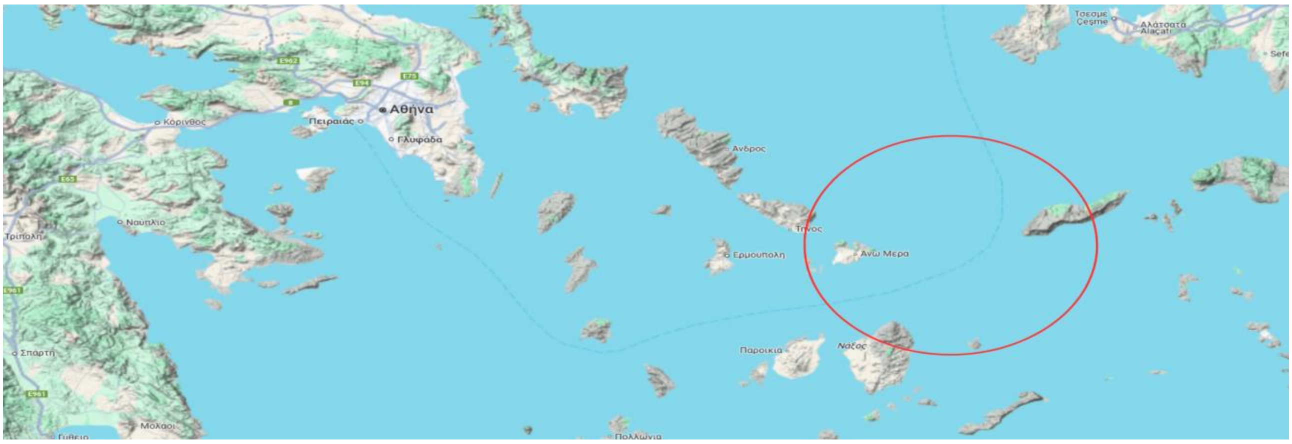

Figure 13. Mykonos - Ikaria Strait location in Central Greece (Source: MCG).

3.4 Marine Litter Accumulation in Key Regions

3.4.1 Northern Aegean (Lesvos, Chios, Halkidiki)

The northern Aegean is one of the primary plastic litter accumulation zones in the Mediterranean due to its complex ocean currents, inflows from the Dardanelles, and seasonal wind variations. The hydrodynamic processes contribute to long-term plastic retention, particularly in regions such as eastern Lesvos, the Gulf of Kalloni, and the coasts of Chios. (Figure 14) The northern Aegean's inflow of Black Sea water introduces additional pollution, affecting the islands and coastal areas.

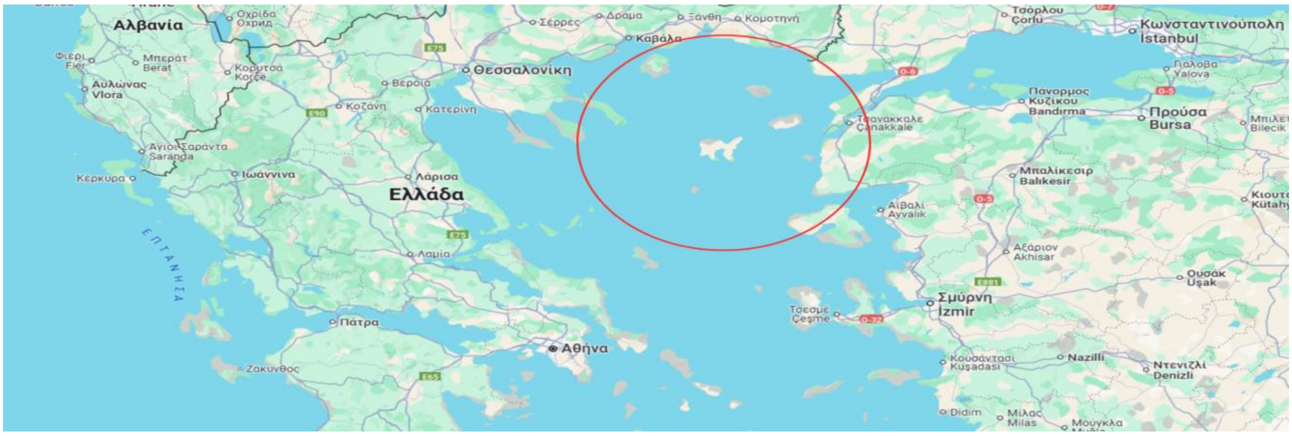

Figure 14. Locations of North Greek Island for investigation (Source: MCG).

3.4.2 Dodecanese Region

The transport of plastic litter in the Dodecanese (Figure 15) is influenced by sea currents, seasonal winds, tourism, and shipping activities. Strong summer Meltemi winds transport plastics southward, while winter storms shift litter dispersal patterns. Notable accumulation hotspots include the eastern coast of Rhodes, the coastal waters of Kos, and the straits of Karpathos.

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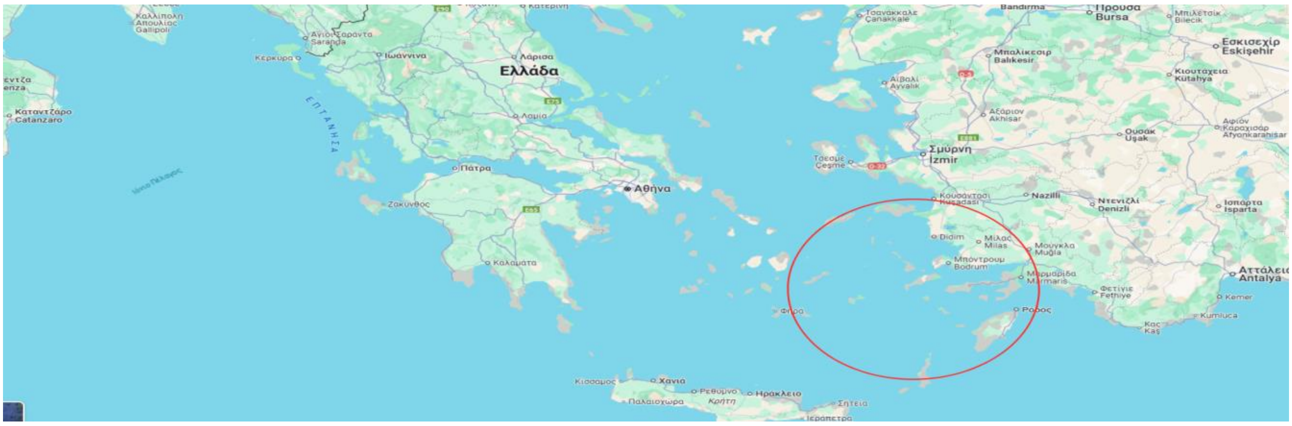

Figure 15. Dodecanese Island for investigation (Source: MCG)

3.4.3 Skyros (Western Aegean)

Skyros, (Figure 16) the largest island in the Sporades, is influenced by both northern and central Aegean currents. Seasonal changes in wind and water circulation result in periodic accumulation of marine litter along its northern and eastern shores. Tourism and fishing activities contribute to additional plastic litter deposition in coastal zones.

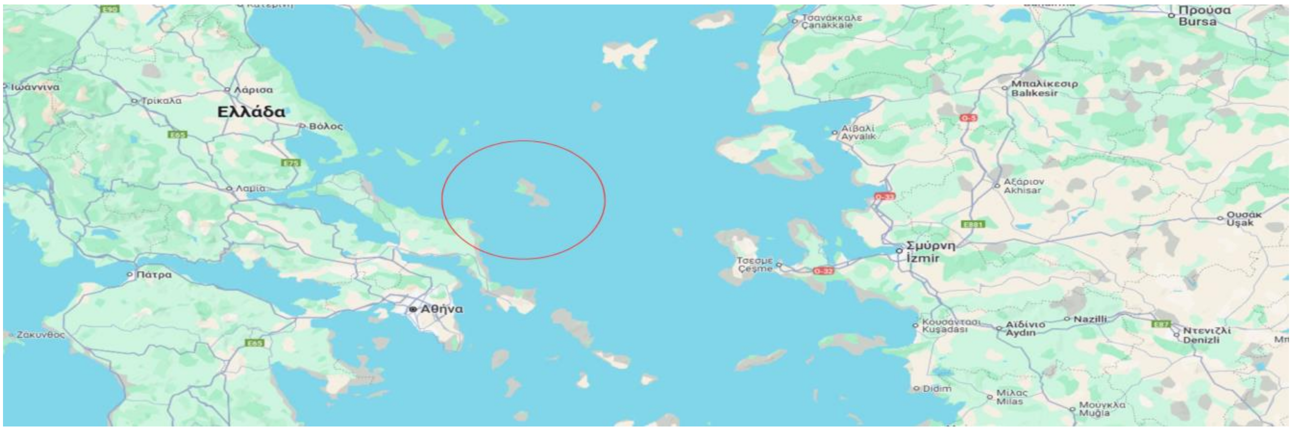

Figure 16. Skyros location At West Aegean (Source: MCG)

3.5 Seasonal weather and human activities affect plastic litter Transport

Winter-Spring: Intense rainfall and snowmelt increase river discharge, carrying large quantities of litter to the sea.

Summer: Lower river flows mean plastics primarily originate from tourism-related activities.

Autumn: Initial rains wash accumulated litter from riverbanks into the sea.

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3.6 Conclusions and Recommendations

Marine litter monitoring in the Aegean Sea is essential for understanding the transport and accumulation dynamics of plastic pollution. This study highlights key regions of concern, where the combined effects of ocean currents, wind patterns, and human activities determine litter dispersion. Effective mitigation strategies should focus on targeted clean-up operations, regulatory measures to limit plastic pollution at the source, and enhanced monitoring of riverine and coastal litter pathways. Future efforts should integrate high-resolution hydrodynamic models with field data to improve predictive capabilities and develop long-term intervention strategies to safeguard the marine environment of the Aegean Sea.

4. Technology description and preliminary testing

A **GPS-equipped buoy** is a floating autonomous device designed to record and transmit its geographic position in real time using the Global Positioning System (GPS). These buoys are typically constructed from durable, weather-resistant materials and may be equipped with additional sensors for environmental monitoring (e.g., temperature, salinity, current velocity).

The **primary aim** of a GPS buoy is to track the movement and dispersion patterns of water masses, floating litter, or pollutants in aquatic environments such as rivers, estuaries, and coastal waters. By analyzing the trajectory data collected over time, researchers can gain insights into hydrodynamic processes, assess pollution transport pathways, and inform mitigation strategies for marine litter and other environmental threats.

4.1 Buoy with GPS casing

For the construction of the buoy casings, environmentally friendly materials such as wood and cork were initially selected. The buoys needed to be resistant to the marine environment, including salt and humidity, while also being lightweight to simulate household waste.

The first trials utilized cork casings (Figure 17), as cork is an ecological, cost-effective, and very lightweight material. However, this approach was quickly abandoned since cork is porous and highly susceptible to moisture.

Figure 17. Construction of a buoy from cork (Source: MCG)

The second material tested was wood in various forms (Figure 18), including solid white pine, iroko, composite treated wood, and marine plywood. The size of each casing was designed not to exceed 15–18 cm, closely resembling a 500 ml water bottle and most common types of litter found on a beach.

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Figure 18. Construction of buoys from several types of wood (Source: MCG)

In *Table 1*, below is the comparative table presenting the properties of each type of wood.

Table 1. Pros and Cons of tested wooden buoys

Material	Advantages	Disadvantages	Weight	Cost	Water Resistance
Marine Plywood	- Good water resistance when high-quality water-resistant adhesives are used - Easy to process and cut - Relatively economical solution	- Susceptible to leaks and decomposition if not properly maintained - Risk of delamination over time	Medium	Low – Medium	Good, with regular maintenance
Iroko	- Natural, high durability and long lifespan - Excellent water resistance without the need for special treatments - Aesthetically pleasing and weather-resistant	- Heavier compared to other materials - High purchase cost - Requires periodic maintenance to preserve its appearance and protective qualities	Heavy	High	Excellent
Swedish Pine	- Lighter material, facilitating transport and construction - Economical solution - Easy to process	- Low natural water resistance - Susceptible to rot and decomposition without special treatment (e.g., pressure treatment,	Light – Medium	Low – Medium	Moderate – improved with treatment

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Material	Advantages	Disadvantages	Weight	Cost	Water Resistance
	for various applications	painting, or chemical treatment)			
Composite Impregnated Wood	- Designed for high water resistance and extreme weather conditions - Reduced need for continuous maintenance - Consistent quality and uniformity	- More expensive option - Often heavier than natural wood - Difficult to repair in case of damage due to its composite nature	Medium – Heavy	High	Excellent

Marine Plywood:
Its performance is highly dependent on the quality of the adhesives and coatings employed. It is ideal for applications where cost and ease of construction are significant factors, though regular maintenance is required to ensure long-term reliability.

Iroko:
Due to its natural durability and excellent water resistance, Iroko is an excellent choice for high-demand projects. However, its high cost and substantial weight can be limiting factors in certain applications.

Swedish Pine:
This material offers an economical and easy-to-use option, but without proper treatment, it may not meet the stringent requirements of a marine environment, particularly in prolonged applications.

Composite Impregnated Wood:
This material provides the best performance regarding water resistance and longevity. However, its higher cost and increased weight must be carefully considered during the design and construction phases.The initial shape chosen was cylindrical (Figure 19), both to simulate the form of a bottle and to minimize the risk of the buoy flipping over due to wave action. Flipping could cause the GPS device inside to be submerged upside down, leading to a loss of signal, as these devices do not transmit below the water's surface.

Figure 19. Construction of buoys with cylindrical shape (Source: MCG)

However, this approach was also quickly discarded, as even with the softest wood, such as white pine, processing proved to be particularly difficult, time-consuming, and costly.

The final design featured a rectangular shape (Figure 20) composed of three flat wooden layers of marine plywood connected with adhesive and stainless steel screws. The bottom layer was thicker than the others, serving as a counterweight to keep the buoy upright if overturned by waves. The marine plywood (Figure 20) was initially chosen as the best option among the other types of wood due to its mechanical strength, waterproofing properties, and relatively good weight compared to the others. Additionally, the cost/performance ratio was very good.

Figure 20. Construction of buoys with GPS with rectangular shape (Source: MCG)

Furthermore, the use of marine plywood offered significant advantages in terms of workability, owing to its layered composition as opposed to a homogeneous solid structure. This multilayered configuration enhanced vertical stability when submerged (Figure 21), which was essential for the reliable transmission of signals from GPS devices. Additionally, the material's machinability allowed for greater precision during fabrication, contributing to optimized weight distribution and overall functional performance.

Figure 21. Buoys with GPS first test into water (Source: MCG).

The middle layer had a precisely cut slot matching the GPS device's dimensions (8 cm × 4 cm), ensuring that the device remained securely in place. The top layer was the thinnest and functioned as a lid, onto which an aluminum plate was attached with Instruction what to do when found and short brief about REMEDIES project, displaying the program's identification details (Figure 22).

Figure 22. Remedies Label on a buoy (Source: MCG).

4.2 GPS Device selection

The next step in the development of the buoy was the selection of a suitable GPS device. Given that the project had a planned duration of two years, the device's battery had to sustain operation for an extended period. Additionally, it needed to be waterproof and robustly constructed to withstand vibrations from waves and potential impacts with rocks if it were to reach the shore. Finally, it had to be capable of transmitting data digitally to enable integration with the REMEDIES platform.

For this purpose, several GPS devices were evaluated, with three selected for further comparison and final selection. The devices under consideration were the Lightbug Pro, Trackerone S20, and GF07 Magnetic Mini Car Tracker GPS.

A detailed comparison of each device can be found in *Table 2*.

Table 2. Pros and Cons of GPS Devices (source lightbug.io, trackerone.vip)

GPS Tracker	Photo	Details	Potential Applications
Lightbug Pro		- Robust design for extreme environmental conditions (IP67/IP68) - Advanced real-time tracking technology - Extended battery life with potential solar panel integration - High positional accuracy	- Monitoring of floating devices (buoys) for environmental research and marine litter tracking - Maritime search and rescue operations - Integration into USVs and other marine monitoring systems
Trackerone S20		- Primarily designed for vehicular tracking using GSM/GPRS networks - Real-time tracking and geofencing capabilities - Moderate battery life, requiring additional waterproofing for marine applications	- Fleet management and logistics tracking in urban and suburban areas - Anti-theft systems for commercial vehicles - Customized marine applications with extra protection
GF07 Magnetic Mini Car Tracker GPS		- Extremely compact and discreet device with magnetic mounting - Basic positioning tracking - Ideal for applications with limited space and where discretion is paramount - Limited battery life and water resistance	- Vehicle tracking and anti-theft monitoring for fleets - Equipment tracking for small-scale asset management (e.g., construction machinery) - Limited marine applications with additional protection required

The selection of an appropriate GPS transmitter depends on the specific requirements of the project:

- Lightbug Pro: Recommended for long-term applications in harsh marine environments due to its robust waterproof design, advanced tracking technology, and extended operational life supported by renewable energy options.
- Trackerone S20: Suitable for fleet management and vehicle tracking applications, with the potential to be adapted for marine environments through additional waterproofing measures.
- GF07 Magnetic Mini Car Tracker GPS: Best suited for applications where compactness and discretion are paramount, such as vehicle or equipment tracking, although additional protection is necessary for use in extreme conditions.

In summary, the Lightbug Pro emerges as the most reliable and effective option for deployment in a buoy system operating in a marine environment over an extended period. Based on this assessment, the first 105 GPS devices selected for the project were Lightbug Pro units, due to their superior reliability.

An additional feature of the company was its positioning as a sustainable entity, taking into account not only environmental but also ethical considerations.

However, one of the major drawbacks of this particular device was the significant delay in delivery, as well as the high cost—not only of the device itself but also of the customs clearance process. This was due to the fact that the company is based in the United Kingdom, which is outside the European Union. Notably, the first 100 devices took more than three months to be delivered to Greece.

4.3 GPS Device - Buoy Testing

For the initial tests in a marine environment, eight devices were constructed and placed in buoys made from different types of wood and sealed with various materials, such as adhesives, silicones, and waterproofing agents. Six of these were deployed in the port of Rafina (Figure 23), while two were placed in the port of Kalymnos (Figure 24 and Figure 25) for a period exceeding one month.

Figure 23. Buoy with GPS testing in Port of Rafina (Source: MCG).

The objective was to assess the reliability of the buoy materials in real-world conditions, as well as to evaluate the feasibility of transmitting data from the GPS devices while submerged in water.

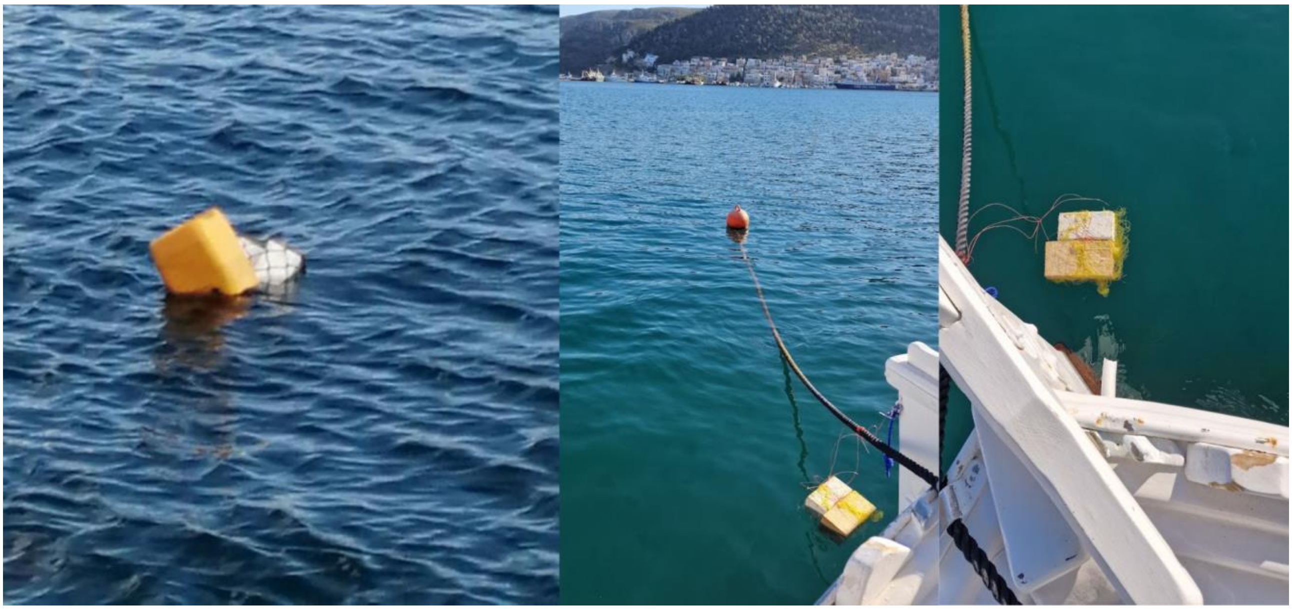

Figure 24. Buoy testing in Port of Kalymnos (Source: MCG).

After two months, it was confirmed that the devices successfully transmitted signals and the most suitable wood for our project was the marine plywood due to its cost/benefits relation as we mentioned above.

Additionally, the buoy casings were reinforced with self-adhesive, UV-resistant, and waterproof membranes featuring the program's logos. This was done both to protect them from passing vessels and to provide additional safeguarding for the casings themselves, as minor degradation of the sealing materials was observed during their time in the water throughout the testing period.

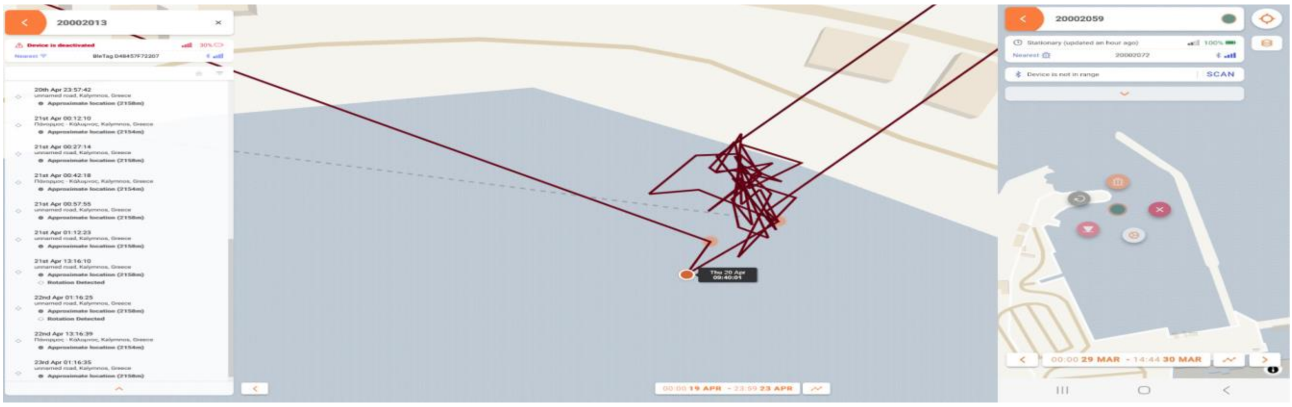

Figure 25. Buoy observation at Port of Kalymnos and Rafina from the app (Source: MCG screen shot from lightbug monitoring app)

4.4 Replacement of Buoy Casing from Wood to Plastic

As previously mentioned, the initial study proposed the construction of wooden buoys using marine plywood. Following several tests, it was observed that this material demonstrated the highest buoyancy among the various types of wood examined.

Although wood is no longer widely used in the construction of buoys, it remains a natural and environmentally friendly material that offers good buoyancy and is easy to process. It does not produce toxic waste and has been traditionally employed in buoy manufacturing. However, it has lower durability compared to other materials, is susceptible to decay due to prolonged exposure to seawater and microorganisms, and requires regular maintenance, including the application of varnishes and sealants. Its lifespan is relatively limited in comparison to modern material alternatives.

During the initial stages of the research, approximately 35 wooden marine plywood buoys were deployed a few months after the preliminary tests. These deployments took place in various locations, including the Evros region, the Aliakmonas River, the strait between Tinos, Mykonos, and Ikaria, as well as the Dodecanese region. Initial measurements indicated normal performance. However, after two months of exposure to real environmental conditions in the water, the devices exhibited operational defects. The primary issues encountered were as follows:

1. **Loss of GPS Signal**
   The first significant issue observed was the loss of GPS signal (Figure 26) after approximately two months in the water. Initially, this was attributed to network unavailability in remote maritime areas, a common occurrence around the Greek islands. However, the fact that no further signals were received from these devices led the research to focus on the buoy casings.

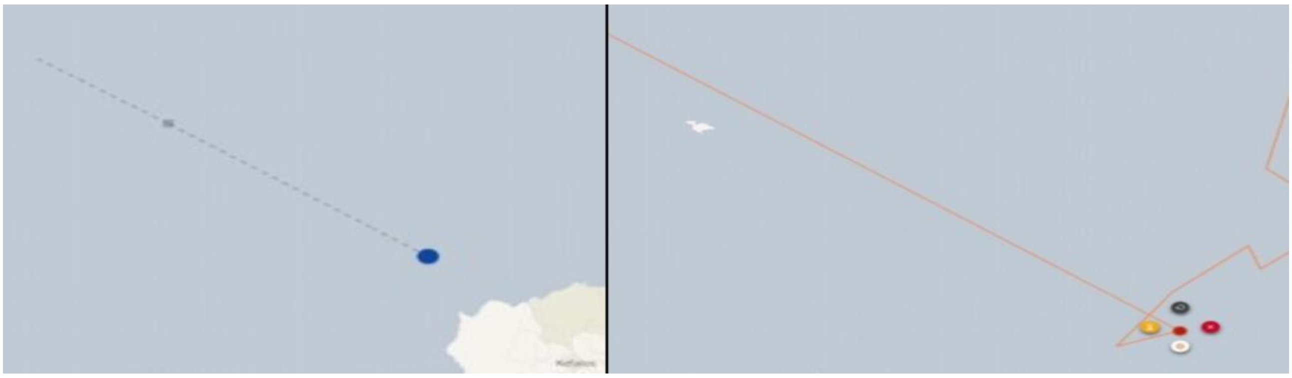

Figure 26. Example of buoy who lost its signal and sank observed via the app (Source: MCG screenshot from lightbug app).

Tests conducted in a controlled environment with seawater exposure revealed significant wood decay after approximately two months (Figure 27), even with the application of protective varnishes and preservatives. Given that these buoys were deployed during the meltemi season, when they were subjected to extreme conditions, including winds of 7–8 Beaufort and waves reaching up to 2 meters in height, it was concluded that the decay of the wooden structure likely led to water ingress, ultimately causing the buoys to sink.

Figure 27. Damages and Degradations to Wooden Buoy During Testing (Source: MCG).

2. Increased Weight
   During the initial monitoring phase in the Aliakmonas River region, no significant changes in the buoys' condition were noted post-deployment. This was initially attributed to the low water levels in the riverbed during the summer and early autumn, as the water level remains low with minimal flow and currents during this period (Figure 28).

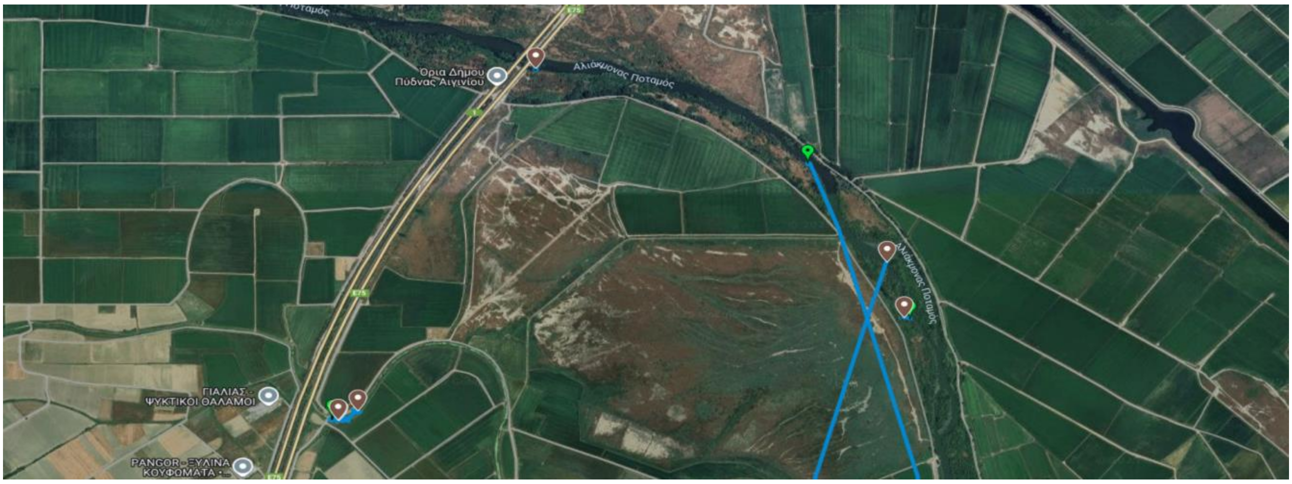

Figure 28. Stuck buoys at Aliakmonas due to their heavy weight (Source: MCG).

Concurrently, a comparative experiment was conducted in the Dodecanese region, where both a wooden buoy and a plastic buoy constructed from a TRITAN material bottle (Figure 29) were deployed simultaneously to assess their respective performance. The results were striking. The plastic buoy, being significantly lighter at 258 grams compared to the 685 grams of the wooden buoy, travelled four times faster, ultimately altering its final destination compared to the wooden counterpart. Combined with the findings from the Aliakmonas River experiments, these results led to a strategic shift from wooden to plastic buoy construction.

Figure 29. Wooden and plastic buoy ready for launch at Dodecanese region. (Source: MCG).

Plastic offers excellent resistance to corrosion and the chemical effects of seawater. It is lightweight (compared to wooden buoys), easy to transport (Figure 30 and Figure 31) and deploy, impact-resistant, and generally difficult to break, making it ideal for operations involving rocky environments or large waves. Furthermore, its production cost is relatively low, and certain plastic types can be recycled. However, concerns exist regarding its environmental impact, particularly the potential release of microplastics over time. Additionally, plastic can degrade due to ultraviolet (UV) radiation if not properly treated. To address these concerns, LHDPE polymer type plastics was selected as a more practical alternative and was reinforced with UV protection to enhance durability and sustainability.

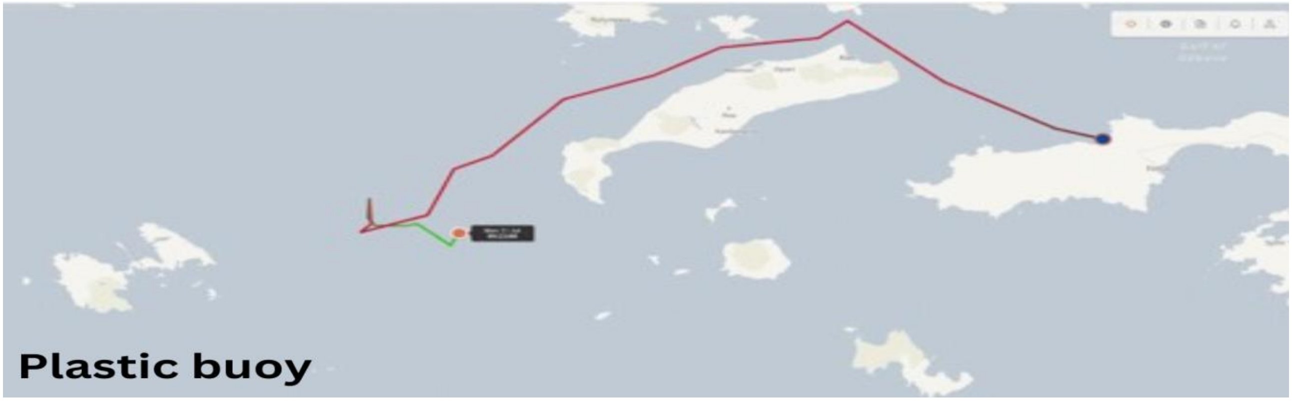

Figure 30. Movement of a plastic buoy (Source: MCG screenshot from app).

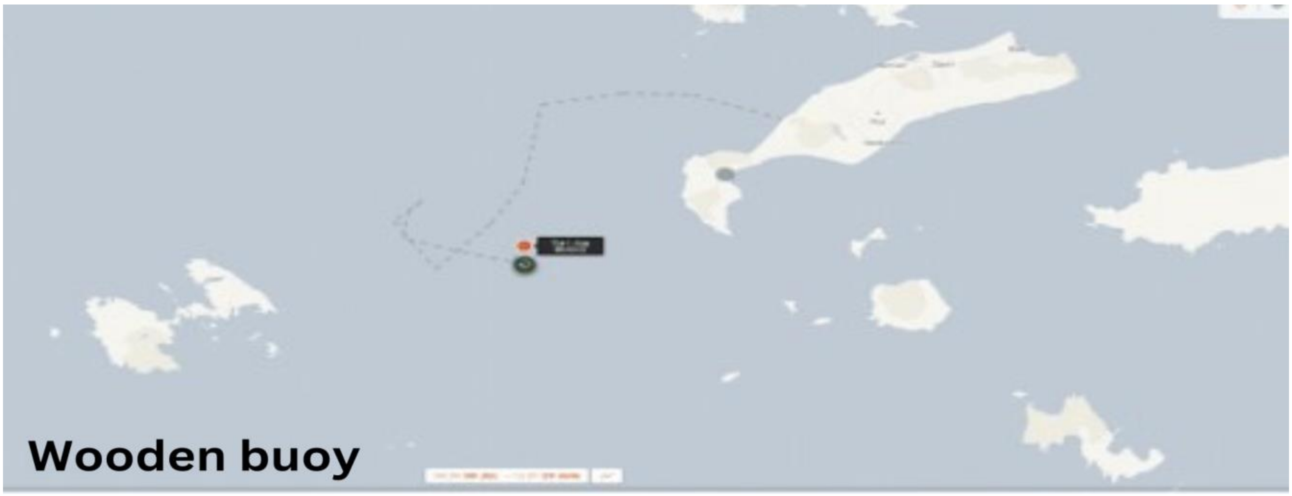

Figure 31. Movement of a wooden buoy at the same time with the plastic (Source: MCG screenshot from app).

4.5 Removal of Program Identifiers to Prevent Device Retrieval from the Sea

Both the wooden and plastic buoys initially deployed in the water were labelled with program identifiers, including the project name, device number, and information about the buoy's purpose, as well as instructions on what to do if found. These labels were printed in fluorescent colours, making them highly visible from a distance to prevent accidents involving passing vessels and facilitate easier tracking. Additionally, they were made from UV-resistant and waterproof materials (Figure 32) to ensure durability in seawater. Aesthetically, these markings also enhanced the appearance of the buoys, giving them a more polished and professional look.

Figure 32. Buoy with GPS ready for launch at Aliakmonas (Source: MCG).

Figure 33. Buoy with GPS ready for launch at Strymonas (Source: MCG).

However, these very features made the buoys vulnerable to human curiosity, leading many individuals to retrieve them from the water out of interest in their contents — despite the clear instructions advising against removal. As a result, over 30 devices were retrieved. In some cases, the individuals who removed them contacted the relevant authorities, allowing the devices to be recovered and redeployed. However, in most instances, the buoys were either opened and discarded or kept as souvenirs by tourists (Figure 34).

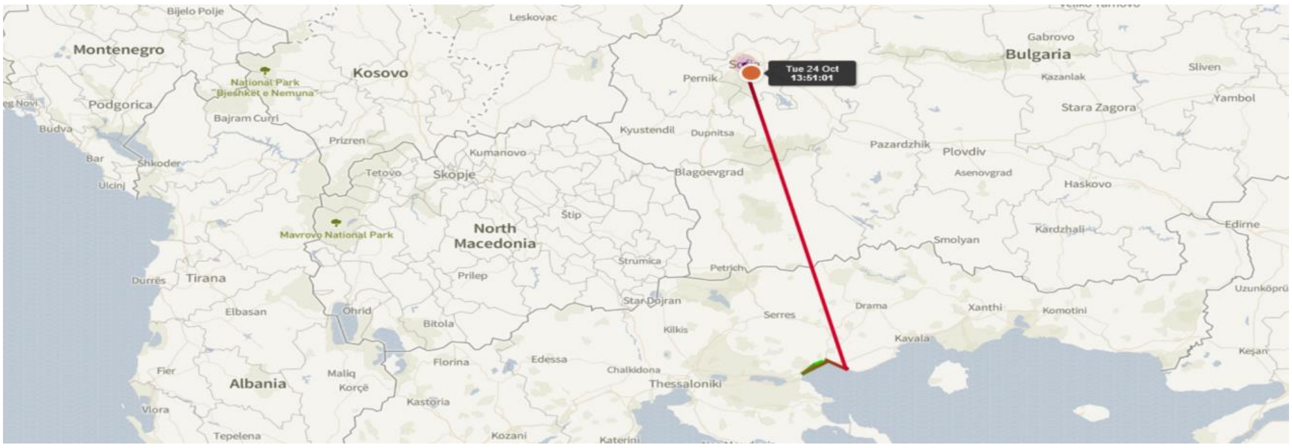

Figure 34. Example of the buoys were either opened and discarded or kept as souvenirs by tourists. Buoy were taken from Strymonas to Bulgaria (Source: MCG screenshot from lightbug app).

To address this issue, all external identifiers were removed (Figure 35) and the devices were designed to resemble common marine litter, making them less conspicuous and reducing the likelihood of human interference. A small internal tag containing the program's details was placed inside each buoy, ensuring that if a device was eventually found, the person could contact the appropriate team to facilitate its return.

Figure 35. Transition from buoys with identifying markers to unmarked (Source: MCG).

4.6 Changing the GPS device

During the submission of the program proposal, the initial design included the use of GPS devices from the company Lightbug, as mentioned earlier. Lightbug is based in the United Kingdom, with its raw material supplier located in China. The company assembles the supplied components and manufactures its devices. Additionally, it has developed a highly user-friendly platform that allows users to easily track their devices at any given time.

The initial offer included the acquisition of 200 devices in accordance with the program's specifications. However, following Brexit, the United Kingdom imposed tariffs on European Union countries, resulting in a change in the company's pricing policy.

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As a consequence, the prices of the devices increased significantly, customs duties were imposed—almost doubling the cost of each device—and the shipping time, including customs clearance, extended to approximately 2–3 months. This posed a potential risk to the project's progress, both in terms of the scheduled timeline and overall costs.
As a result, it became necessary to identify an alternative device supplier that would meet the program's requirements while maintaining equivalent material quality.

To ensure the smooth execution of the program, MCG procured 105 devices from Lightbug at a special price, under the condition that MCG would be responsible for collecting the devices directly from the United Kingdom, which was successfully carried out.

The remaining devices were procured from the company TrackerOne, based in China, with a much shorter delivery time while maintaining nearly the same level of reliability and compliance with the required specifications.

4.7 Integration of GPS tracking data into the Remedies Portal

The monitoring data related to the GPS position of buoys has been shared with the project partner INFOR for integration into the REMEDIES Portal. This portal serves as the central repository for the project, storing all monitoring data from WP1.

In the initial phase, GPS trackers from Lightbug MCG were used. INFOR received documentation on how to use the Lightbug API (Application Programming Interface) to retrieve telemetry data from the buoys and store it within the REMEDIES Portal. Later, when different GPS trackers were selected, INFOR was provided with updated monitoring data for integration into the portal.

These devices transmit positional data via GSM using 2G to 4G connections. The REMEDIES Portal collects this data through Machine-to-Machine (M2M) communication with the Lightbug Web API, syncing multiple times per day. The portal then processes the GPS data to compute metrics such as distances travelled and average speeds.

INFOR completed the necessary software enhancements to enable the collection of GPS data and display initial statistics on the REMEDIES Portal. These include:

- an inventory of GPS trackers and buoys
- detailed logs of all recorded GPS positions per tracker
- the dropping points of the buoys

The processed data has been used to calculate average movement speed (km/h), generate animated maps illustrating buoy trajectories, and develop KPIs aligned with the project's objectives.

Additionally, the portal incorporates support algorithms that monitor GPS tracker parameters—such as battery level and signal strength—and trigger alerts in case of anomalies or abnormal positions. A dedicated 'trapped device' feature is also included to detect buoys that remain stationary for over two days, signalling potential entrapment or arrival at their final location.

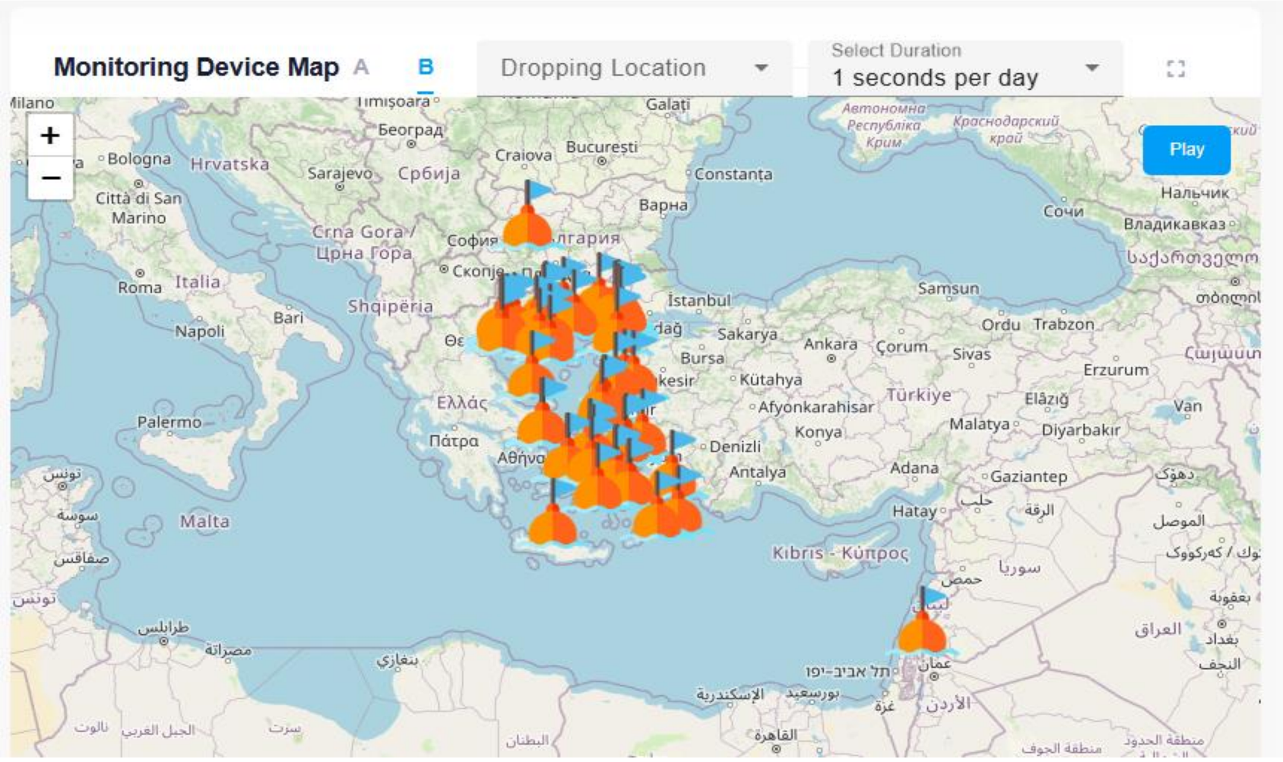

Figure 36. Animated map of buoys position over time with dropping location filter (REMEDIES portal screenshot).

REMEDIES

Home

Monitoring Campaigns

Cleanup

KPI

Dashboard

Monitoring Device Campaigns Home · Monitoring Device Campaigns

active | inactive | completed | waiting for removal

Filter

ID	DESCRIPTION	START DATE	END DATE	USER ID	LAST LNG	LAST LAT	STATUS	DEVICE ID
3	20002162 - LHDPE PLASTIC	07/10/2023	09/10/2023	System User1	23.854277	40.784466	completed	20002162
8	20002189 - LHDPE PLASTIC	08/10/2023	09/10/2023	System User1	22.9492091	40.590662	completed	20002189
13	20002279 - LHDPE PLASTIC	29/09/2023	06/10/2023	System User1	26.035254	40.747374	completed	20002279
15	20002205 - WOODEN	29/09/2023	06/10/2023	System User1	25.9597516	40.8611158	completed	20002205

Figure 37. Inventory of buoys with general specifications (REMEDIES portal screenshot)

5. Activities (Round 1)

5.1. Activity central Cyclades region extended to the Dodecanese

This action involved the release of 12 wooden buoys and one plastic buoy, which, as previously mentioned, was included to allow a comparison between wooden and plastic buoys. The deployment focused on the area of the Tinos – Mykonos – Ikaria channel, extending to Astypalaia (Dodecanese) (Figure 38), as during this period the prevailing *meltemi* winds were active, with northerly winds reaching 5–7 Beaufort. This created ideal conditions for studying the influence of currents both between the islands and in the open sea.

The deployment was carried out from a commercial ferry operated by the Blue Star Company.
This specific deployment from a ferry also enables the understanding of the movement of litter discarded into the sea by vessels, particularly that resulting from human activities, which intensify during the summer season due to tourism.

The buoys were gradually released into the sea in pairs at various locations, including the islands of Serifos, Sifnos, Paros, Naxos, Amorgos, and offshore Astypalaia.

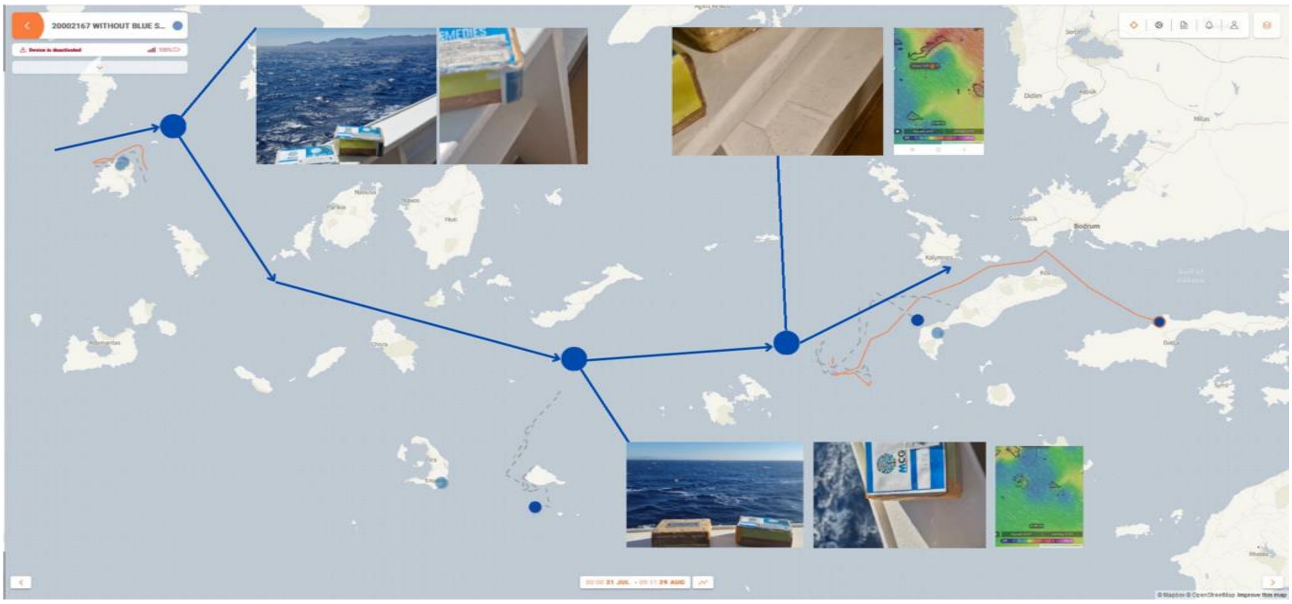

Figure 38. Buoy launch from a Blue Star Ship during a trip to Dodecanese (Source: MCG).

As part of the same research initiative, a second deployment of tracking devices was conducted a few days later, in August 2023, in the same general area, specifically within the Mykonos–Ikaria channel. This deployment was once again carried out from a commercial ferry operated by Blue Star, but in contrast to the previous release, it was conducted further north, in the region between Mykonos and Ikaria (Figure 39). The decision to shift the deployment location slightly northward was made to assess whether variations in buoy trajectories and dispersion patterns could be observed due to minor geographical and hydrodynamic differences within the broader study area.

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Figure 39. Buoy launch from a Blue Star Ship during a trip to North Cyclades (Source: MCG).

The primary objective of this second deployment was to compare its results with those obtained from the earlier deployment conducted in the southern section of the study area in July 2023. Since the meteorological conditions during both periods were nearly identical characterized by the persistence of strong meltemi winds with a northerly direction (5–7 Beaufort) (Figure 40) this comparison allowed for a controlled analysis of current-driven transport and dispersion patterns in the region.

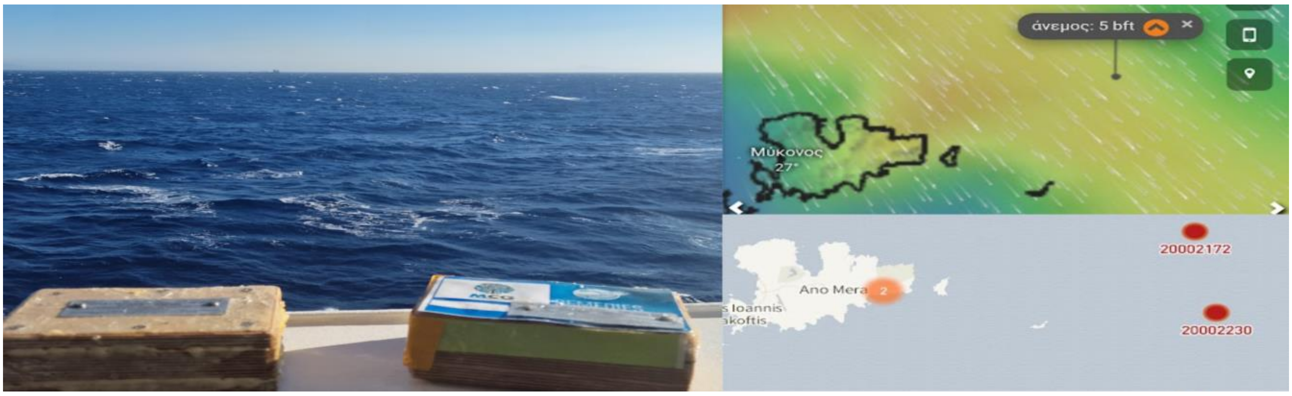

Figure 40. Buoy ready for launch from a Blue Star Ship north of Mykonos (Source: MCG).

This deployment included five wooden buoys and one plastic buoy, following the same experimental design as the previous deployment. The presence of both wooden and plastic buoys was crucial, as it enabled a direct comparison of their respective movement patterns, highlighting potential differences in their drift behaviour due to variations in buoyancy, material properties, and interactions with wind and surface currents.

5.2. Activity in Rivers (Aliakmonas - Evros)

The next phase of the research was conducted in September 2023. Although originally scheduled for an earlier date, the deployment faced unforeseen delays due to the need for official research permits from the relevant governmental authorities. This requirement arose because the targeted study areas—the Aliakmonas and Evros river deltas—are classified as protected ecosystems, necessitating strict regulatory approvals before any scientific activities could proceed.

This phase of the study aimed to expand the understanding of how riverine currents transport floating litter toward the sea. To achieve this, the deployment involved the release of ten tracking devices in the Aliakmonas River delta. These devices were sent to the Municipality of Katerini, which actively supported the initiative by facilitating local logistics and coordinating a team of volunteers (Figure 41) to assist with the project. Concurrently, another ten tracking devices were deployed in the Evros River delta, with the Forest Protection Agency of the Ministry of Environment overseeing their release.

Figure 41. Buoy launch at Aliakmonas with the help of Citizens from Local Municipality (Source: MCG).

This deployment was particularly significant as it marked the final use of wooden buoys in the study. As discussed in previous sections, the wooden buoys encountered several operational challenges, including structural failures and inconsistencies in their tracking performance. These limitations ultimately led to their replacement with more durable plastic buoys, which provided improved reliability and long-term resilience in the aquatic environment.

Recognizing the necessity of refining the methodology, an additional five plastic buoys—constructed from LDPE (Low-Density Polyethylene)—were deployed in the Evros River delta. The primary objective of this addition was to conduct a comparative analysis between the wooden and plastic buoys, evaluating their respective drift characteristics, durability, and interaction with river and coastal currents. Unfortunately, due to the timing of the Greek national elections and shifting administrative priorities within the Municipality of Katerini, a similar comparative deployment could not be carried out in the Aliakmonas River delta.

The selection of the deployment sites was a critical aspect of the study. Following recommendations from local environmental agencies and field experts, both the Aliakmonas and Evros river deltas were identified as optimal study locations. These regions serve as natural accumulation zones for floating plastic litter, making them ideal for assessing the transport dynamics of anthropogenic waste. The insights gained from this deployment are expected to contribute to a broader understanding of plastic pollution pathways, particularly in river-to-sea transport systems.

The timing of the GPS buoy deployments in autumn is of critical importance for understanding seasonal variations in marine and riverine litter transport. During this period, weather patterns, hydrodynamic conditions, and river discharge rates differ significantly from those observed in the summer months, when previous deployments were conducted. In particular, increased precipitation and stronger river outflows in autumn can lead to enhanced transport of plastic litter and floating litter from inland sources to the sea.

Additionally, seasonal shifts in wind patterns and coastal currents may influence the dispersal trajectories of floating materials. By deploying GPS-equipped buoys during this transitional season, researchers can capture a more comprehensive picture of how hydrometeorological factors impact the movement and accumulation of pollutants in aquatic environments. These insights are essential for developing more effective litter management strategies and improving marine conservation efforts.

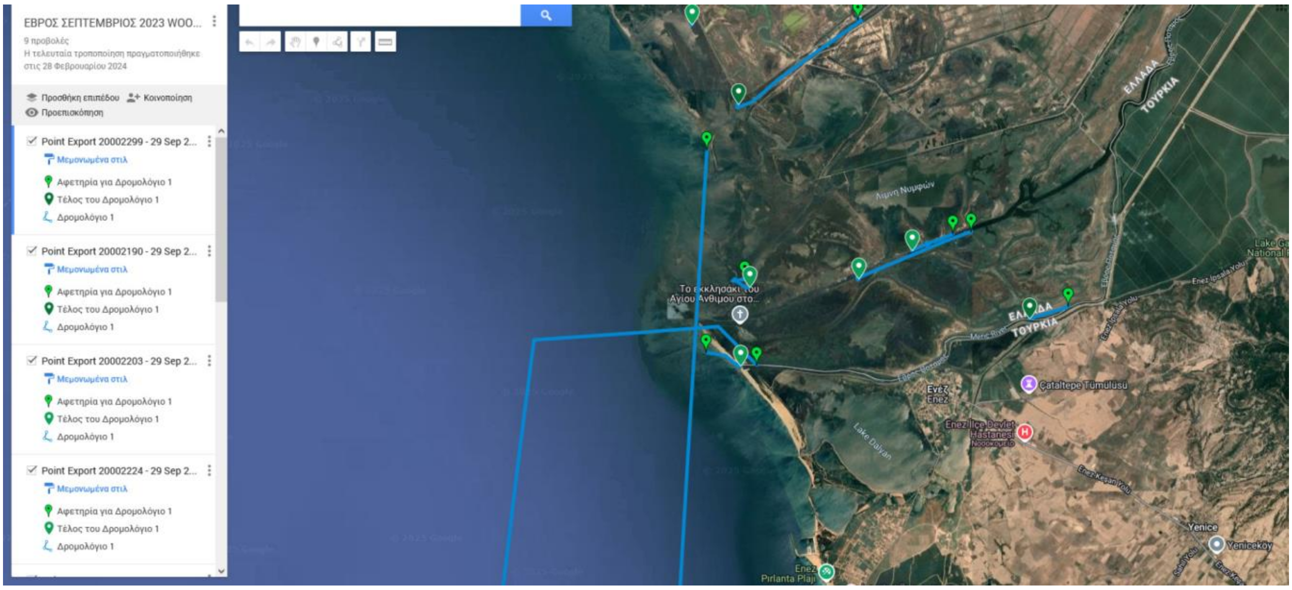

Figure 42. Buoy launch at Evros with the help of Citizens from Local Ministry (Source: MCG).

5.3. Activity in Rivers (Strymonas - Axios)

The next phase of the research was conducted in October 2023 in the Axios and Strymon River regions (Figure 43). As in previous deployments, the timing of the release was a key factor in the experimental design. The decision to conduct this deployment in autumn was based on the seasonal hydrodynamic shifts that occur during this period. Specifically, the onset of early winter rainfall significantly increases river discharge, mobilizing large amounts of litter that have remained trapped within the river systems throughout the dry summer months. By deploying buoys during this transitional phase, the study aimed to capture real-time data on how floating litter is transported downstream, eventually reaching coastal and marine environments.

This phase of the study involved the deployment of ten GPS-tracked buoys in the Strymon River. Of these, four were released near the river delta, allowing them to track immediate dispersion patterns at the river's outflow into the sea, while the remaining six were deployed approximately 10 km upstream, following natural river currents and tributary inflows before entering coastal waters. This dual placement strategy was essential for assessing how litter accumulates and moves along different points of the river's course, providing insight into localized hydrodynamic effects on pollutant transport.

Figure 43. Buoy launch at Strymonas (Source: MCG).

Additionally, five buoys were deployed in the Axios River delta, specifically at the point where the river discharges into the Thermaic Gulf. The selection of this site was deliberate and methodologically significant. The Axios River flows (Figure 44) in close proximity to the Aliakmonas River, creating an interconnected hydrological system that may facilitate interactions between their respective currents. In addition to tracking the dispersion of floating litter, this deployment was designed to explore whether cross-current interactions exist between these two river systems, influencing plastic litter accumulation and transport trajectories. Understanding these hydrodynamic relationships is essential for predicting pollutant pathways, informing coastal litter management strategies, and improving regional conservation policies.

Figure 44. Buoy launch at Axios (Source: MCG).

A notable aspect of this deployment was the exclusive use of newly designed buoys made from LDPE (Low-Density Polyethylene). This marked the complete transition away from wooden buoys, following previous research findings that identified structural weaknesses and performance limitations in earlier prototypes. The LDPE buoys were selected for their enhanced durability, resistance to environmental degradation, and superior tracking capabilities, ensuring longer operational lifespans and more reliable data collection. The adoption of these advanced materials represents an important methodological refinement, enhancing the accuracy and efficiency of long-term monitoring efforts related to plastic pollution transport in freshwater and marine ecosystems.

The deployments were conducted on October 7 and 8, 2023 and involved the release of 15 GPS-equipped devices. In this deployment, all buoys were replaced with ones made of LDPE plastic material.

5.4. Activity Gulf of Mount Athos and Thassos Island

In January 2024, a large-scale deployment of GPS-equipped tracking devices was carried out in the Gulf of Mount Athos and the coastal waters of Thasos (Figure 45). The objective of this operation was to trace the movement of marine litter, identify accumulation hotspots, and analyse the influence of seasonal hydrodynamic conditions on litter dispersion in the region.

A total of 17 GPS devices were released into strategic locations, taking advantage of favourable winter oceanographic conditions. During this period, the prevalence of strong and well-defined sea currents, combined with reduced tourist and fishing activities, provided an optimal setting for accurately monitoring litter transport patterns. The absence of summer-induced variability ensured more consistent data collection, offering valuable insights into the long-term movement and accumulation of floating litter.

This initiative is expected to contribute significantly to the understanding of marine litter dynamics in the area and aid in the development of targeted mitigation strategies. The recorded data will be analysed to support environmental management efforts and inform future policies aimed at reducing pollution in these ecologically significant waters.

Figure 45. Buoy launch at Agio Oros with the help of Citizens (Source: MCG screenshot from gps app).

5.5. Activity Mykonos – Tinos Strait - Kavo Doro

In January 2024, a targeted deployment of GPS-tracked drifter buoys was conducted in the Kavo Doro area and the Mykonos-Tinos Strait to study the movement of marine litter and identify pollution hotspots. The deployment, carried out end route from a Blue Star Ferries vessel, aimed to utilize the strong winter currents and winds to trace the dispersion of floating litter, providing valuable data on litter transport dynamics in this highly active maritime corridor.

A total of eight GPS-equipped devices (Figure 46 & Figure 47) were strategically released at different points along the ferry's route, leveraging the vessel's frequent crossings and access to open-sea conditions. The timing

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of the deployment in January was advantageous due to the prevalence of strong northerly winds (Meltemi remnants and winter gales) and intensified Aegean surface currents, which help reveal natural litter transport pathways. Additionally, winter presents minimal interference from tourism-related marine activity, allowing for cleaner tracking of litter movement patterns.

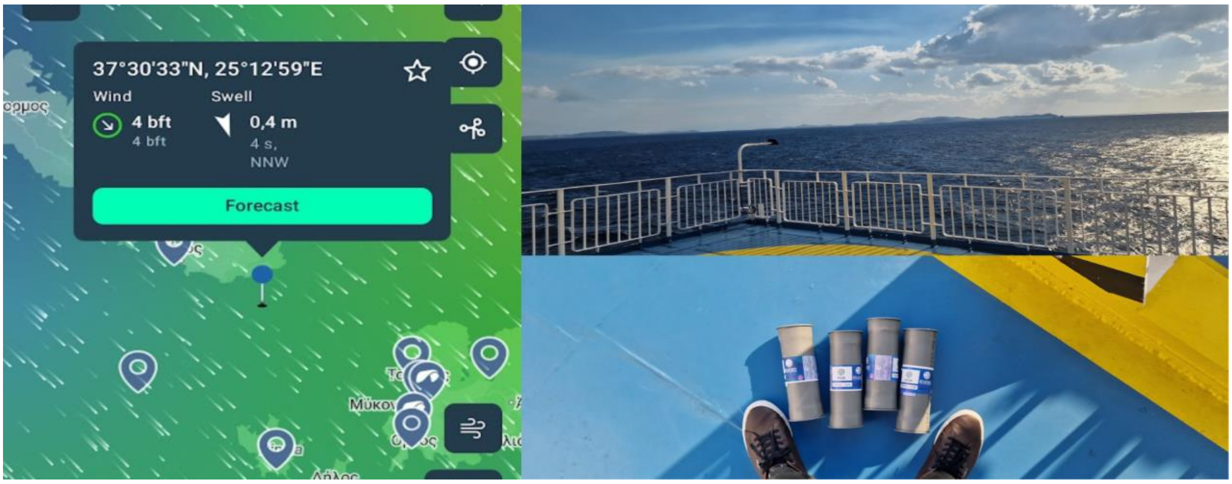

Figure 46. Buoy launch at Kavo Doro in Winter 2024 (Source: MCG).

The two chosen deployment areas offer unique characteristics for litter monitoring. Kavo Doro, known for its powerful cross-currents and high-energy marine environment, serves as a natural dispersion zone where floating litter from the northern Aegean is redistributed. Meanwhile, the Mykonos-Tinos Strait, a major passage between the central and northern Aegean, is influenced by both wind-driven and tidal currents, making it a critical point for tracking the movement of plastic litter that could accumulate in island convergence zones.

By releasing devices along the ferry's trajectory, the study maximized spatial coverage while also ensuring efficient data collection under real-world maritime conditions. The recorded drift trajectories will help pinpoint high-risk pollution areas and contribute to strategic marine litter management efforts in the Aegean region.

Figure 47. Buoy launch at Andros Island in Winter 2024 (Source: MCG).

5.6 Activity Mytilene Coastal Waters - Oinousses

In February 2024, a targeted deployment of 15 GPS-equipped buoys was conducted in the waters surrounding Mytilene (Lesvos) and Oinousses, with the goal of tracking the movement of marine litter and identifying potential pollution hotspots. This initiative was carried out by local fishermen and members of the NERDFISHING team (Figure 48), whose extensive experience in the area provided valuable insight into key locations where marine litter accumulates. Their deep knowledge of regional currents, wind patterns, and seafloor topography ensured that the devices were strategically placed to maximize data collection.

Figure 48. Buoy launch at Oinousses and Lesvos with the help of Citizens (Source: MCG).

5.7. Mykonos – Ikaria channel (Second Round)

The final deployment of the first phase of this research was conducted in March 2024, involving the release of ten buoys with GPS in the Mykonos–Ikaria channel. This deployment was designed to build upon previous experiments in the same region and to examine the effects of seasonal and meteorological variations on floating litter transport and dispersion patterns.

Notably, this release took place in the exact same geographical area as the initial deployment of this research phase, which was carried out in August 2023 with the release of six tracking devices (Figure 49). However, the seasonal differences between the two deployments were significant. The August deployment occurred at the peak of the meltemi season, when strong and persistent northerly winds dominate the Aegean, influencing both surface currents and the movement of floating materials. In contrast, the March deployment was carried out in spring, a period marked by the absence of continuous meltemi winds and the occurrence of alternating wind regimes, with northerly winds (4–6 Beaufort) frequently shifting to strong southerly winds.

The primary aim of this deployment was to assess how different seasonal wind, and current conditions influence the movement of floating objects in the Mykonos–Ikaria channel. Existing scientific studies suggest that during the spring months, a south-to-north flow of surface currents is often observed in the central Aegean, contrasting with the dominant north-to-south movement seen during the meltemi period. This deployment was strategically designed to test whether these seasonal shifts have a measurable impact on the dispersion and accumulation of floating litter. Understanding these dynamic processes is crucial for improving marine litter management strategies, predicting pollution pathways, and enhancing coastal conservation efforts. The buoys were deployed from a commercial ferry operated by BLUE STAR, ensuring that their release occurred under realistic maritime conditions, mimicking the potential transport of litter originating from vessel activities or land-based sources. At the time of deployment, the prevailing wind conditions were northerly at 4 Beaufort, offering ideal conditions for tracking initial drift trajectories.

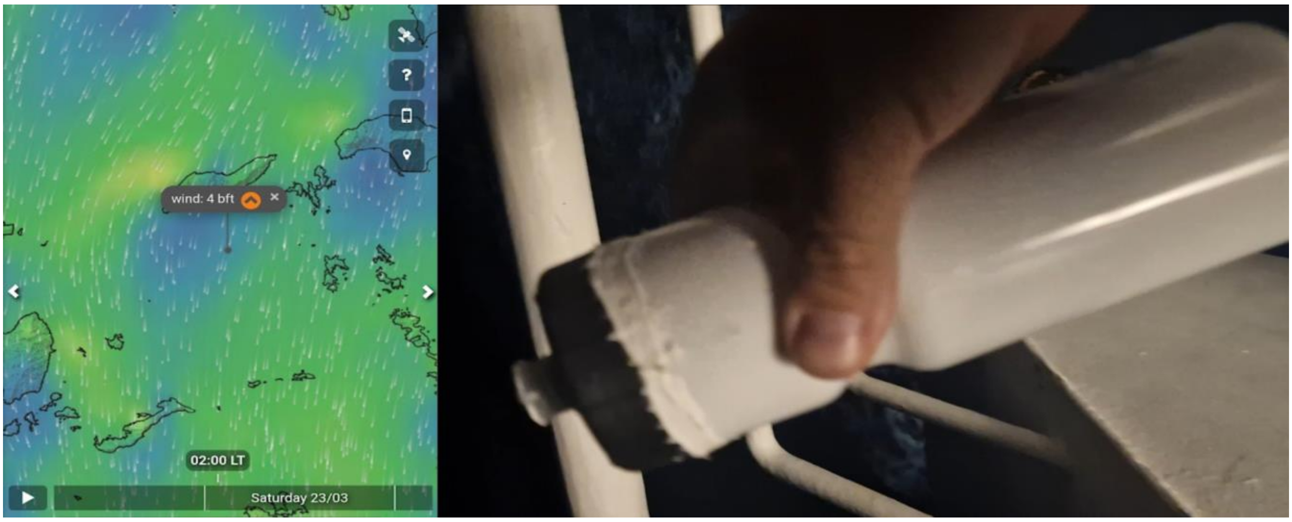

Figure 49. Buoy launch at Central Aegean. (Source: MCG)

This experiment also played a key role in the ongoing refinement of tracking methodologies by allowing a direct comparison between wooden and plastic buoys. Unlike the first deployment in August, which involved a combination of wooden and plastic buoys, this deployment exclusively utilized plastic buoys, marking a complete transition away from the wooden models.

This deployment serves as an important final dataset for the first phase of the research, allowing for direct seasonal comparisons and contributing to a comprehensive understanding of floating litter transport mechanisms in the Aegean Sea. The insights gained from this study will be instrumental in shaping future marine conservation policies, refining litter mitigation strategies, and informing environmental decision-making processes at both regional and international levels.

5.8. Conclusions and outlooks from activities in round1

With the completion of the above action, a cycle of activities spanning approximately nine months comes to an end. This initiative involved the deployment of over 100 GPS devices at all critical locations identified as potential hotspots for plastic litter accumulation, the devices already covered more than 11.000km distance as well as a broader tracking of their movement. The monitoring also included the largest rivers in Northern Greece.

During these operations, several challenges arose, leading to multiple adjustments to the initial plan to ensure the program's successful completion and long-term sustainability. For instance, as indicated above, the buoy casing was modified from wood to plastic.

In the following section below, we will detail the modifications implemented and the reasons that necessitated these changes. Moreover, we will see the next phase or the research, which includes 100 more Buoys with GPS but at this time with new GPS devices and in new Strategic locations (Figure 50).

Figure 50. Spatial dispersion of buoys throughout the Aegean Sea at the conclusion of the first phase of the study (Source: MCG screenshot from gps app).

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6. Activities (Round 2)

6.1. Expanded Deployments and Adjustments

The second phase of the research involved the deployment of an additional 100 buoys with GPS in either previously studied locations but at different seasonal periods or entirely new locations. The primary objective was to track the previously deployed buoys over an extended period and, based on their recorded trajectories and results, determine the most suitable locations for the subsequent deployment of the remaining 100 buoys with GPS.

After a monitoring period of approximately 3–4 months, the first dataset of results and initial conclusions had been analyzed, allowing researchers to identify the optimal locations for the next round of deployments. However, as the project's timeline was approaching its conclusion, it became evident that the final deployment sites needed to be selected within the available time constraints.

To address this issue, MCG thought the coordinators submitted request for a one-year extension (*prolongation*) to ensure that deployments could be carried out in specific critical locations. These included river systems, where adverse winter conditions in 2024 resulted in insufficient data collection, and northern Greece (Thasos, Halkidiki), where a winter-time comparison study was planned.
Despite the request, the MCG was granted only a six-month extension, which was officially confirmed shortly before the end of 2024.

During this period, an unexpected challenge emerged. The original GPS device manufacturer, LightBug, based in the United Kingdom, reported significant delays in the delivery of the remaining 100 tracking devices due to a shortage of raw materials from China. This setback meant that the new batch of devices would take approximately 4–5 months to be delivered to Greece, factoring in both production time and the necessary shipping and customs clearance procedures.

To mitigate this delay, the research team sourced an alternative supplier who could deliver the required devices more quickly, at a lower cost, and with nearly identical features and performance capabilities. This decision ensured that the study remained on schedule and that the deployment of the second batch of buoys with GPS proceeded without further disruptions.

Selection of Deployment Locations for the Second round

The locations selected for the second phase (Figure 51) were largely the same as those in the first phase, with a few strategic additions:

1. The Kavo Doro Region – This area was identified as a critical corridor for marine litter movement, yet very little data had been available from previous studies. Given its geographical position and strong current systems, Kavo Doro plays a key role in the redistribution of floating litter, making it a high-priority study site for this phase of the research.Euboean Gulf – Deployments were also conducted in the Euboean Gulf, an area previously omitted from the first phase. Given its semi-enclosed nature and strong tidal influences, the gulf presented a unique opportunity to study how floating litter behaves in restricted water bodies compared to the open sea.
2. Skyros Island – This region was included in the second phase after it was determined that no buoy data had been collected from the western Aegean during the first phase. This addition aimed to fill the data gap and provide a more comprehensive understanding of floating litter transport patterns across the Aegean Sea.

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3. Second Release at Dodecanese region
4. Second Release at Lesvos - Oinousses (North - East Aegean)

Figure 51. Areas for investigation in round 2 (Source: MCG).

By expanding the scope of deployments and refining the selection of study areas, the second phase of the research aimed to generate more robust and comprehensive insights into marine and riverine litter transport dynamics, ultimately contributing to the development of more effective pollution mitigation and environmental management strategies.

6.2. Activity Mykonos – Tinos Strait - Kavo Doro

During this phase of the research, 49 buoys with GPS were deployed across four distinct locations in the Cyclades (Figure 52) all of which are known for their strong currents and complex meteorological conditions. The deployment was strategically conducted in spring, a period characterized by predominantly northerly winds but with frequent alterations between southerly and easterly wind patterns. This contrasts with the summer season, where the persistent northerly meltemi winds dominate, leading to different hydrodynamic behaviours in the Aegean Sea.

Figure 52. Areas for investigation In Cyclades and Euboean Gulf. (Source: MCG)

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The buoys were released at four key locations, each chosen for its oceanographic significance:
10 buoys in the Kavo Doro Strait – This strait is one of the strongest wind corridors in the Aegean, acting as a critical passage for marine litter and currents between the Euboean Gulf and the central Aegean.

Figure 53. Buoy launch at Kea - Makronisos (Kavo Doro - Euboean Region) (Source: MCG).

12 buoys in the Kea–Makronisos Strait – This narrow channel between Kea and Makronisos is subject to intense hydrodynamic activity, where northern and southern currents frequently interact, making it an important site for studying litter transport.

Figure 54. Buoy launch at Kavo Doro Region (Source: MCG).

10 buoys in intermediate locations between Andros, Tinos, and Mykonos – This region represents a complex marine environment influenced by multiple current systems converging from the northern Aegean and the central Cyclades, impacting the dispersal patterns of floating materials.

17 buoys in the Euboean Gulf – The semi-enclosed nature of the Euboean Gulf, combined with tidal influences, makes it an important area for examining how floating litter behaves in restricted coastal environments.

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The primary goal of this deployment is to compare the drift trajectories of the buoys with previous deployments conducted in winter 2024 and summer 2023. The seasonal contrast is particularly important, as the spring wind regime consists of strong northerly winds interspersed with southerly and easterly wind events, whereas the summer meltemi season is characterized by continuous, powerful northerlies. By analyzing the differences in buoy movement, this research aims to provide valuable insights into the seasonal variations of current-driven transport dynamics in the Aegean.

As with previous phases of the study, all buoys were deployed from commercial ferries operating on established routes. This approach was chosen to ensure optimal distribution of the buoys, minimizing the risk of immediate beaching or unintended retrieval by swimmers or fishermen. Deploying buoys in this manner allows them to better integrate into natural current patterns, providing more accurate and representative data on floating litter transport across these critical marine corridors.

6.3. Activity Skyros (West Aegean)

As part of this research phase, 10 GPS-tracked buoys were deployed in the southern coastal waters of Skyros, a strategically significant location for studying the transport dynamics of plastic litter in the Aegean Sea. Skyros is situated in the western-central Aegean, making it a critical junction in the movement of marine litter. This region is directly influenced by current systems that transport litter from two major sources:

Northern Greece – litter from riverine and coastal outflows in the northern Aegean is transported southward, passing through this corridor before being redistributed toward the central and southern Aegean. Eastern Greece and the Thermaic Gulf – The Thermaic Gulf, which receives high volumes of anthropogenic litter from urban and industrial centers, serves as another key entry point for plastic pollution into the Aegean. Oceanographic patterns suggest that much of this litter follows southward drift pathways, eventually reaching the waters around Skyros.

The seasonal timing of this deployment is particularly relevant, as it allows for a comparative analysis of plastic litter dispersion under different hydrodynamic conditions. Given that Skyros lies at the intersection of multiple current systems, studying its role in seasonal plastic transport is essential for understanding how floating litter is redistributed across the Aegean.

By deploying buoys in this region, the study aims to track real-time movements of plastic litter, contributing to a broader assessment of pollution hotspots and accumulation zones in the Aegean Sea. These insights are crucial for improving litter management policies, informing marine conservation strategies, and enhancing predictive models of plastic pollution transport in the region.

6.4. Activity Dodecanese

As part of this research phase, 15 GPS-tracked buoys were deployed (Figure 55) in the waters between Patmos and Leros, within the Dodecanese island complex. This region was strategically selected due to its dynamic current systems, which play a crucial role in the transport and accumulation of plastic litter in the southeastern Aegean Sea.

The Dodecanese region serves as a key transit zone for floating litter, influenced by seasonal variations in wind and current patterns. The spring 2024 deployment was specifically designed to compare plastic litter movement under different seasonal conditions, building on previous deployments conducted in summer 2023 and March 2024. In summer 2023 the activity was conducted during the meltemi season, when strong, persistent northerly winds dominate the Aegean, causing a southward push of surface currents, expected to result in faster and more direct transport of floating litter toward the southeastern Aegean and beyond.

On the other hand, Spring 2024 Deployment carried out during a period of weaker, alternating wind patterns, where northerly, southerly, and easterly winds fluctuate and allows for the study of more complex drift trajectories, as plastic litter movement is likely to be less linear and more influenced by regional current interactions.

By analyzing the differences between these seasonal deployments, this research seeks to better understand the variability of plastic litter transport dynamics in the Dodecanese. The findings will contribute to improved predictive models, helping to identify pollution hotspots and optimize marine conservation efforts in this ecologically significant region.

Figure 55. Buoy launch at Dodecanese Region (Source: MCG).

6.5. Activity Mytilene (East Aegean)

As part of this research phase, 10 GPS-tracked buoys were deployed (Figure 56) in the broader marine area surrounding Lesvos, Chios, and Oinousses, a region of high oceanographic importance for plastic litter transport in the northeastern Aegean Sea.

The Lesvos–Chios–Oinousses region is a critical zone for studying floating litter movement, as it lies along major current pathways connecting the northern Aegean with the central and eastern Mediterranean. This deployment was specifically designed to compare litter transport dynamics under different seasonal conditions, building on previous research conducted in winter 2024 within the same area.

The Winter 2024 deployment was conducted during a period of strong and dominant northern winds, which facilitated the direct and rapid transport of litter southward toward the central Aegean. The prevailing currents during this season were relatively stable and directional, resulting in high-speed drift patterns with limited deviations.

In contrast, the Spring 2024 deployment took place during a seasonal transition, characterized by alternating wind patterns, including northerly, southerly, and easterly winds. This variability created an opportunity to examine more complex and dispersed drift trajectories, as the changing wind conditions and weakened dominant currents led to a less predictable movement of floating litter. By analyzing the differences between these two seasonal deployments, the study aims to better understand how seasonal wind and current variations influence the transport of plastic litter in the northeastern Aegean. Given that this region is an important gateway for marine pollution movement between the northern and central Aegean, these findings will provide key insights into long-term plastic litter dispersion trends, supporting marine conservation strategies and pollution mitigation efforts.

Figure 56. Buoy launch at Lesvos (Mytilene) (Source: MCG).

6.6. Activity Limnos (North-East Aegean)

As part of this research phase, 16 GPS-tracked buoys were deployed in the marine area surrounding Limnos (Figure 57) marking the first deployment in this region within the framework of this study. The strategic timing and location of this release were carefully selected to examine the hydrodynamic characteristics of the area, particularly in relation to plastic litter transport dynamics.

Limnos is situated in a crucial transition zone between the northern and central Aegean, making it an important site for studying regional current patterns and their role in the redistribution of floating plastic litter. The seasonal timing of this deployment in spring allows for a comparative analysis of how different wind and current conditions influence litter movement, particularly in relation to wintertime circulation patterns observed in earlier phases of the study.

A key aspect of this deployment is the investigation of the influence of salinity variations on plastic litter movement. The northern Aegean is directly affected by lower-salinity waters originating from the Black Sea, which enter through the Dardanelles and mix with local currents. This contrast in salinity levels can affect buoyancy, drift speeds, and dispersion trajectories, making Limnos an ideal location for assessing these processes.

This study also aims to compare findings from the Limnos deployment with previous research conducted in winter 2024 in the broader Mount Athos and Thasos region. The winter deployment took place under strong and sustained northern winds, which resulted in rapid, southward-directed litter transport. In contrast, the spring deployment in Limnos occurs during a period of fluctuating wind patterns, including northerly, southerly, and easterly influences, which may lead to more complex and variable drift trajectories. By analyzing the differences between these seasonal deployments, this research seeks to enhance our understanding of how regional hydrodynamic forces influence plastic pollution transport in the northern Aegean. These findings will contribute to improved predictive models of marine litter accumulation and inform environmental management strategies aimed at mitigating plastic litter impacts in the region.

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Figure 57. Buoy launch at Limnos (Source: MCG).

6.7. Conclusions from round 2

At the end of March 2024, the second phase of buoy deployments was successfully completed, marking the conclusion of all in-field deployment activities carried out as part of the REMEDIES program. This milestone represents a significant step toward understanding the transport dynamics of plastic litter across the Aegean Sea and major Greek river systems.

By this stage, a total of 203 GPS-tracked buoys had been strategically deployed across a wide range of locations, including the open Aegean, critical marine straits, and major river mouths. These deployments were designed to cover all potential plastic pollution entry points into the Mediterranean, ensuring a comprehensive seasonal and meteorological analysis of floating litter transport. The study accounted for variations in current regimes, wind patterns, and hydrological conditions, offering valuable insights into how plastic litter is redistributed throughout the region. In certain key locations, repeat deployments were conducted to refine the dataset, enabling a direct comparison of seasonal variability and the identification of persistent pollution pathways. The buoys collectively travelled over 15,000 kilometres, significantly surpassing the initial targets set for the program. As of March 2024, the research has successfully achieved all major Key Performance Indicators (KPIs) outlined for this phase, including:

- The successful deployment of 200 buoys, reaching the program's primary quantitative target.
- Tracking over 15,000 kilometres of drift trajectories, far exceeding the initial 10,000 km objective.
- Identification and mapping of plastic accumulation hotspots, which will inform future mitigation efforts.

With these objectives met, the program now transitions into its final phase, focusing on the retrieval of buoys from the sea. This retrieval process is scheduled to take place by the end of the program, in parallel with Task 2.4, ensuring that all environmental impact considerations are addressed. A detailed presentation and analysis of the findings from these deployments will be provided in Chapter 6, where the plastic accumulation hotspots identified throughout the study will be examined, alongside other key research outcomes, offering a comprehensive assessment of plastic litter transport and distribution in the region.

7. Research and Findings

7.1. Preliminary Observations on the Movement of GPS Buoys in the River Systems of Northern Greece

The deployment of GPS buoys in selected rivers of Northern Greece during the monitoring period provided limited results, which can be attributed to a combination of hydrological, meteorological, and logistical factors. The following key challenges were identified:

1. **Reduced River Discharge Due to Prolonged Drought Conditions**

   The autumn of 2023 and the winter of 2024 were marked by unusually low precipitation levels, leading to significantly reduced river discharge across much of Northern Greece. These hydrological conditions followed a particularly dry summer, compounding the overall water scarcity. As a result, the buoy trajectories were limited in distance and speed, with several units exhibiting minimal or no displacement over time.

2. **Temporal and Technical Constraints of the Study**

   The monitoring campaign was constrained by a relatively short observation window and a limited number of available buoys. Given the seasonal variability of river systems—particularly in Mediterranean climates—longer-term data collection is essential to capture representative flow patterns and litter transport dynamics. Moreover, the research period coincided with atypical weather conditions, including persistent southern winds. These prevailing winds, contrary to the more common northerly winds, further disrupted the expected flow-driven movement of the buoys and may have altered surface water circulation within the river channels.

Despite the aforementioned limitations, the collected data allows for several important conclusions regarding the origin and transport of plastic litter in the studied river systems:

- **Predominantly Domestic Waste Sources in Certain River Deltas**
  In the deltas of the Axios, Aliakmonas, and Strymon rivers, the majority of detected macroplastic litter appears to be of domestic origin, likely linked to local tourism, agricultural runoff, and industrial activities. This pattern is largely attributed to the presence of hydroelectric dams along these rivers, which act as retention structures. These dams effectively block the downstream movement of litter originating from upstream transboundary sources, thereby isolating the river basins from international plastic inputs.

- **Transboundary Waste in the Evros River Basin**
  Conversely, in the Evros River, where no such dams exist, the detection of foreign-origin plastics—primarily from Bulgaria and Turkey—was more pronounced. This highlights the transboundary nature of plastic pollution in shared river systems and underscores the need for international collaboration in riverine litter management.

- **Impact of Hydrotechnical Infrastructure on Waste Transport Dynamics**
  Beyond acting as physical barriers, hydroelectric dams also significantly modify the hydrodynamic behavior of rivers. By regulating discharge and altering flow velocity, they directly influence the rate and trajectory of litter transport, affecting both the dispersion and the eventual accumulation zones of plastic litter within the riverine and estuarine environments.

7.1.1 Axios River: Evidence of Waste Accumulation in Deltaic Reedbeds

Among the four rivers studied through the deployment of buoys with GPS, the Axios River demonstrated the lowest mobility. None of the devices launched in this river travelled a significant distance; instead, most became rapidly entrapped in dense reeds (*Phragmites sp.*) shortly after deployment.

These observations suggest that the Axios contains extensive zones of stagnant or low-flow water (Figure 58) particularly in its lower reaches, which impede the downstream transport of floating objects. As a result, the river delta functions as a major accumulation zone—or hotspot—for plastic litter, especially under conditions of reduced river discharge. In such scenarios, litter tends to become trapped within reedbeds, preventing further movement toward the marine environment.

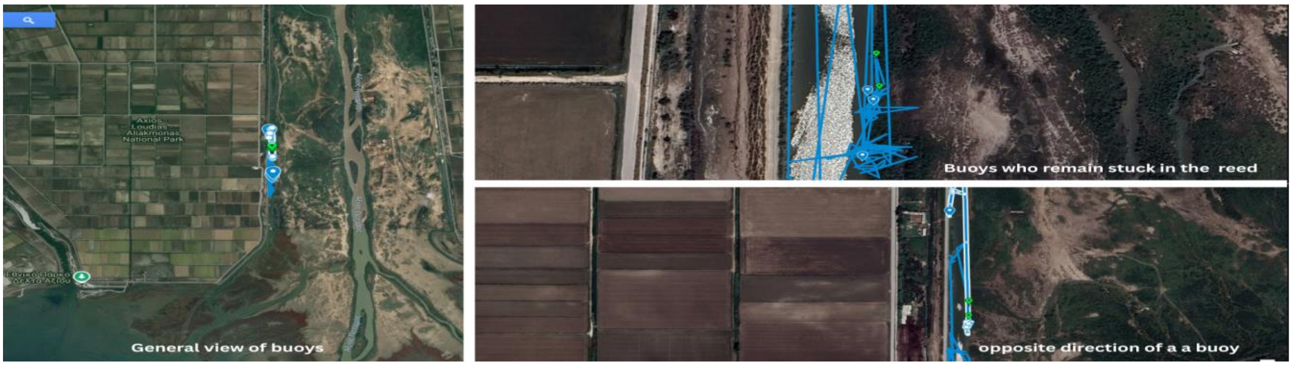

Figure 58. Buoy at Axios river and stuck devices (at the right) (Source: MCG).

Supporting this conclusion, average daily speeds of all buoys were extremely low (*Buoys at Axios distance and Speed*), indicating minimal flow velocity throughout the study period. Notably, the maximum distance travelled by a single buoy was a mere 2.6 kilometres over nearly three months, further reinforcing the hypothesis that floating litter within the Axios River is either retained within the fluvial system or immobilized in riparian vegetation (Figure 59)

Table 3.Buoys at Axios distance and Speed

Buoy identification number	Maximum Distance (km)	Maximum Speed (km/h)
20002161	1.0	0.02
20002189	1.0	0.05
20002254	2.6	0.04
20002213	2.0	0.02

These findings underscore the importance of identifying natural retention zones within riverine networks, as they play a critical role in the spatial distribution of plastic pollution. Moreover, they highlight the necessity for targeted litter management strategies in such high-retention environments to mitigate long-term environmental accumulation.

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Figure 59. Buoy at Axios river. This Figure presents how many time the device send a location at the same spot. (Source: MCG)

7.1.2 Buoy Deployment in the Aliakmonas River:

Following the study of the Axios River, attention was turned to the Aliakmonas River, where 10 buoys with GPS were deployed. Of these, 9 buoys successfully transmitted data, while one remained inactive for unknown reasons.

It is worth noting that the devices used in the Aliakmonas deployment were among the earliest prototypes of the study, constructed primarily from wooden materials. Later findings revealed that the buoy material significantly affects transport dynamics, as wooden devices tend to have higher mass and lower buoyancy, potentially altering their movement compared to plastic litter typically found in aquatic environments.

Despite their heavier structure, the buoys in the Aliakmonas exhibited higher average daily velocities (*Buoys at Aliakmonas distance and Speed*) than those in the Axios. This suggests that the Aliakmonas maintains a more stable and continuous flow regime, which appears to facilitate the long-distance transport of floating litter. Supporting this, three buoys were observed exiting the river delta, traveling considerable distances in the Aegean Sea. One of these even approached the island of Skiathos.

Table 4. Buoys at Aliakmonas distance and Speed

Buoy identification number	Maximum Distance (km)	Average Daily Speed (km/h)
20002208	9.526	0.155
20002032	0.3	0.108
20002117	7.483	0.169
20002170	16.78	0.107
20002206	205.01	0.399
20002211	14.323	0.237
20002215	0.029	0
20002223	38.5	0.255
20002196	2.437	0

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As illustrated in Figure 1, prevailing coastal currents in the area tend to move parallel to the shoreline, traveling southward along the western coast of the Aegean before veering toward the central Aegean through Cape Kafireas (Kavo D'Oro). In line with this pattern, two of the three buoys followed this coastal trajectory, eventually reaching Alykes Kitrous and Korinos Beach, a well-known tourist area with several beachfront hotels.

One of these buoys was actually retrieved by a local hotel owner, who reported that it had washed ashore in an area where plastic litter frequently accumulates—providing field-based validation that the site may serve as a coastal hotspot for marine litter.

The third buoy that exited the delta followed a similar path, driven by surface currents and wind, and ultimately reached the vicinity of Skiathos Island (Figure 60), confirming the potential for long-range litter transport from riverine to insular environments in the northern Aegean.

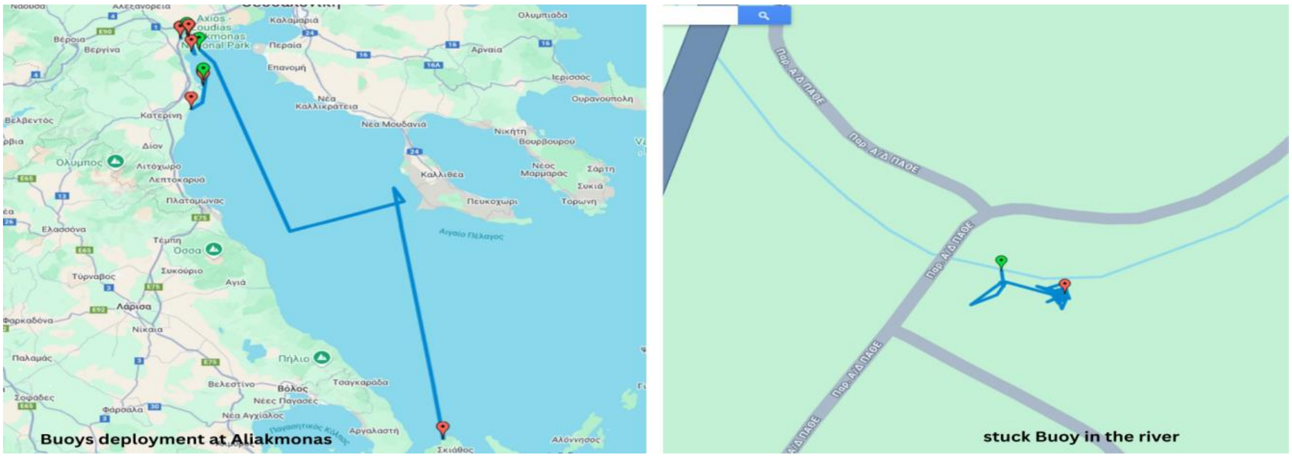

Figure 60. Buoy at Aliakmonasriver. This Figure presents the movement of buoys via the app an a stuck device at the right (Source: MCG).

7.1.3 Strymonas River: Low Flow, Entrapment, and a Potential Coastal Hotspot

The Strymonas River exhibits buoy movement patterns similar to those observed in the Aliakmonas River, with greater mobility (*Table 5*) than the Axios, yet still characterized by generally low buoy velocities due to reduced river flow conditions during the monitoring period.

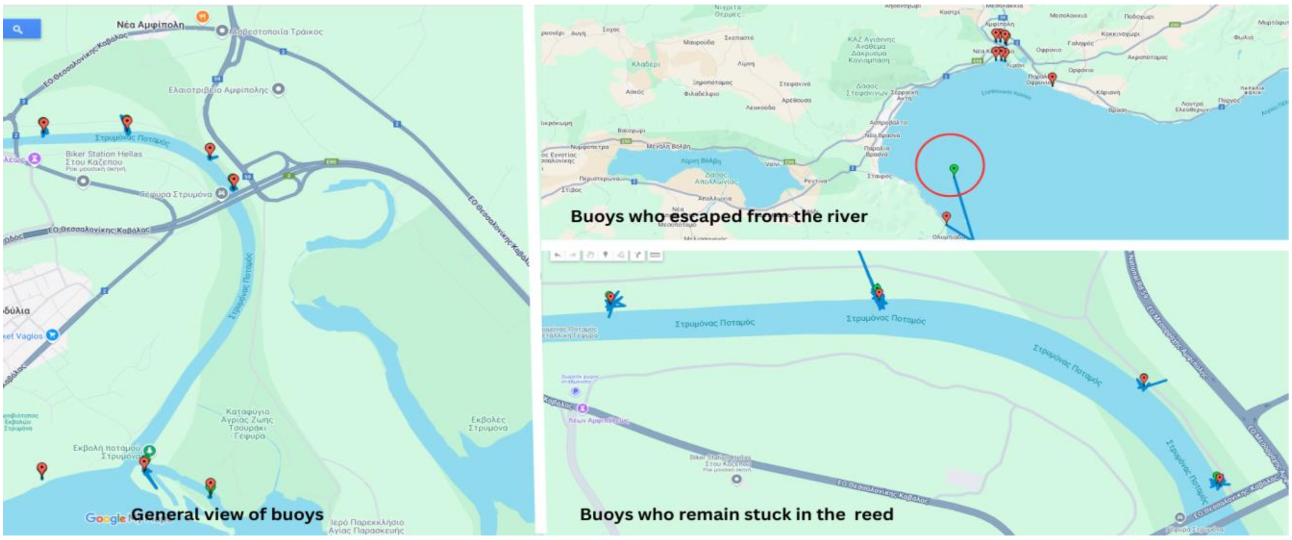

Figure 61. Buoy at Strymonas. This Figure presents the movement of buoys via the app and stuck devices at the right (Source: MCG).

Table 5. Buoys at Strymonas distance and Speed

Buoy identification number	Maximum Distance (km)	Average Daily Speed (km/h)
20002053	0.1	0.06
20002068	1.0	0.04
20002162	0.1	0.06
20002171	2.9	0.05
20002194	1.2	0.08
20002198	0.2	0.06
20002204	0.1	0.07
20002210	0.1	0.06
20002246	0.4	0.05
20002262	11.2	0.06

In addition to the low discharge, the meandering nature of the river—with frequent curves and directional shifts—tends to deflect buoys toward the riverbanks (Figure 61 and Figure 62). There, in combination with the presence of dense, tall reeds beds, the devices often become entrapped, preventing them from continuing their journey toward the sea as was the case shown in Figure 62.

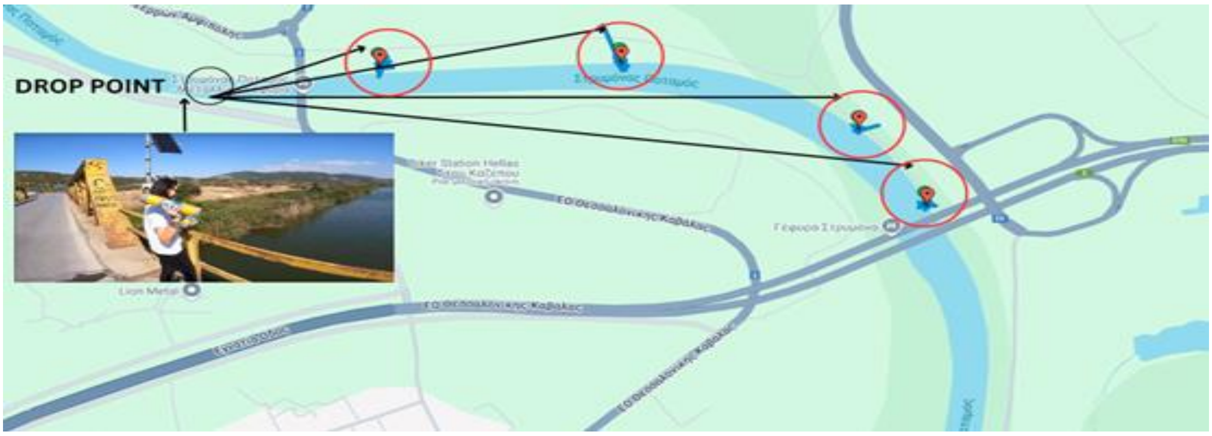

Figure 62. Buoy at Strymonas. (Source: MCG)

This pattern is further illustrated by the number of GPS signals transmitted by each device from the same location over extended periods—an indicator of prolonged stationary phases caused by physical obstructions near the banks.

Of all the deployed buoys in the Strymonas, only one successfully exited the river system and entered the marine environment (Figure 63). Interestingly, despite prevailing southerly wave and wind conditions at the time, the buoy followed the wind and wave trajectory and eventually reached the Olympiada coastal area. As observed in the accompanying satellite imagery, this location appears to act as a potential hotspot for marine litter accumulation, further supported by the orientation of nearby small streams and drainage basins, which also converge toward this specific coastal zone.

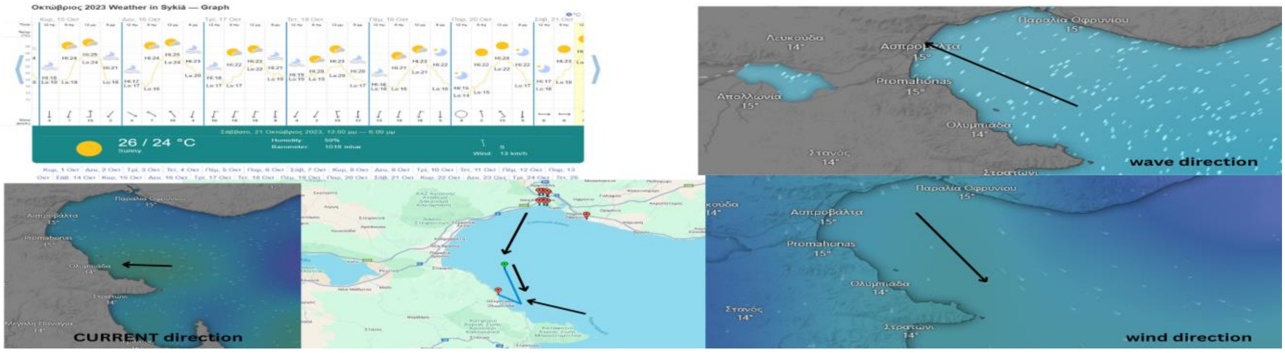

Figure 63. Weather conditions and current movement at Strymonas during the research in Autumn 2023 (Source: MCG).

These findings highlight the complex interplay between river morphology, river flow dynamics, and wind-wave interactions, and point to the importance of considering both inland and coastal hydrodynamics when identifying key plastic accumulation zones.

7.1.4 Evros River: High Mobility and Transboundary Marine Litter Transport

Among all rivers examined in this study, the Evros River demonstrates the highest degree of hydrodynamic activity and litter mobility (*Table 6*). Notably, it is the only major river in Northern Greece that remains undammed by hydroelectric infrastructure, allowing an uninterrupted flow of water—and by extension, floating litter—towards the Aegean Sea. This makes the Evros a critical vector for transboundary marine litter, with litter originating from upstream regions in Bulgaria and Turkey. The significance of this issue has been corroborated by local environmental authorities, who also provided support during the deployment of tracking devices and field data collection.

Table 6. Buoys at Evros distance and Speed

Buoy Identification Number	Max Distance (km)	Average Speed per Day (km/h)
20002109	1.6	no data
20002121	0.1	no data
20002176	53.9	2.0
20002179	0.3	no data
20002182	0.5	no data
20002182	3.4	no data
20002190	0.0	no data
20002203	0.9	no data
20002205	0.5	no data
20002207	3.2	no data
20002217	156.3	2.0
20002224	0.7	no data
20002279	1.9	no data
20002299	0.0	no data
Total	223.3	no data

In line with observations from other rivers, several GPS-tracked buoys deployed in the Evros became entangled in riparian vegetation (Figure 64), particularly dense reed beds, resulting in localized stagnation and immobilization. However, a substantial proportion of the devices managed to traverse distances exceeding 20 kilometres, a clear indication of robust flow regimes and continuous hydrological connectivity to the marine environment.

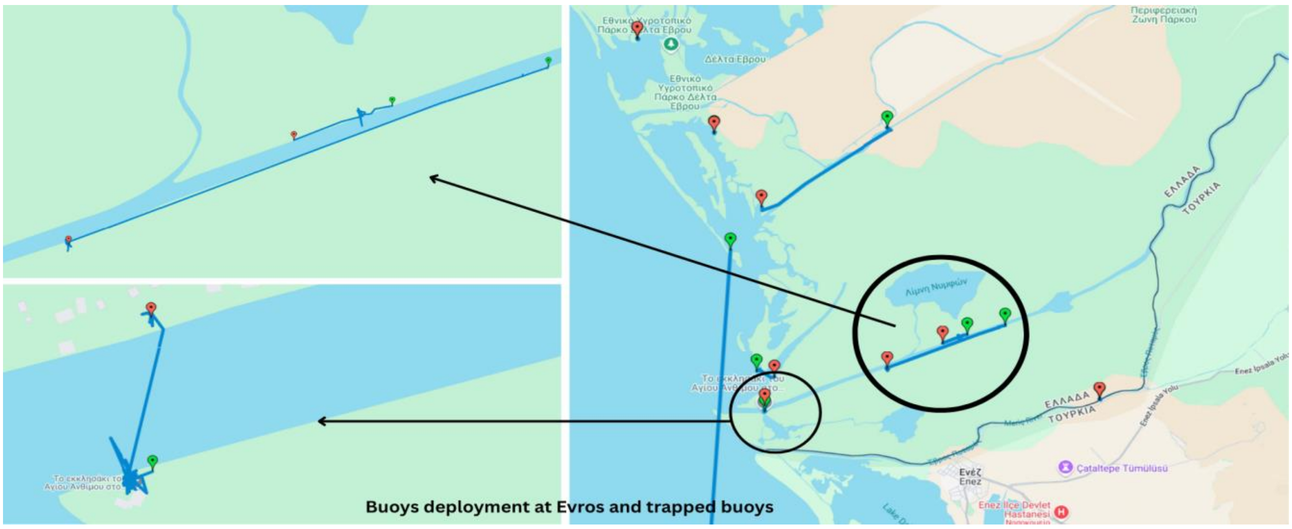

Figure 64. Buoy with GPS at Evros. This Figure presents the movement of buoys via the app and stuck devices at the right (Source: MCG).

To investigate the interaction between fluvial discharge, marine currents, and prevailing wind conditions in the transport of floating litter, we examine in detail the trajectory of device ID 20002217 (Figure 65). This unit was deployed on September 29, 2023, at the estuary of the Evros River under moderate southerly winds. Owing to favourable conditions and an open-water entry point, the device remained unobstructed and stationary for two days.

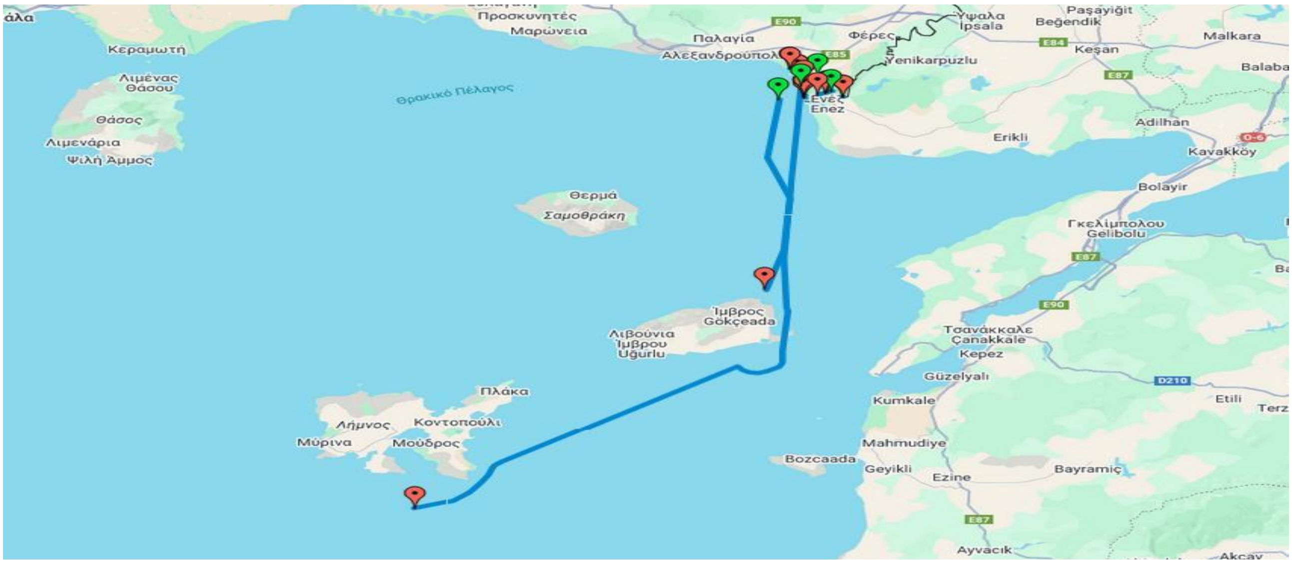

Figure 65. Buoy with GPS at Evros. This Figure presents 2 device escaped from the river into the sea (Source: MCG).

On October 1, 2023, northerly winds commenced, prevailing for the following week (Figure 66). This resulted in a sustained southward movement of the device at an average velocity of approximately 2 km/h, ultimately covering a total distance of nearly 90 km.

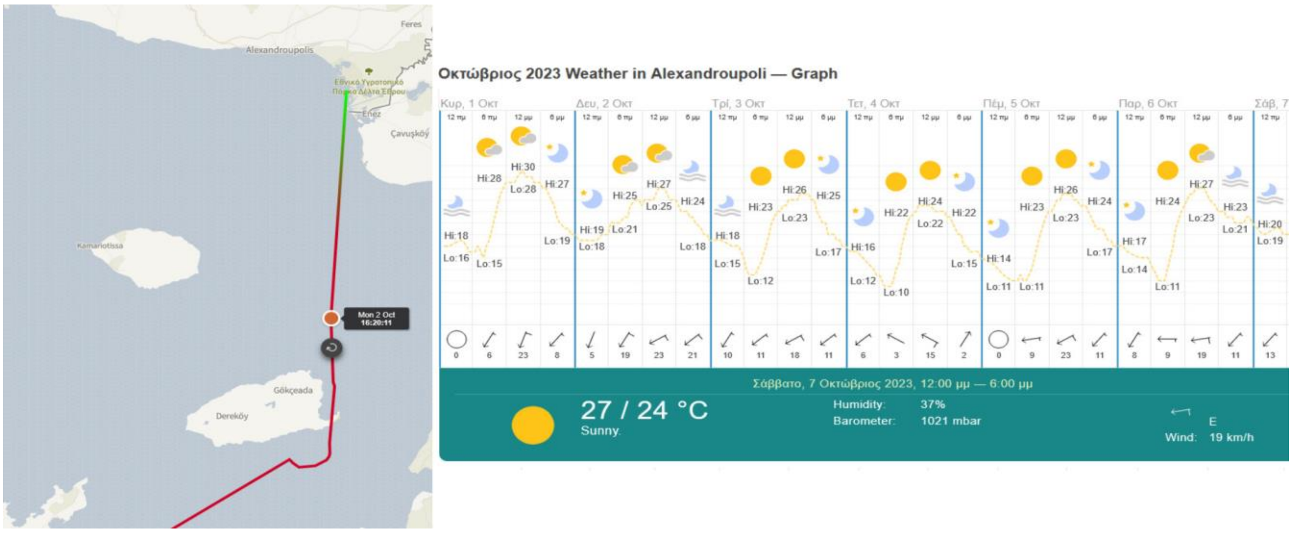

Figure 66. Weather conditions at Evros during the Research (Source: MCG).

On October 3, 2023, (Figure 67), the device approached the island of Imvros, while easterly winds of 17 km/h were recorded in the vicinity. Despite these easterly winds, the device did not drift eastward as expected; instead, it continued on a south-westerly course. This deviation is attributed to the influence of northward-flowing marine currents entering the Aegean from the Thracian Sea. Consequently, the device bypassed the eastern coastline of Lemnos and was eventually retrieved on its southern shores by a local fisherman.

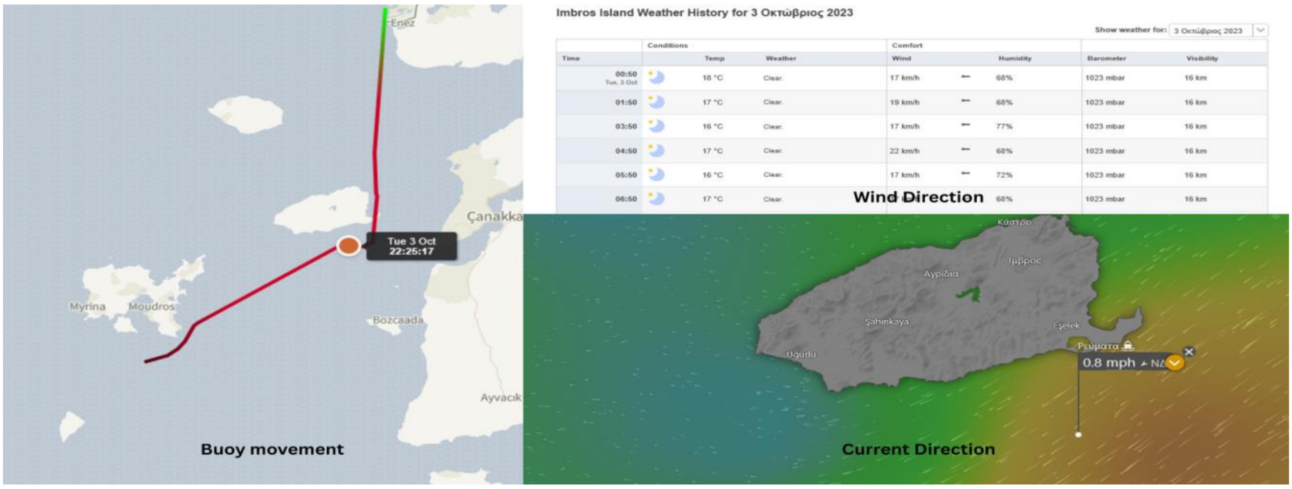

Figure 67. Weather conditions at Imvros and Limnos during the Research (Source: MCG).

This case highlights the predominance of marine currents over wind forcing (Figure 67) in determining the final trajectory of floating objects. Even marginal shifts in current direction can induce significant course deviations. This is further illustrated by the path of device ID 20002176, which initially mirrored the trajectory of 20002217 but diverged on October 2, likely due to a small-scale hydrodynamic variation.

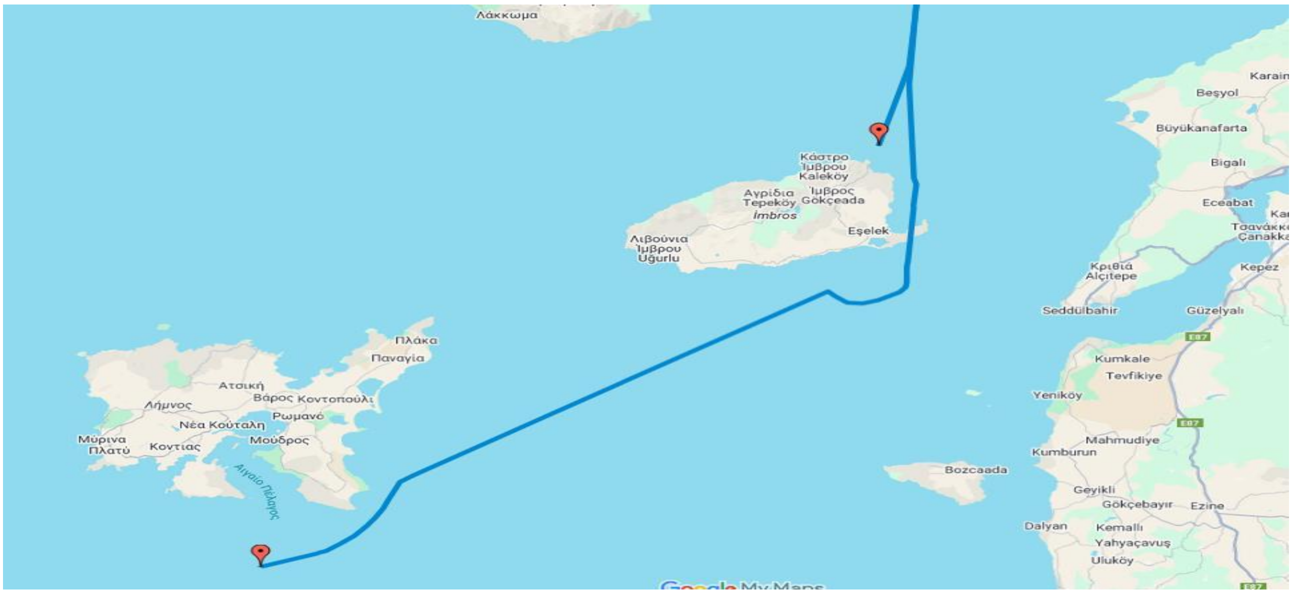

Figure 68. Movement of buoy near Imvros and Limnos (Source: MCG).

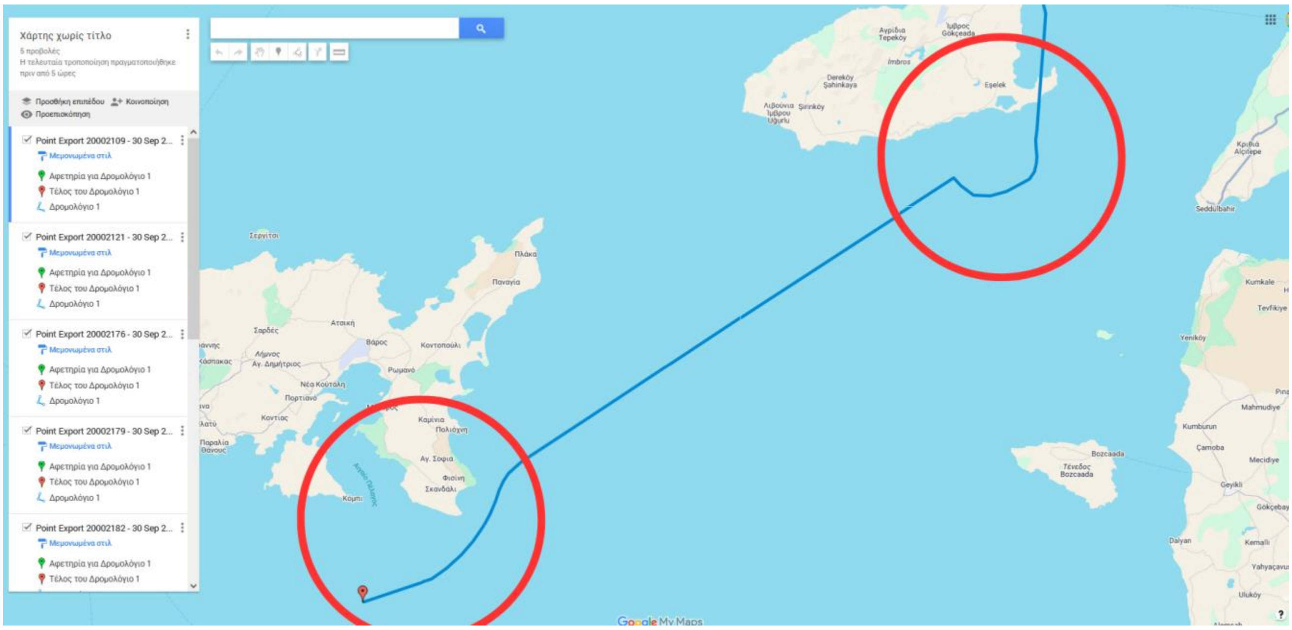

Figure 69. Recurring phenomenon around Limnos and Imvros (Source: MCG).

A recurring phenomenon (Figure 68 and Figure 69) was also documented in the trajectory of buoy 20002217, and later observed near Cape Kafireas (Kavo D'oro), where several devices followed an arced trajectory around island masses instead of making direct landfall. Although not the primary focus of the current study, this phenomenon merits further investigation. Potential contributing mechanisms include:

7.1.4.1 Interaction Between Surface Wind and Subsurface Currents

- Wind exerts direct influence on the sea surface, whereas ocean currents drive the overall mass transport of floating materials.
- Coastal currents moving parallel to shorelines can redirect litter along or around coastlines, even when wind is pushing toward land.

7.1.4.2 Mesoscale and Microscale Circulation Features

- Localized eddies (gyres), both cyclonic and anticyclonic, frequently form around islands, creating retention zones where floating litter circulates instead of reaching shore.
- These features may stem from natural current interactions or bathymetric characteristics such as underwater ridges and shallow shelves.

7.1.4.3 Seafloor Morphology and Topographical Influence

- Light litter, especially plastics, can be deflected by seabed gradients, reefs, or underwater obstacles that modulate current pathways.

7.1.4.4 Windage Effect

- Objects with high surface-area-to-mass ratios (e.g., bottles, bags) are more susceptible to wind drift, though strong opposing subsurface currents may counteract this, preventing coastal deposition.

7.1.4.5 Combined Wind-Current Dynamics and Lateral Drift

- The interaction between wind and current often results in oblique or arcuate trajectories, especially in coastal transition zones, where the path of litter encircles islands or bends around headlands.

Finally, it is important to emphasize that even slight wind changes in proximity to river deltas can dramatically alter litter pathways. Such shifts can divert materials into shallow, vegetated zones or directly onto beaches, where they become trapped and cease to be mobile (Figure 70). This phenomenon was observed not only in the Evros River but also in the Strymonas and Aliakmonas rivers, underscoring the role of deltaic and coastal morphology in floating litter fate.

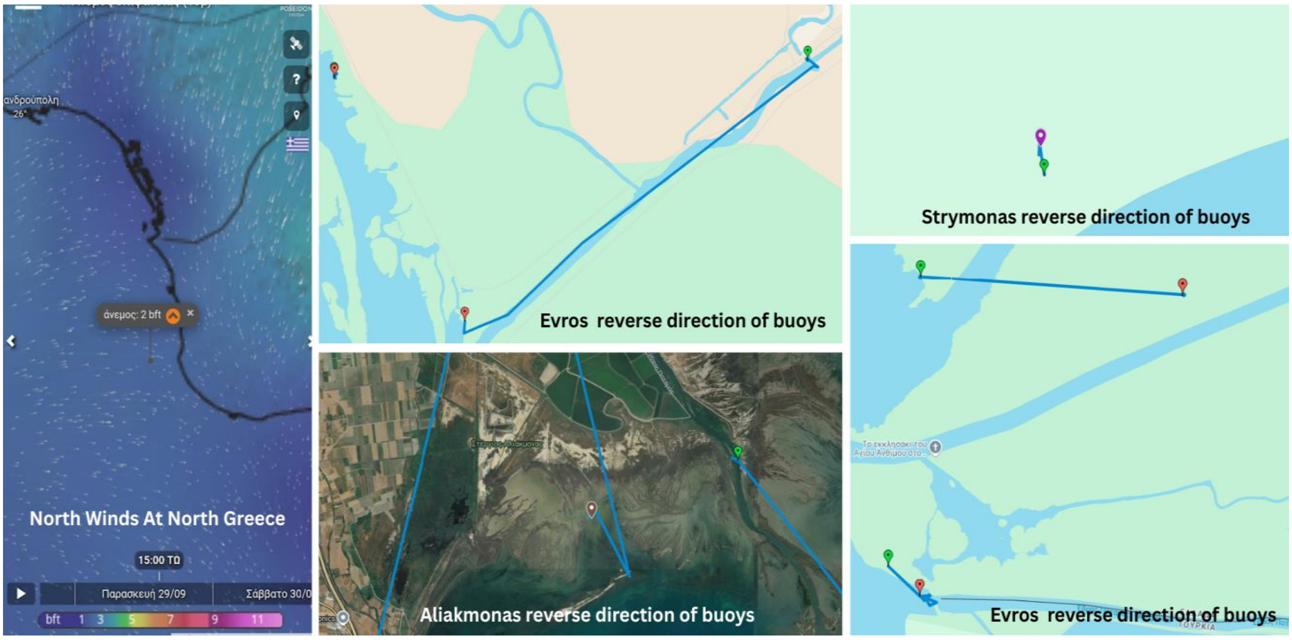

Figure 70. Reverse movement of devices in Rivers due to North winds (Source: MCG).

7.2 Conclusion – Summary and Findings from Rivers

The pilot tracking of GPS buoys in the river systems of Northern Greece revealed key insights into the movement of macroplastics, strongly influenced by hydrological regimes, seasonal weather, and hydraulic infrastructure.

7.2.1 Key findings:

- Drought conditions and reduced river discharge (especially in autumn 2023) significantly limited buoy mobility, particularly in the Axios and Strymonas rivers.
- The Axios River emerged as a plastic accumulation zone, where reedbeds and stagnant zones trapped litter.
- The Aliakmonas River, despite early wooden prototypes, showed higher flow and long-range litter transport (over 200 km in some cases).
- The Strymonas demonstrated moderate movement, but buoys were often entrapped in banks and vegetation.
- The Evros River, undammed and hydrodynamically active, enabled high litter mobility, including transboundary transport from Bulgaria and Turkey, with some buoys reaching the shores of Lemnos and Imvros.

7.2.2 Core conclusions:

- Hydrotechnical barriers like dams play a pivotal role in modifying litter flow and trapping zones.
- River deltas and shallow coastal areas serve as natural retention hotspots for floating litter.
- The interplay of wind and current dynamics creates complex buoy trajectories, with minor shifts greatly altering litter fate.

The findings underscore the urgent need for international cooperation and localized mitigation strategies to combat riverine and marine plastic pollution.

7.3 North Aegean (Thasos- Lemnos - Chalkidiki - Lesvos)

In the Northern Aegean, we obtained a greater volume of data from the tracking devices, as this region was deemed particularly significant for investigation due to its geomorphological complexity and the intense environmental phenomena that influence it. The specific areas studied within the Northern Aegean included the islands of Thasos, Lesvos, and Lemnos, as well as the region of Mount Athos. All areas, with the exception of Lemnos, were investigated during the winter of 2024. The study of the Lemnos region was conducted in the spring of 2025 in order to allow for a seasonal comparison of the results.

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7.3.1 Mount Athos Region: Wind-Current Interaction and Litter Retention Phenomena

In the region surrounding Mount Athos, six GPS-tracked devices were deployed in January 2024 as part of a focused investigation into the dynamics of surface marine litter transport. This specific deployment provides valuable insight into how the interplay between sea currents and surface wind patterns influences the trajectory and fate of floating litter in coastal marine environments. The deployment was conducted in early February 2024, during a period characterized by highly variable wind conditions — both in direction and intensity — on a daily and intra-daily basis (Figure 71).

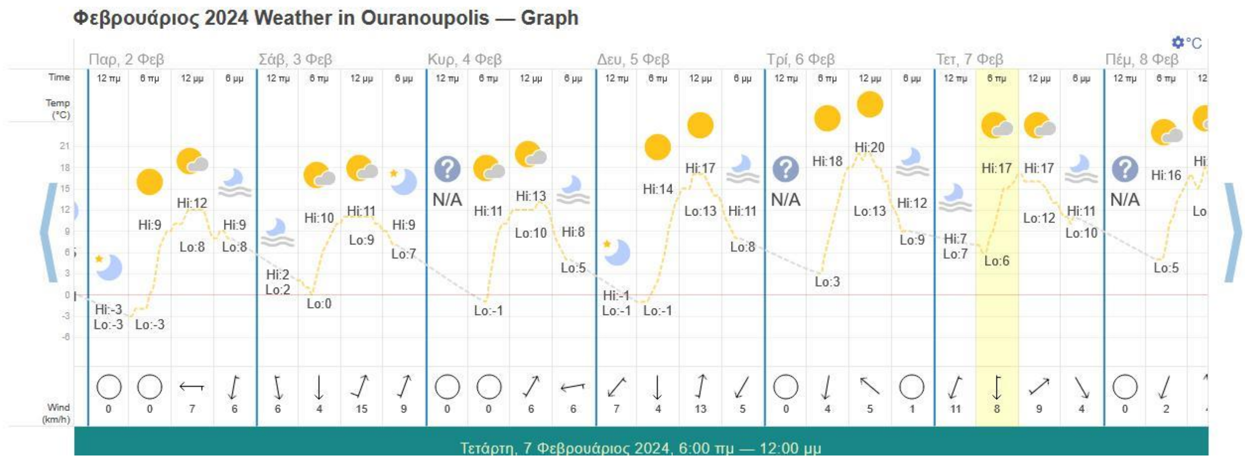

Figure 71. Weather Conditions at Ouranoupoli during Research (Source: MCG).

Between February 2nd and 3rd, 2024, strong northerly winds initiated a southward and irregular movement of the buoys. The erratic nature of their paths during this phase is attributed to the continuous wind fluctuations and shifting coastal currents.

By February 5th and 6th, 2024, the buoys had reached the southern sector of the second peninsula of Halkidiki. At that time, weak northerly winds (4–6 km/h) were insufficient to sustain further southward transport. As a result, the devices became trapped in localized cyclonic circulation patterns—mesoscale eddies—formed in the area. These gyres effectively retained the buoys in rotational motion for approximately 2–3 days (Figure 72).

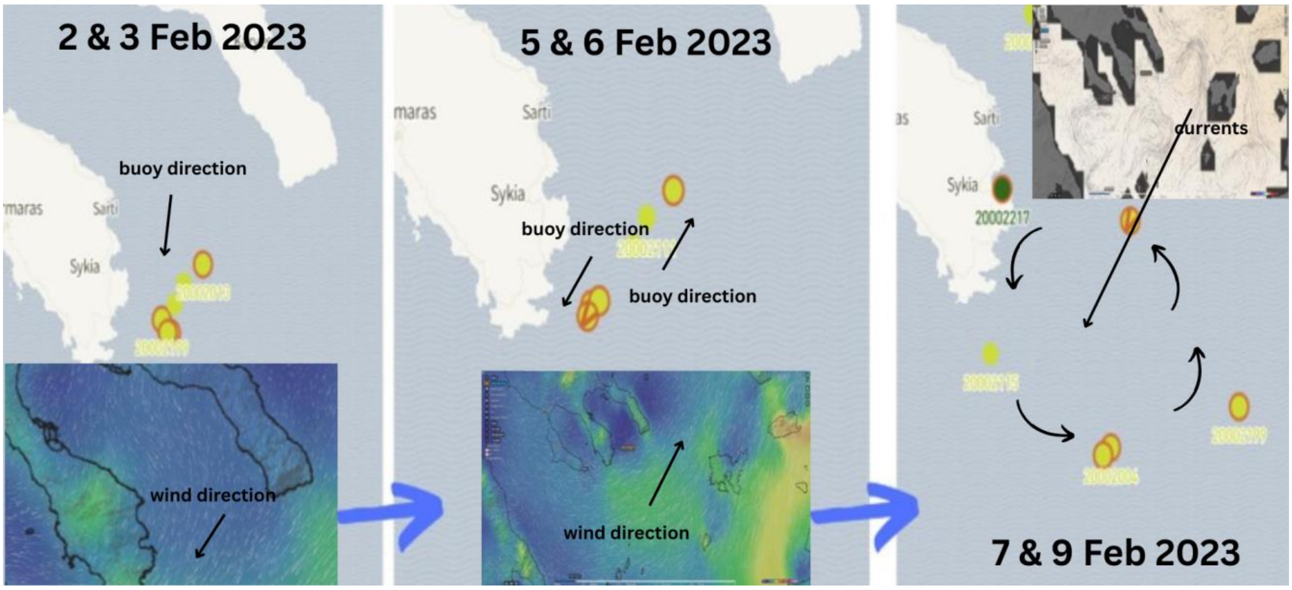

Figure 72. Influence of currents and winds on devices in the Mount Athos area (Source: MCG).

Subsequently, the emergence of stronger southerly winds reversed this pattern, pushing the buoys back toward the coastline. Depending on their initial position within the gyre, each device followed a distinct return trajectory, highlighting the spatial variability in how currents and wind forcing affect litter transport (Figure 73).

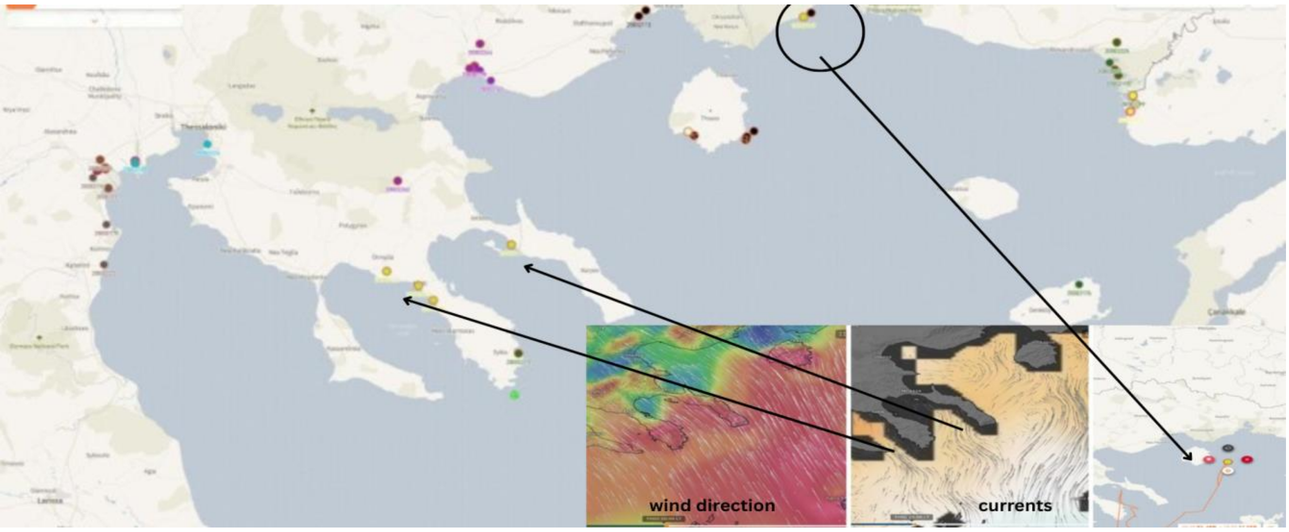

Figure 73. Influence of currents and winds on devices in the Mount Athos area - Final destination (Source: MCG).

This case clearly demonstrates that the effect of marine currents on floating objects is strongly modulated by wind intensity. Under conditions of weak wind forcing, litter can become entrained and retained within local circulation systems. In contrast, the onset of stronger winds is capable of overcoming this retention and redistributing floating materials over wider areas (Figure 74).

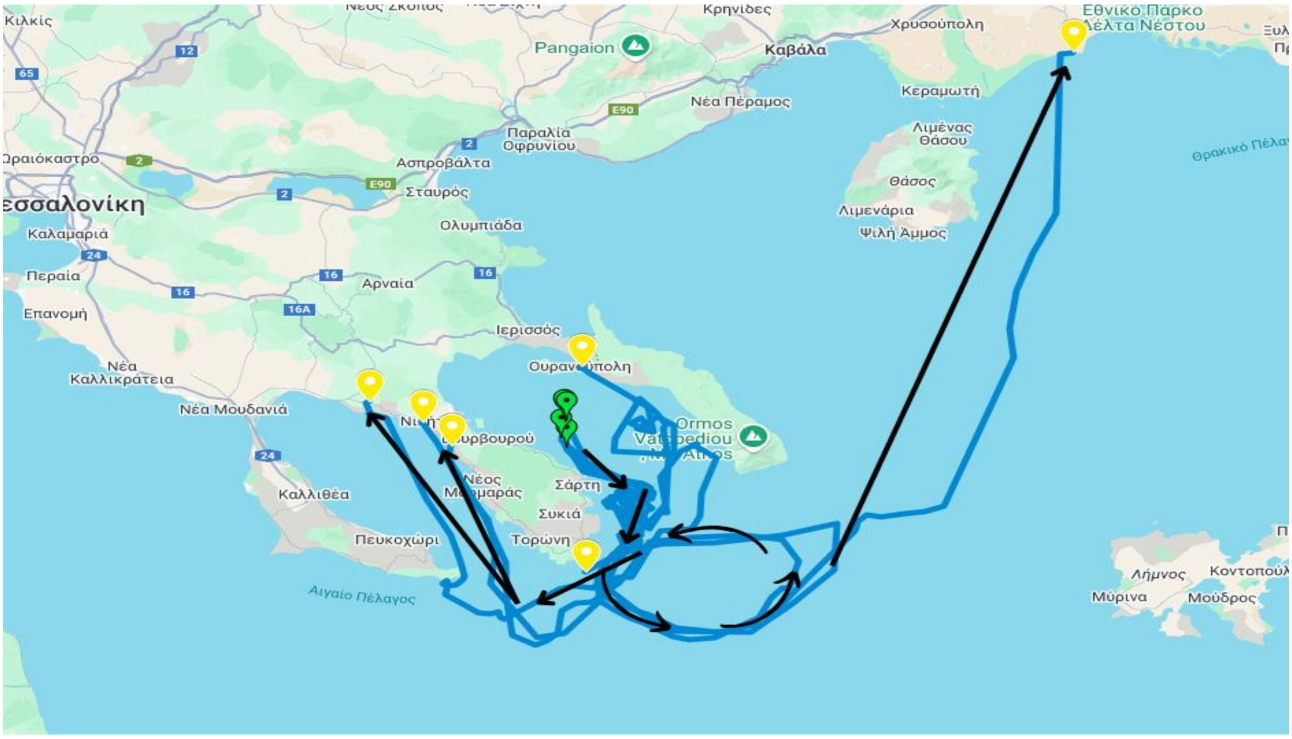

Figure 74. Influence of currents and winds on devices in the Mount Athos area - Their route and the final destination observed from app (Source: MCG).

The Mount Athos deployment thus serves as a representative example of wind–current coupling in semi-enclosed basins, offering important implications for understanding litter accumulation zones and potential cleanup strategies.

7.3.2 Thasos Island: Evidence of Localized Island-Induced Circulation

On February 7th, 2024, a total of ten buoys with GPS were deployed off the eastern coast of Thasos Island as part of a targeted investigation into coastal hydrodynamic behavior in the Northern Aegean Sea. During the deployment period, the island was subject to variable wind conditions, with alternating northerly and southerly flows. However, southerly winds were slightly more predominant, shaping the initial dispersion of the devices. (Figure 75).

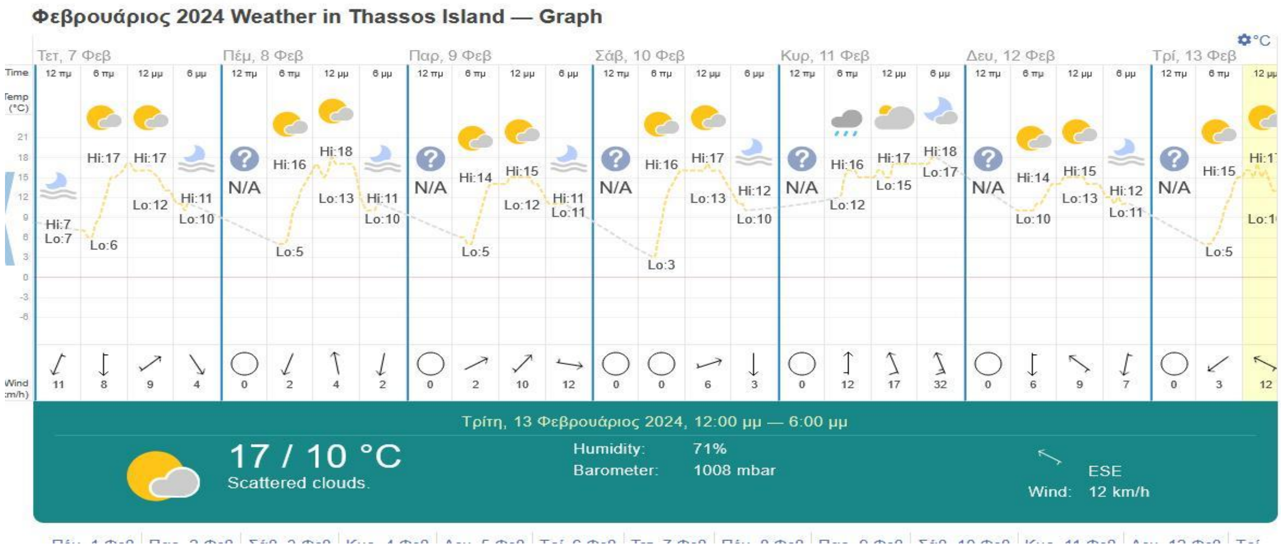

Figure 75. Weather condition in Thassos during the research (Source: MCG).

Thasos provides a compelling case study for examining the presence of localized circulation cells—phenomena (Figure 76) previously identified in the vicinities of Imvros and Lemnos. These nearshore cyclonic or anticyclonic gyres are often generated by a combination of island-induced bathymetric features and persistent current-wind interactions. Such systems appear to exert a significant influence on the movement and retention of floating litter around island masses.

Preliminary observations suggest that several of the deployed buoys exhibited circular or semi-circular trajectories, indicating their temporary entrapment within these localized current systems. This behavior highlights the role of small-scale hydrodynamic features in modulating litter transport pathways and potentially contributing to the formation of marine litter accumulation zones near island shorelines. Further analysis is warranted to quantify the duration, extent, and driving forces behind these retention zones, particularly under varying seasonal wind regimes.

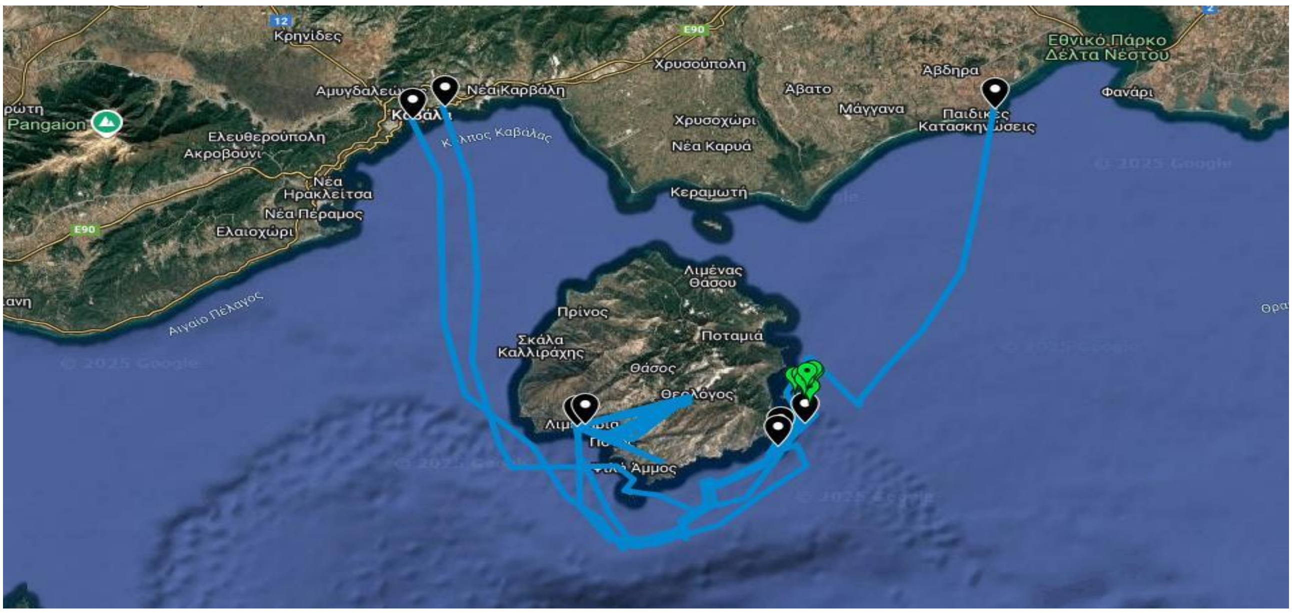

Figure 76. Movement of devices at Thassos (Source: MCG).

In this specific case from Thasos, we examine the trajectory of buoy device 20002113. The device was deployed on February 7th, 2024, and from 06:00 to 12:00 followed a southeastward path, consistent with the prevailing southwesterly winds recorded during that time, as illustrated in the corresponding wind data imagery (Figure 77).

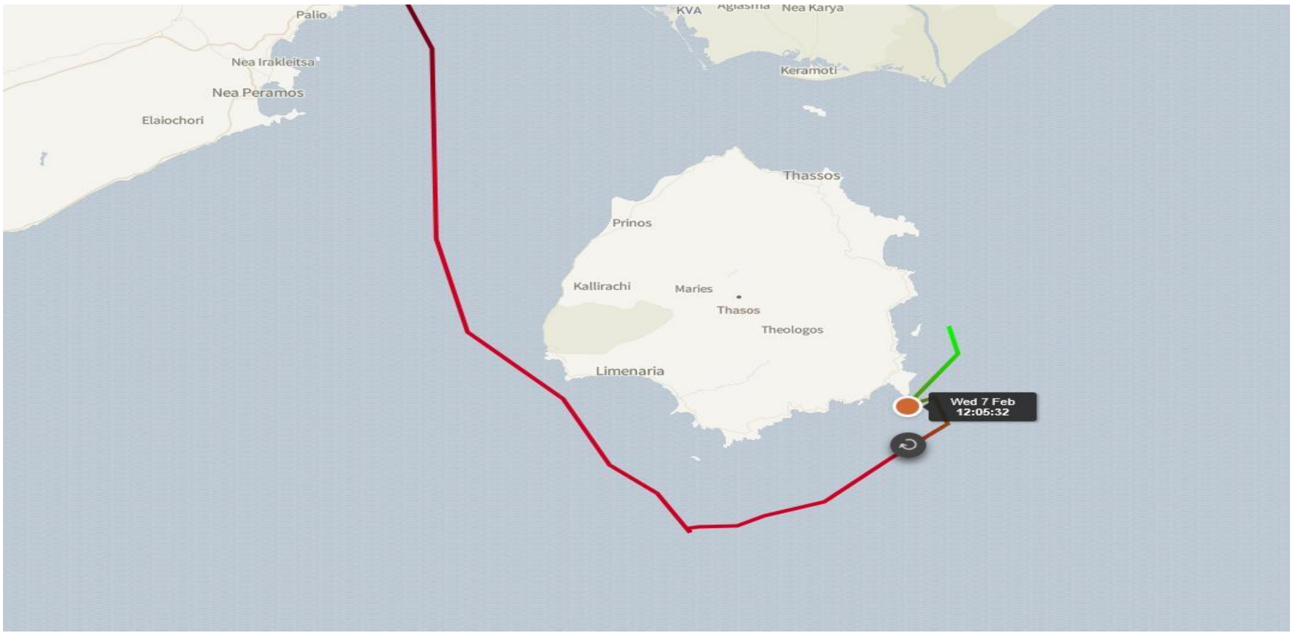

Figure 77. Detailed movement of a device around Thassos 1 (Source: MCG).

Subsequently, the buoy's trajectory shifted first northward and then southwestward, mirroring short-term changes in wind direction throughout the day. Following this period of variability, moderate southwesterly winds prevailed, gradually driving the buoy along the island's southwestern coastline until February 9th. During this interval, the buoy maintained a relatively stable and consistent trajectory, unaffected by short-term hourly fluctuations in wind intensity or direction (Figure 78).

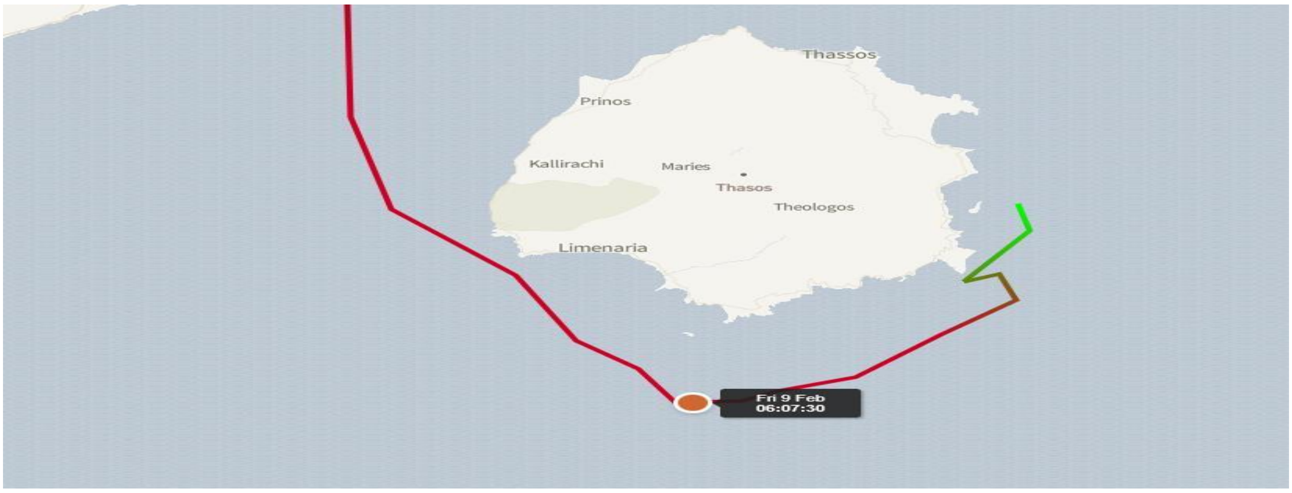

Figure 78. Detailed movement of a device around Thassos 2 (Source: MCG).

On February 10th, the device altered course again, this time adopting a southeastward trajectory—likely influenced by localized surface currents. This new direction did not align with the prevailing wind, which remained weak and southwesterly. Such deviation underscores the potential dominance of local hydrodynamic features over wind in determining buoy movement under low wind conditions (Figure 79).

Figure 79. Detailed movement of a device around Thassos 3 (Source: MCG).

Finally, on February 11th, wind conditions intensified significantly, with strong southerly winds reaching speeds of up to 32 km/h. These more forceful winds ultimately pushed the device back toward the shore, bringing its journey to an end (Figure 80).

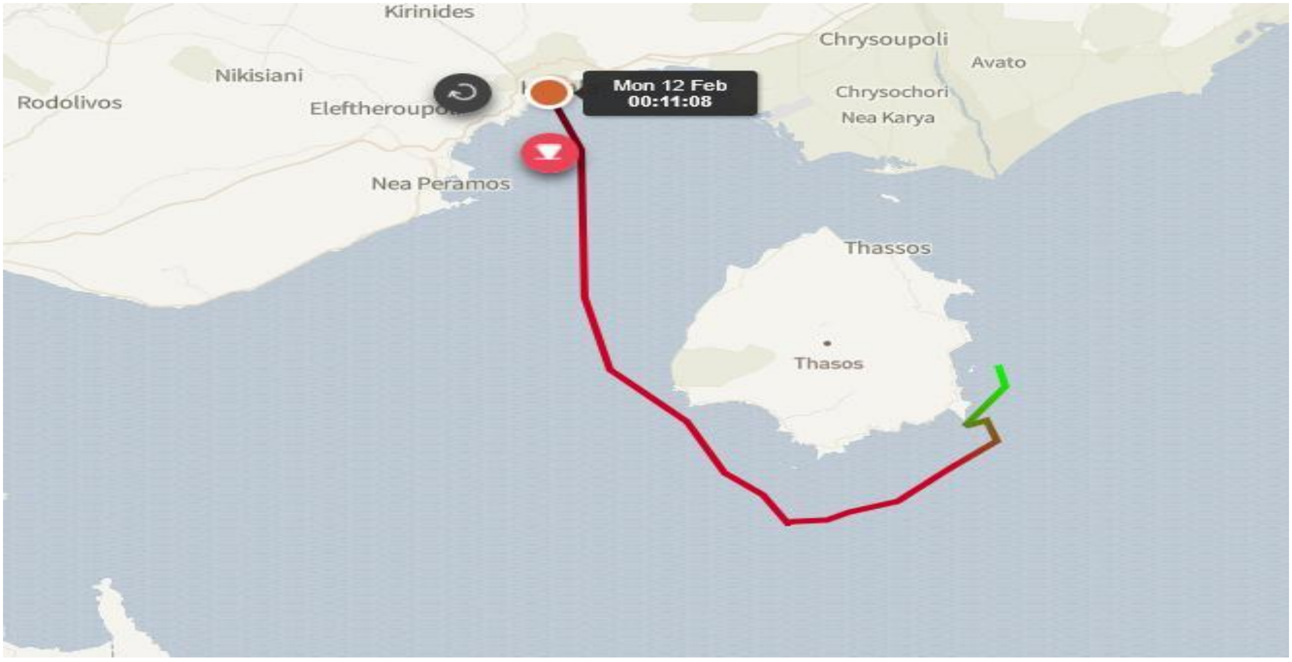

Figure 80. Detailed movement of a device around Thassos 4 final destination (Source: MCG).

This example clearly illustrates the critical role played by localized currents in shaping the movement of floating litter when wind intensity is low. It also highlights how the eventual outcome of a buoy's trajectory results from the combined—and often competing—influences of wind and water currents in the nearshore environment.

7.3.3 Lemnos Case Study

As observed in previous case studies throughout the Northern Aegean, local and regional current systems play a pivotal role in determining the movement and final destination of drifting litter. These currents may be shaped by the unique geomorphology of each island or influenced by the broader inflow of waters from the northern seas entering the Aegean via the Dardanelles (Hellespont). In either case, their presence significantly impacts the behavior of drifting buoys with GPS and, by extension, the transport pathways of marine litter.

Additionally, our analysis indicates that both during winter and spring months, southerly winds tend to dominate in the northern Aegean basin. When acting in concert with surface currents and shifting wind regimes, these southerly flows tend to “trap” the buoys within the northern part of the Aegean, inhibiting their southward drift toward the central basin. This dynamic confinement of floating material is an important factor in understanding litter accumulation zones and regional transport mechanisms.

To further examine this phenomenon, targeted buoy deployments were conducted in both central and eastern sectors of the Northern Aegean. Specifically, devices were released near the island of Lemnos, centrally located within the basin, as well as near Lesvos and Chios, representing the eastern sector.

On March 26th, 2025, sixteen GPS-tracked drifting devices were deployed around Lemnos Island. Of these, thirteen transmitted valid data and are currently part of an ongoing monitoring campaign. The deployment occurred under weak northerly wind conditions, which initially pushed the buoys southward (Figure 81).

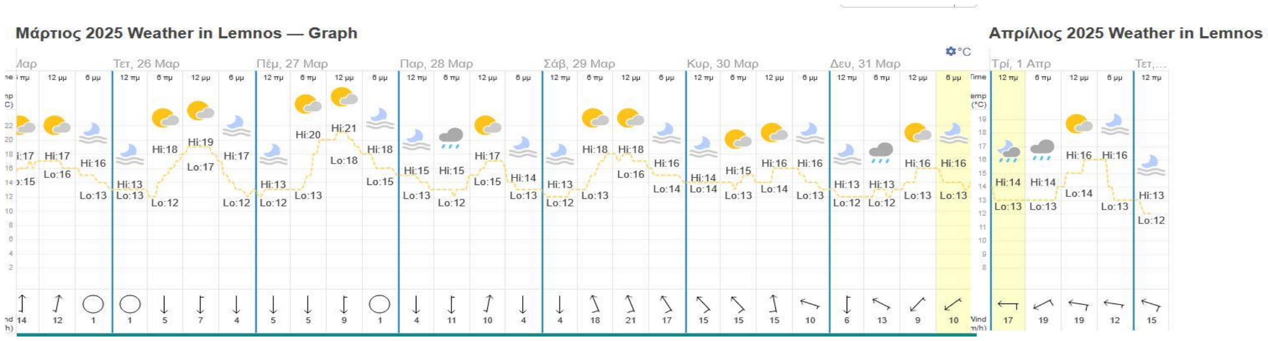

Figure 81. Weather condition at Limnos during the research (Source: MCG).

Subsequent shifts in wind patterns and the influence of prevailing currents from the northern Aegean redirected many of the devices eastward (Figure 82). This movement occurred during a period of calm atmospheric conditions, reinforcing the idea that the trajectory was governed primarily by hydrodynamic forces rather than wind (Figure 83).

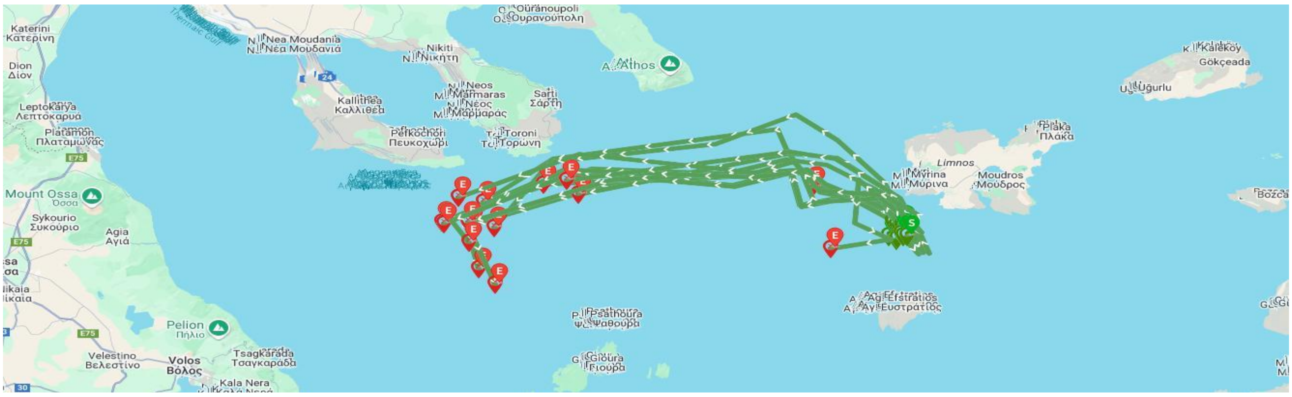

Figure 82. Movement of buoys from Lemnos to the west influenced by the currents and the winds (Source: MCG).

The behaviour observed during this campaign closely mirrors the movement patterns seen in the Mount Athos deployment, with buoys exhibiting limited displacement and remaining within a confined range, likely due to similar environmental conditions and positioning.

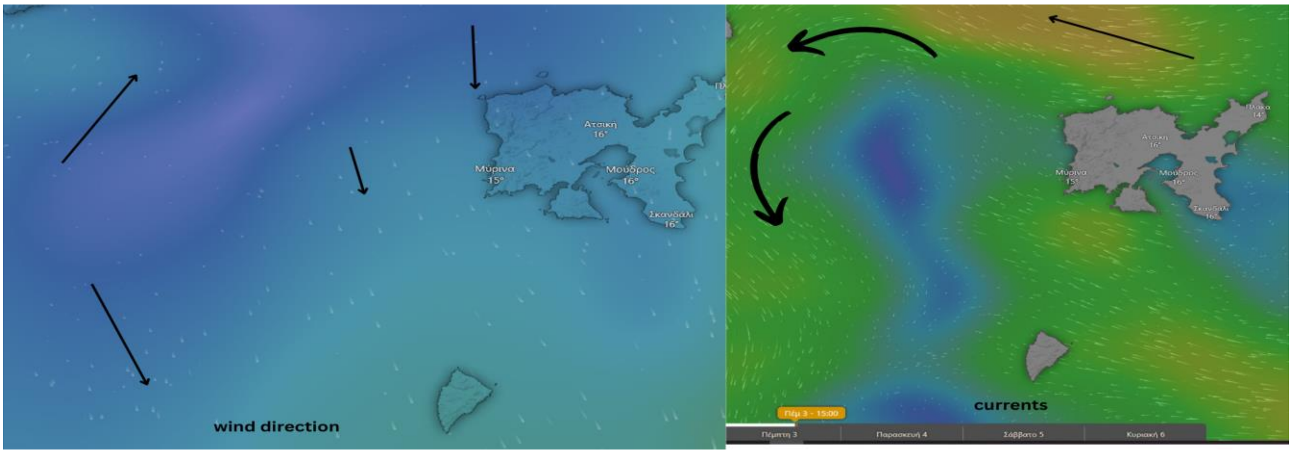

Figure 83. Wind and current direction during the research (Source: MCG).

Later in the observation period, the onset of stronger northerly winds is anticipated to push the devices further south, possibly toward the Sporades archipelago. Conversely, if southerly winds begin to dominate, the buoys may be redirected northwest toward the Thermaic Gulf or northeast toward the Strymonian Gulf.

7.3.4 Eastern Northern Aegean Hotspot: Lesvos, Chios, and Oinousses

The final group of islands studied in the Northern Aegean includes Lesvos, Chios, and Oinousses, located in the northeastern sector of the basin, just south of the Black Sea outflow zone. This region is particularly dynamic due to its geographical positioning and the interaction between wind patterns and incoming currents from the north.

In Lesvos, two separate deployment campaigns were conducted. The first took place on February 3rd, 2024, with the release of 16 buoys with GPS. However, due to currently unknown reasons, only two of the devices transmitted location data. Despite local reports indicating that several devices were found near the southern part of the Kalloni region—confirmed by residents who contacted the research team—the tracking platform failed to register their actual trajectories (Figure 84).

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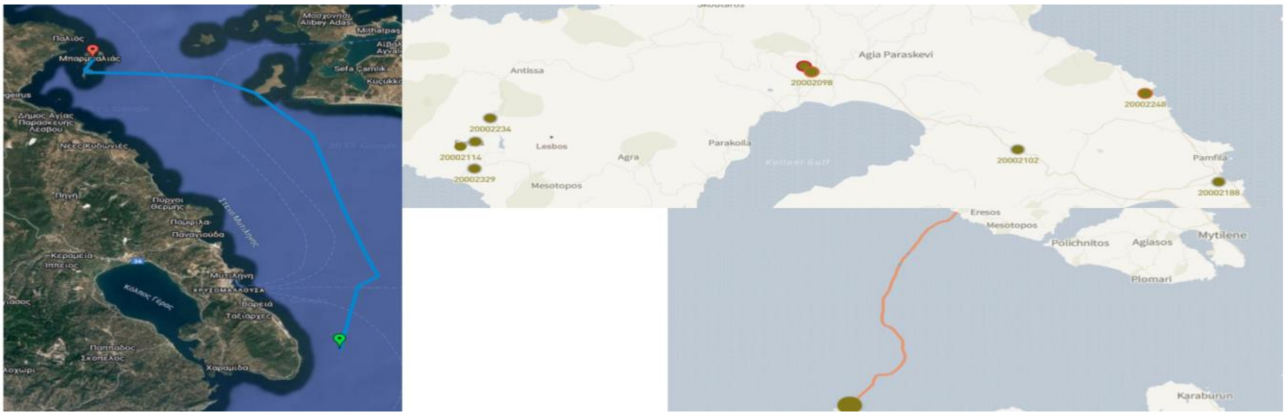

Figure 84. Buoys with GPS at Lesvos (Source: MCG).

To address this gap, a second deployment was carried out almost exactly one year later, involving 10 devices. Five of these were deployed in the southern part of Lesvos, in the marine area between Chios and Oinousses. In this case, the data collected provided much clearer insights. This area, situated just below the Black Sea inflow, forms a semi-enclosed embayment. The incoming surface currents from the northern seas appear to be funnelled directly into this pocket, rarely dispersing far from it. Coupled with the prevailing northerly and north-easterly winds, these hydrodynamic conditions create a natural retention zone. As a result, the devices deployed in this area were consistently drawn toward and ultimately stranded on the island of Oinousses (Figure 85).

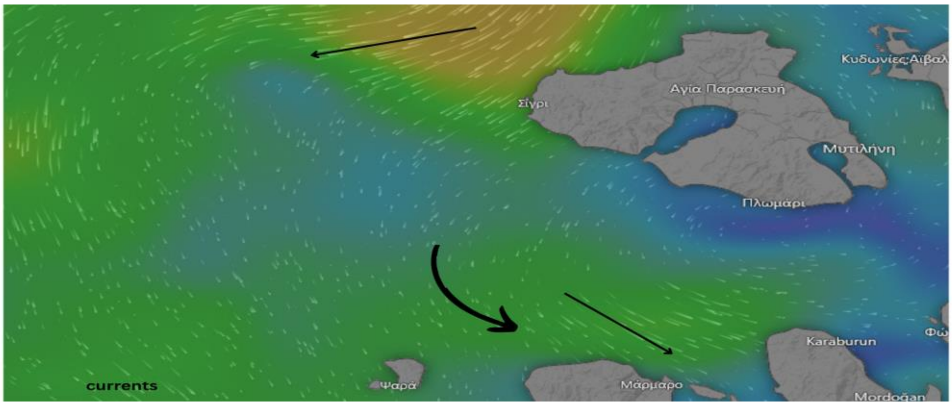

Figure 85. Wind direction at Lesvos during the research (Source: MCG).

A characteristic observation is that all buoys released in this zone were eventually trapped on Oinousses, clearly demonstrating the area's potential as a litter accumulation hotspot.

Figure 86. Buoys movements from the launch to their Final destination at Oinousses (hotspot) (Source: MCG).

Further supporting evidence comes from the earlier February 2024 deployment, where devices released in northern Lesvos showed limited mobility even when southerly winds were present at the time of deployment. Local topography, particularly mountainous terrain, likely inhibited wind strength in the coastal zone, preventing effective southward movement. Once the wind direction shifted to northerlies, the buoys were quickly driven back to shore and became trapped (Figure 86).

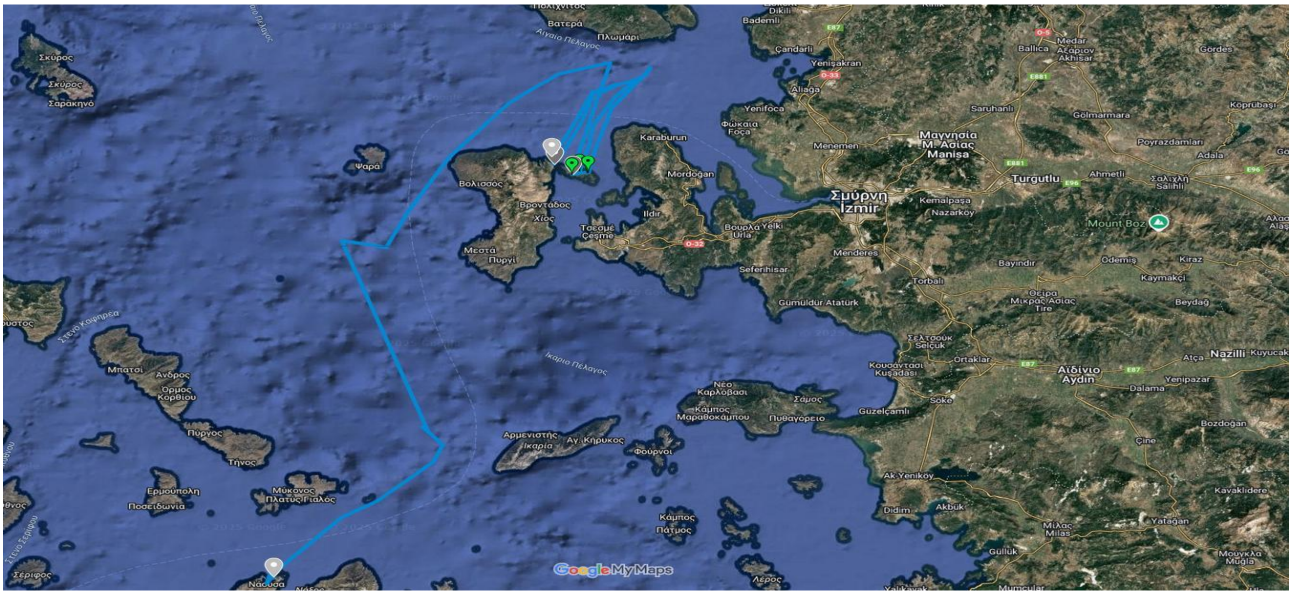

Figure 87. Escaped device from Oinousses to Central Aegean with Paros as Final Destination (Source: MCG).

The Figure 88 illustrates the spatial concentration of the buoys within this confined zone and highlights the significance of the region as a key convergence area for floating litter.

Figure 88. Hotspot at Oinousses. The current situation in the spot that devices located (Source: MCG).

It is also worth noting that only one of the deployed devices managed to escape the system, traveling southward into the central Aegean (Figure 89). This rare occurrence suggests that under specific conditions, lightweight floating plastics may be capable of re-entering offshore circulation and continue their journey toward more southern regions of the Aegean Sea.

Figure 89. Device from Oinousses to Paros observed in app (Source: MCG).

7.4 The Mykonos–Ikaria Strait and the "Bottleneck Effect" on Floating Litter Transport in the Aegean Sea

The marine passage between Mykonos (northeastern Cyclades) and Ikaria (eastern Aegean) constitutes one of the main conduits for water exchange between the northern/central and southern Aegean Sea. Studies indicate that after entering through the Dardanelles, surface waters from the Black Sea (Black Sea Water – BSW), which carry a significant load of floating litter, move westward and split into two branches: one flows northward toward the Thracian Sea, while the other heads southwest, reaching the southern Aegean via the Kafireas and Mykonos–Ikaria straits(Ioakeimidis et al., 2020).

Thus, the Mykonos–Ikaria Strait acts as a conduit through which surplus waters (and floating litter) from the northern Aegean are discharged toward more southerly regions (Ioakeimidis et al., 2020).
A defining characteristic of this strait is the intensity of winds and currents. The summer meltemi winds (northerlies) accelerate water flow through the Cyclades. According to a 10-year wind and wave climatology, the area north to northeast of the Cyclades, particularly the Mykonos–Ikaria Strait, experiences some of the most severe wave and sea turbulence conditions in the Aegean (researchgate.net). The islands of the northeastern Cyclades serve as "barriers" that partially buffer the meltemi winds, but at the same time funnel and intensify the flow of air and water through the channels – a channelling effect reminiscent of a "bottle-neck" phenomenon (researchgate.net). As a result, the Mykonos–Ikaria Strait generates a faster "current" that carries plastic items (bottles, bags, etc.) southward at increased speeds. Floating litter that enters narrow straits in the Aegean Sea is typically not retained for extended periods.

Due to the region's dynamic hydrodynamic regime and continuous current inflows, litter is rapidly dispersed toward broader marine areas, and there is no evidence of persistent accumulation zones (i.e., stable "garbage patches") within the open Aegean basin (Liubartseva et al., 2018). However, these straits may act as temporary accumulation points on a localized scale. Lateral eddies, transient gyres, and calm hydrodynamic conditions in semi-enclosed coastal environments—such as the eastern coast of Mykonos or the western bays of Ikaria—can temporarily trap floating plastics nearshore.

Over the long term, most of this litter either continues its path toward the central or southern Aegean or becomes stranded on beaches or sinks to the seafloor. Research suggests that plastics frequently lose buoyancy through biofouling or physical degradation and ultimately settle on the seabed, often entangled in benthic vegetation or mixed with sediments, thus avoiding the formation of long-standing surface accumulation zones (Liubartseva et al., 2018).

7.4.1 The "Bottleneck Effect" and Its Impact

The term bottleneck effect is used metaphorically to describe the phenomenon in which a flow is restricted through a narrow passage – similar to water being poured through the neck of a bottle. In the context of ocean currents, a narrow strait can accelerate the flow of water (Venturi effect): the same volume must pass through a narrower space, thus increasing its speed. For floating litter, this means that within the strait, transport occurs more rapidly and at higher concentrations compared to open waters.

However, beyond the strait, as the currents expand into wider marine areas, flow velocity decreases, allowing litter to disperse over a broader region. The bottleneck may also generate turbulence and eddies at its margins, where some litter may be temporarily trapped. In summary, the bottleneck effect does not result in the permanent retention of marine litter but significantly influences the speed and dispersion patterns of floating materials: it functions as both an accelerator and a "distributor" toward adjacent marine sectors. In the Aegean Sea, this effect is most pronounced in the narrow passages between islands, due to the prevailing meltemi winds and geomorphology. The Cyclades, for example, while moderating wave intensity within their enclosed basins, simultaneously enhance the flow of air and water through the gaps between them (Liubartseva et al., 2020). – Thereby facilitating the transport of litter through these "bottlenecks."

7.4.1.1 The Role of Etesian Winds (Meltemia) in Surface Circulation and Marine Litter Transport

During the summer months, particularly from late spring through early autumn, the Etesian winds locally known as meltemia prevail across the Aegean Sea. These are strong, dry northerly winds that play a crucial role in shaping surface circulation patterns and influencing the transport of floating litter.

The meltemia generates a characteristic northeast-to-southwest flow pattern across the Aegean basin. Originating from northerly to northeasterly directions near the Dardanelles, the winds gradually shift toward northwesterly directions as they reach the southern Aegean. This persistent wind regime drives surface waters and any floating material contained within southward, creating a predictable dispersal pathway for marine litter.

This sequence of wind-driven flow, also well-documented in traditional maritime navigation guides, effectively clears certain northern areas of floating litter, which is then transported to more southern regions. As a result, while some northern coastal zones experience temporary relief from surface litter during the summer, southern coastal areas face increased accumulation pressures.

A striking example of this dynamic is observed along the northeastern coasts of Crete, which exhibit high concentrations of plastic litter carried southward from the central and northern Aegean. Numerical dispersal models confirm that this phenomenon intensifies during spring and summer months, particularly from April to July, when meltemia occurs more frequently. Consequently, there is a notable increase in litter deposition along downstream shorelines during this period.

The summer deployments conducted in July and August 2023 revealed distinct patterns of accelerated movement, with several devices drifting rapidly towards the southeastern Mediterranean, reaching as far as the coast of Israel.

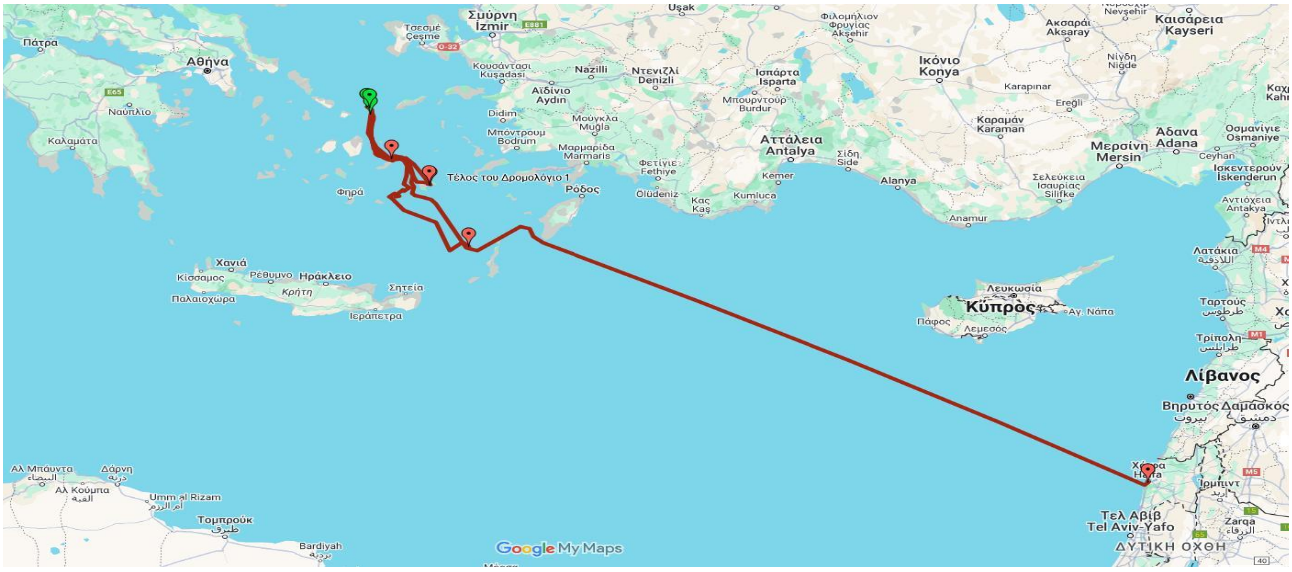

Figure 90. Deployment of drifting devices in the Central Aegean Sea under Etesian wind conditions (Source: MCG).

During the July 2023 deployment, both wooden and plastic devices were used with the explicit aim of comparing drift behaviors under identical environmental conditions (Figure 90 and Figure 91). This comparison was based on the understanding that object density, size, and buoyancy characteristics significantly influence movement in aquatic environments.

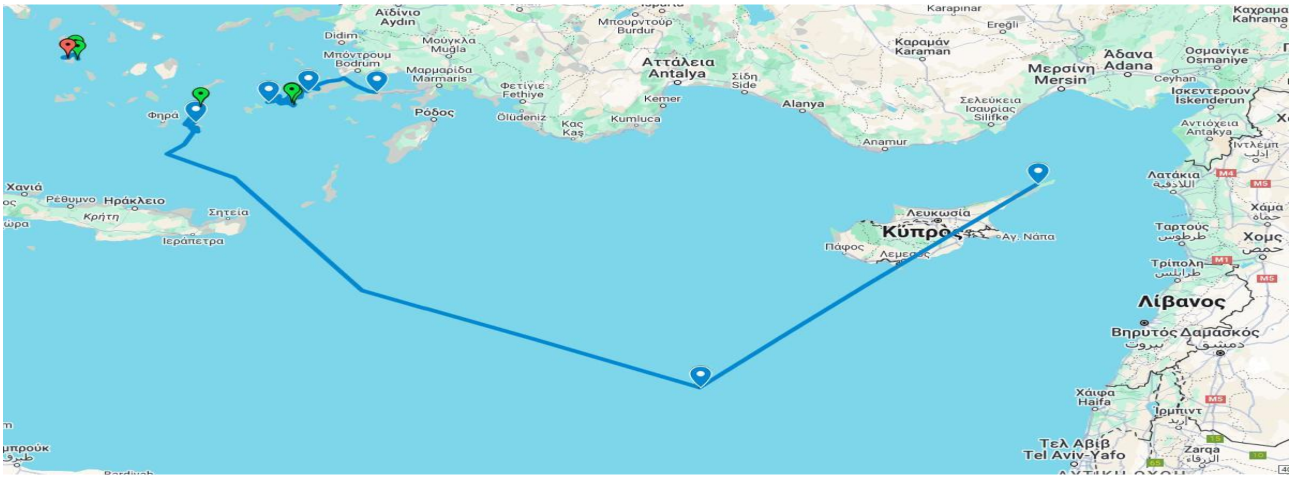

Figure 91. Deployment of drifting devices in the Dodecanese Region under Etesian wind conditions (Source: MCG).

When an object is mostly submerged—either due to high density, small size, or a shape that allows it to sit low in the water—it primarily follows marine currents, as only a minimal portion is exposed to wind influence. In such cases, the wind has limited effect, and the object's trajectory is largely governed by water movement.

For instance, a piece of wood or plastic that is nearly fully submerged will drift along with the current, largely unaffected by wind direction. In contrast, when a significant portion of an object remains above the water's surface, wind can exert considerable force. These objects do not merely follow the current; instead, they tend to drift off-course in the direction of the prevailing wind. Examples include floating buoys, plastic barrels, or bottles that remain prominently above water these can move rapidly downwind, at much greater speeds than neighbouring, low-profile objects.

In our case, this distinction was clearly evident: the plastic bottle used in the July deployment successfully reached the shores of Israel, driven predominantly by wind influence due to its high windage. In contrast, the wooden devices, although initially following a similar trajectory, were eventually either trapped in circulating currents or sank before reaching distant coastlines.

This field experiment underscores the importance of material-specific drift dynamics and highlights the need to consider windage as a critical factor in the modelling of floating litter movement especially in predicting long-range transport during periods of persistent winds such as the summer Etesians.

7.4.1.2 Winter Period and Atmospheric Fronts: Effects on Litter Transport and Redistribution

During the winter months, the persistent Etesian winds (meltemia) of the summer subside, giving way to more variable wind patterns. These often include southerly and southwesterly winds, which are commonly associated with passing low-pressure systems and frontal disturbances. This seasonal shift can lead to a temporary reversal in surface flow, wherein litter previously transported southward during the summer may, under certain conditions, begin drifting northward or eastward again.
In addition, southerly swells and wave action generated by winter storms can significantly alter the zones of coastal deposition. Unlike the summer, when northern coastlines are more frequently impacted, the southern shores of islands often receive higher litter loads during winter due to wave-driven beaching from the south.

Despite the absence of strong, unidirectional wind regimes like the meltemia, marine litter dispersion remains active and dynamic throughout the winter. No stable "dead zones" or areas of persistent calm are formed in the open sea where litter could accumulate indefinitely. Instead, the succession of storms and wind shifts tends to scatter litter, either depositing it along coastlines or pushing it toward the seabed, especially in nearshore zones.

This continuous redistribution highlights the importance of accounting for seasonal variability
Our own field research, conducted in March 2024 and March 2025, strongly supports the previously described dynamics of wind-driven litter dispersion. During both deployments, the buoys with GPS-tracked devices initially followed a southward trajectory, largely influenced by moderate northerly winds (indicated on our maps with green markers).

However, due to frequent shifts in wind direction, many of the devices were later observed to reverse course (Figure 92), drifting back northward, where they were either dispersed across a wide area or ultimately sank (represented by red markers). This pattern highlights the sensitive dependence of buoy movement on changing wind regimes during the transitional spring period.

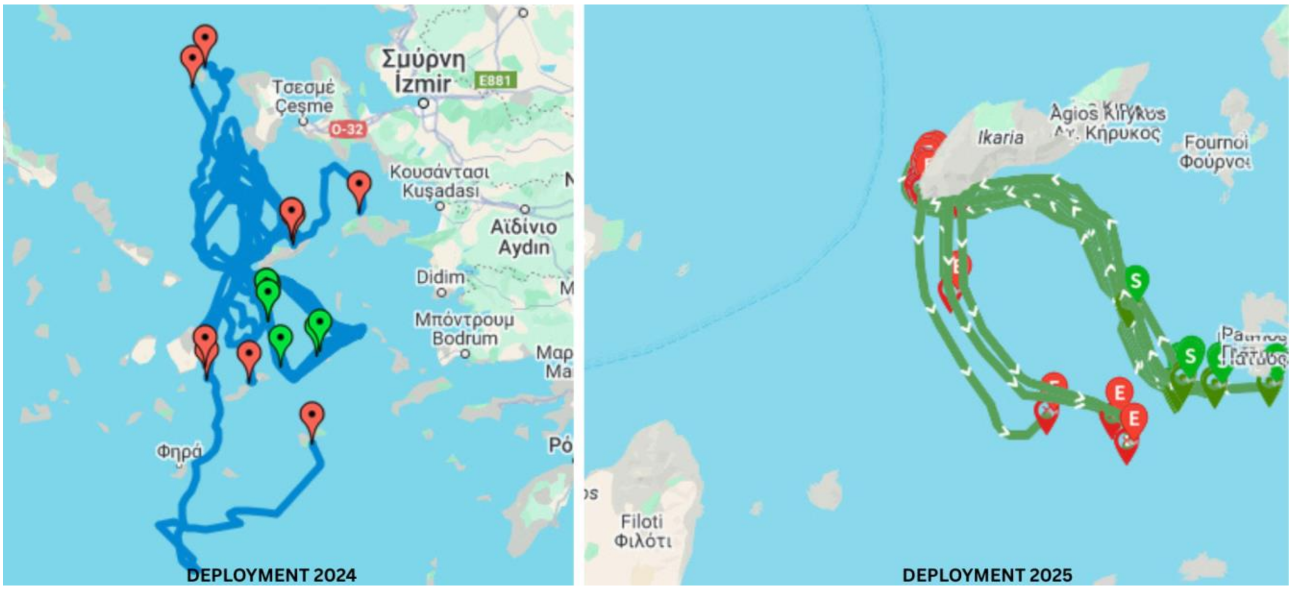

Figure 92. Comparison of buoys movements in Winter 2024 and Winter 2025 (Source: MCG).

A similar phenomenon was documented in a previous chapter involving a winter 2025 deployment near Chios, where the influence of shifting winds and variable currents led to unpredictable and non-linear drift trajectories.

From both the 2024 and 2025 deployments, a clear trend emerged regarding litter accumulation zones in the Aegean Sea. Specifically, the Bay of Aegiali in Amorgos and the western coast of Ikaria were consistently impacted regardless of season. These locations received a notably high number of drifting devices, either as transit points along southward drift paths or as final accumulation zones, where buoys became entrapped and remained for extended periods.

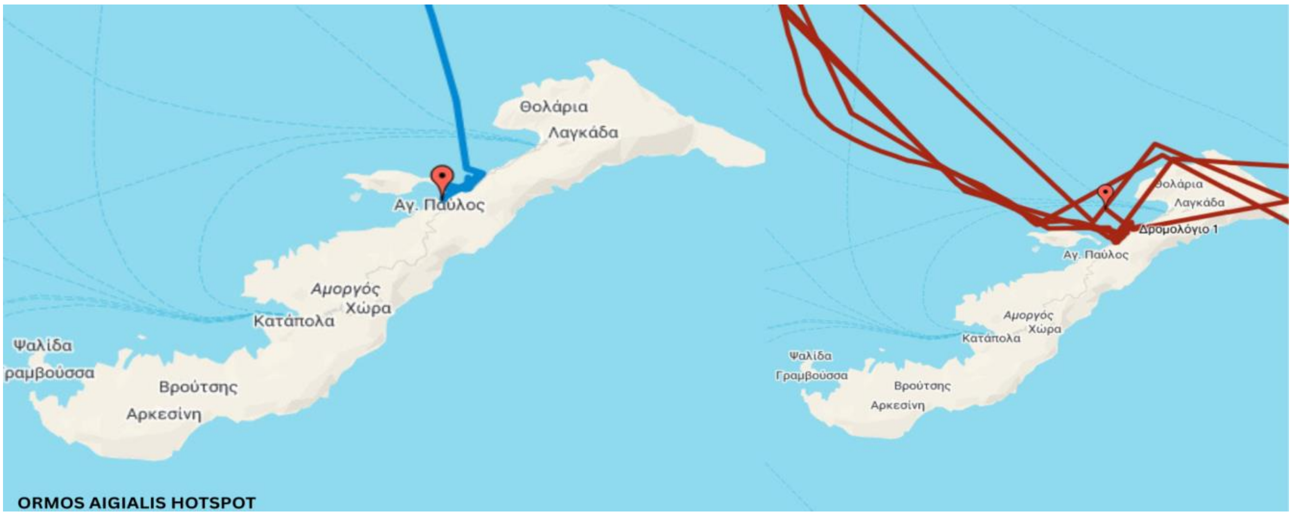

Figure 93. Amorgos hotspot (Source: MCG).

These findings suggest that Aegiali Bay (Figure 93) and western Ikaria (Figure 94) may serve as seasonally persistent hotspots for floating litter deposition, influenced by both current convergence and localized wind effects during both summer and winter months.

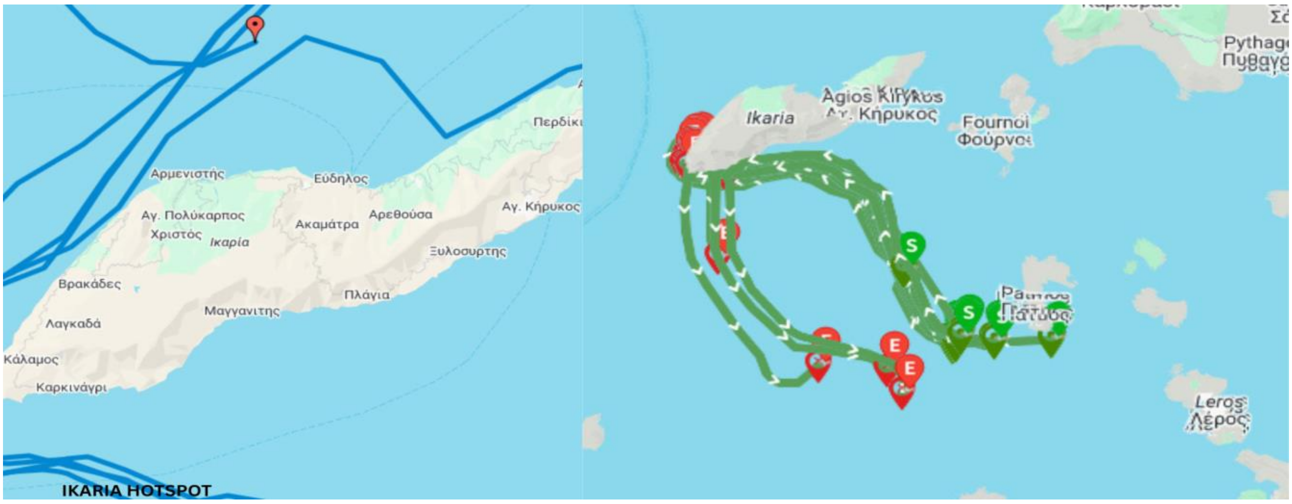

Figure 94. Movement of buoys around Ikaria in March 2024 and March 2025 (Source: MCG).

Finally, it is important to note that even small variations in surface currents or minor positional shifts of floating litter can be sufficient to alter the overall trajectory of otherwise identical objects.

A characteristic example is presented below, in which devices of identical size and weight were deployed simultaneously at the same location. Despite the controlled conditions, slight differences in current flow or micro-positioning led the devices to follow entirely different drift paths. This highlights the high sensitivity of floating objects to subtle hydrodynamic influences and underlines the inherent unpredictability of their movement, especially in complex nearshore environments (Figure 95).

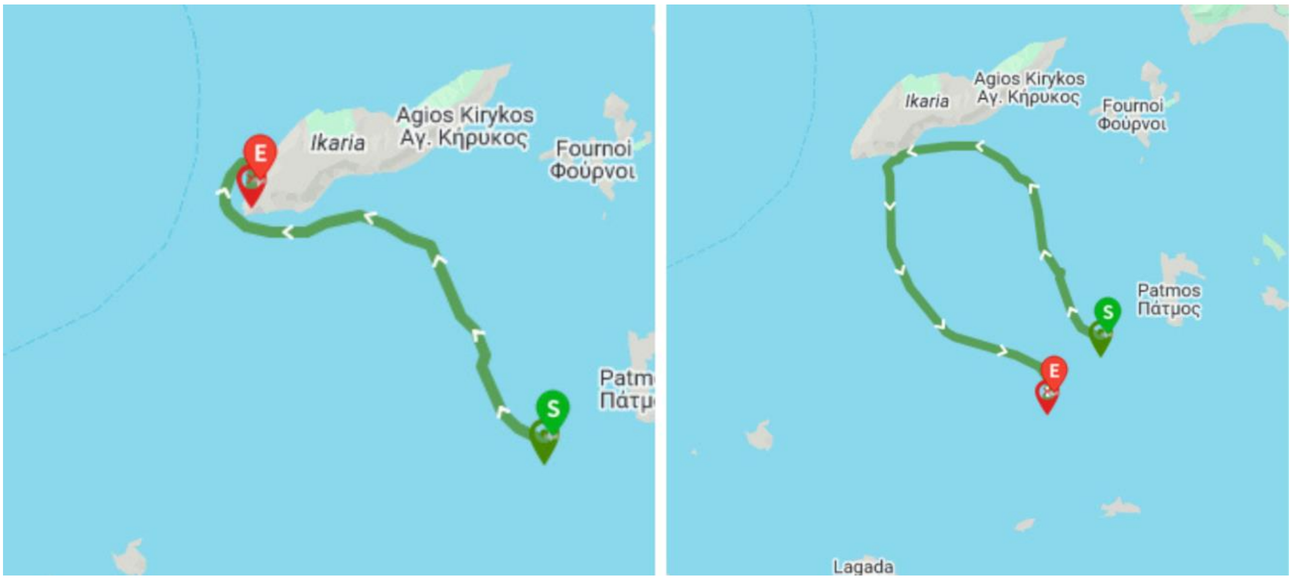

Figure 95. Influence of currents in a buoys final destination at same time launch at Ikaria (Source: MCG).

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7.4.1.3 The Case of Chios: Complex Wind–Current Interactions and Bidirectional Drift in the Central Aegean

The well-documented “bottleneck” phenomenon—where the narrow strait between Mykonos and Ikaria acts as a conveyor belt for marine litter—can also be observed in the Chios case study, especially during the winter months, when strong fluctuations between northerly and southerly winds frequently occur.

In this specific deployment, the buoys with GPS-tracked devices initially drifted rapidly southward due to prevailing northerly winds, reaching as far as Amorgos. Some of the devices became entrapped along the way—two cases were recorded near Astypalaia and Levitha, where local eddies and coastline geometry acted as retention zones.

Figure 96. Movements of buoys from Chios to Central Aegean and backward (Bottleneck phenomenon) (Source: MCG).

Those that avoided entrapment continued their journey, as wind conditions shifted (Figure 96 and Figure 97). Strong southerlies then pushed the remaining buoys back northward, even reaching the island of Psara, located northwest of Chios. A subsequent wind shift back to northerlies, combined with the influence of local currents, caused the buoys to be redirected southward once again.

One device was eventually trapped near Paros, illustrating the dynamic and often bidirectional nature of drift patterns in this region. The other two devices continued traveling, and as of the time of writing this article, remain in active movement, demonstrating the unpredictability of long-term trajectories in this part of the Aegean.

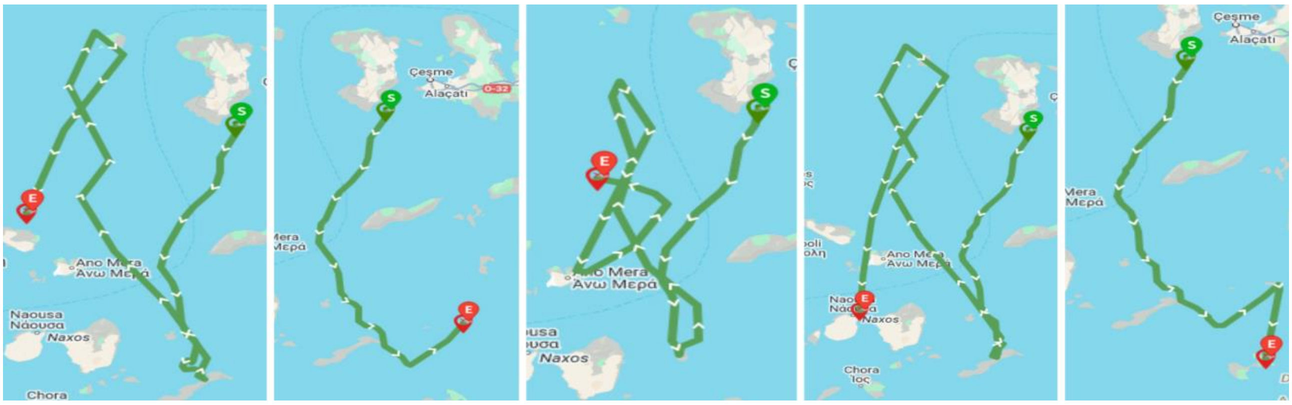

Figure 97. Movements of buoys from Chios to Central Aegean and backward (Bottleneck phenomenon) 2 (Source: MCG).

This case highlights how alternating seasonal wind regimes, combined with island-induced current systems, can result in complex, non-linear drift paths. It also underscores the role of transit zones such as the Mykonos–Ikaria strait, which—far from being static barriers—function as sensitive passageways that channel and redirect litter depending on wind direction and intensity.

7.5 Kavo Doro

The Kavo Doro Strait (Cape Kafireas), located between Euboea and the northern Cyclades, is a major maritime corridor of intense commercial traffic. Many oil tankers and numerous other vessels carrying hazardous cargo pass through these narrow waters every month.

This high traffic density implies that, in addition to marine litter transported by regional currents, the area is subject to significant levels of anthropogenic pollution—including plastics that are accidentally lost or deliberately discharged from passing ships. In the event of a maritime accident, Kavo Doro is considered a high-risk zone due to its narrow width and strategic position. A potential oil spill or mass discharge of litter could rapidly disperse into both the South Euboean Gulf and the surrounding Cycladic waters, with serious environmental implications. Moreover, both the Mykonos–Ikaria Strait and the Kavo Doro region demonstrate strong bottleneck effects in the context of floating plastic transport. These are key convergence points where currents accelerate, funnelling marine litter along dominant north-to-south pathways within the Aegean basin.

While local characteristics such as geography (strait width, proximity to shorelines) and human activity (shipping intensity, coastal pollution sources) may vary, both regions function primarily as transit zones for floating litter, rather than as permanent accumulation areas. Unlike oceanic gyres or enclosed bays, no consistent build-up of litter is observed in open waters; instead, these narrow corridors act as dynamic passageways, temporarily concentrating litter that is then carried farther downstream.

The research conducted in the Kavo Doro region included two seasonal deployments, carried out in January 2024 and February 2025. Despite the absence of the dominant summer Etesian winds (meltemia) during this winter period, the drifting devices exhibited a consistently southward and near-vertical trajectory from the deployment point to their final destinations. This pattern is most likely influenced by the strong and persistent marine currents that characterize the area throughout the year.
From the four devices deployed in January 2024, one successfully navigated through cyclonic current systems surrounding the Cycladic islands and eventually reached the Bay of Chania in Crete, after a long trip of 7 days

in which it covers 241 km (1.4 km/day). The remaining three devices, however, became trapped near the islands of Serifos and Kea, failing to progress further south.

These results highlight the dual role of the Cyclades: not only do they serve as transit zones for floating litter transported from northern regions, but under specific conditions, they also function as natural barriers or retention zones. In certain cases, litter can complete partial or full circular trajectories around these islands and then continue its journey; in other instances, it becomes entrained in local gyres and remains permanently trapped in the vicinity (Figure 98).

The variability in these outcomes underscores the complex interplay between regional current structures, island geomorphology, and seasonal wind activity, which together shape the movement and ultimate fate of floating materials in this critical sector of the central Aegean.

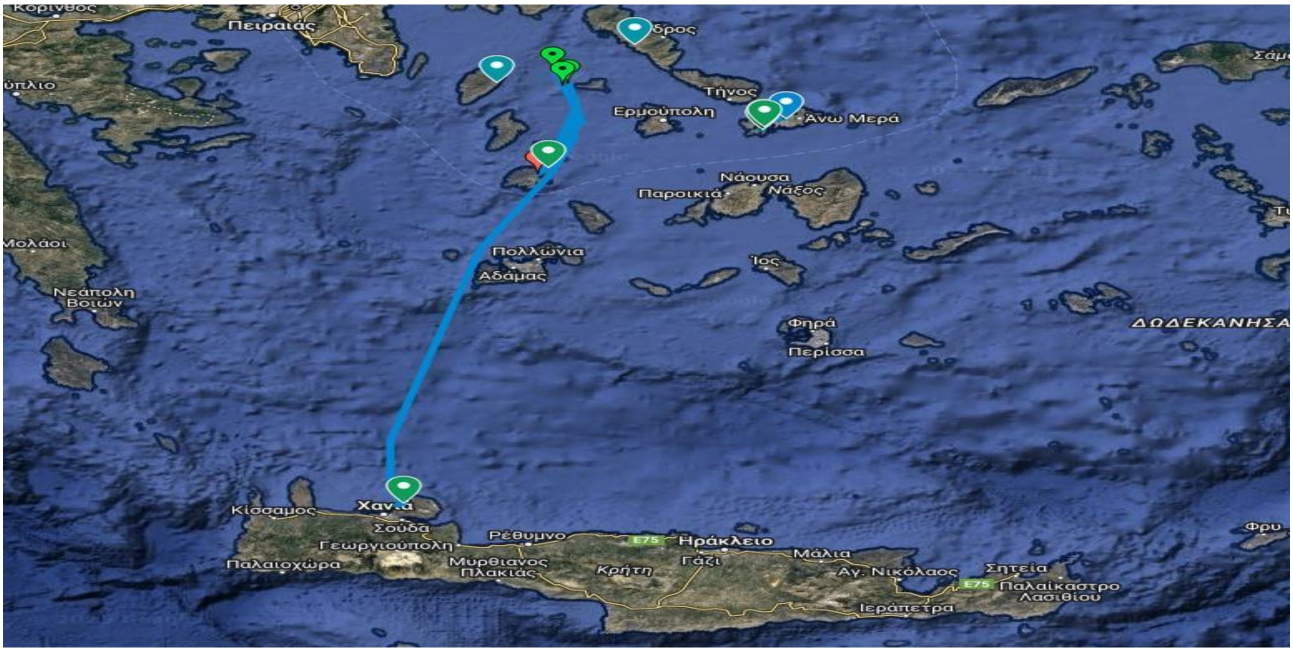

Figure 98. Movements of buoys from Kavo Doro to Crete in 2024 (Source: MCG).

In contrast to the January 2024 results, the February 2025 deployments, conducted in a slightly more westerly location along the Kavo Doro corridor, revealed a markedly different pattern of movement. The drifting devices exhibited a more unobstructed southward flow toward the Southern Aegean (Figure 99), suggesting reduced retention and more efficient transport of floating litter in this adjacent sector.

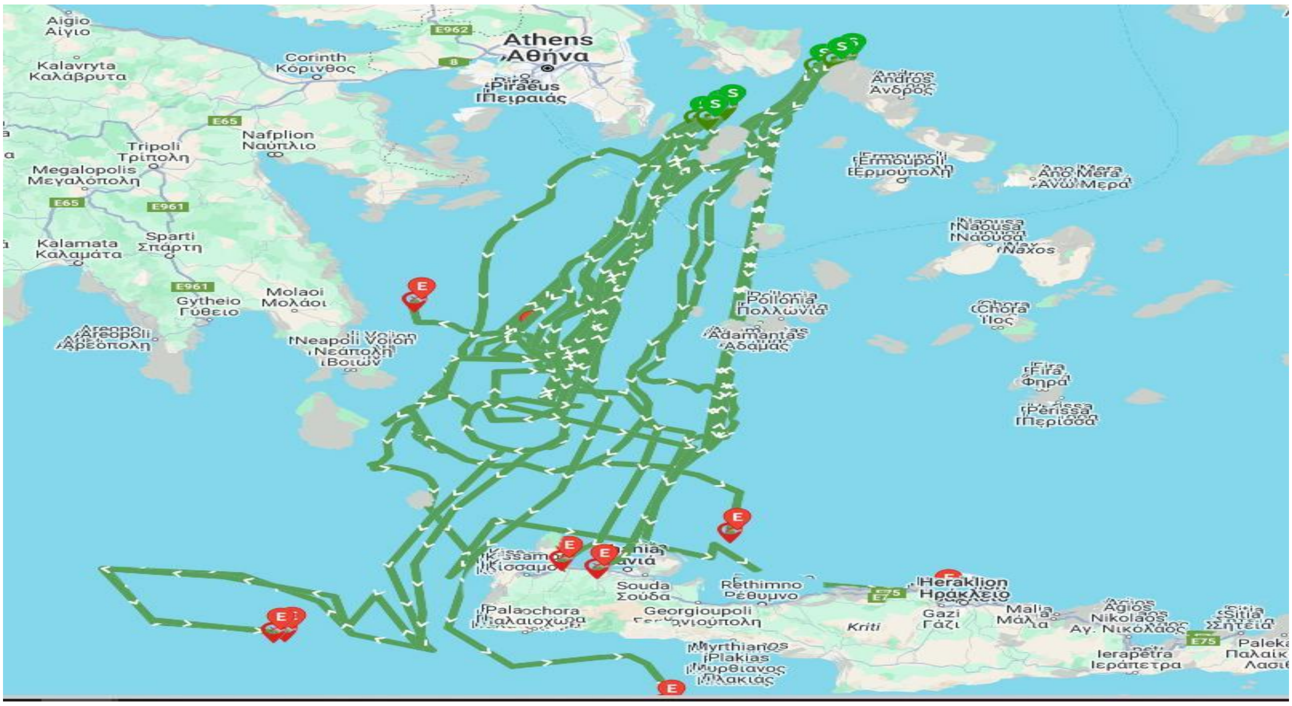

Figure 99. Movements of buoys from Kavo Doro to Crete in Winter 2025 (Source: MCG).

7.5.1 Case Study: Device 52151491 — Wind–Current Interaction and Long-Range Transport Toward the Eastern Mediterranean

Among the GPS-tracked buoys released in the Kavo Doro region that successfully reached Crete, one particular device ID 52151491 (Figure 100) was selected for detailed trajectory analysis to better understand the interplay between wind forcing and surface currents in the central and southern Aegean.

The deployment of this device took place on February 28th, 2025. In the days immediately following, the Kavo Doro region experienced sustained northerly winds of 5–6 Beaufort, blowing in a southwesterly direction. As expected under such favourable wind–current alignment, the device moved rapidly southward, covering a distance of 295 kilometers by March 9th, averaging approximately 26 km per day.

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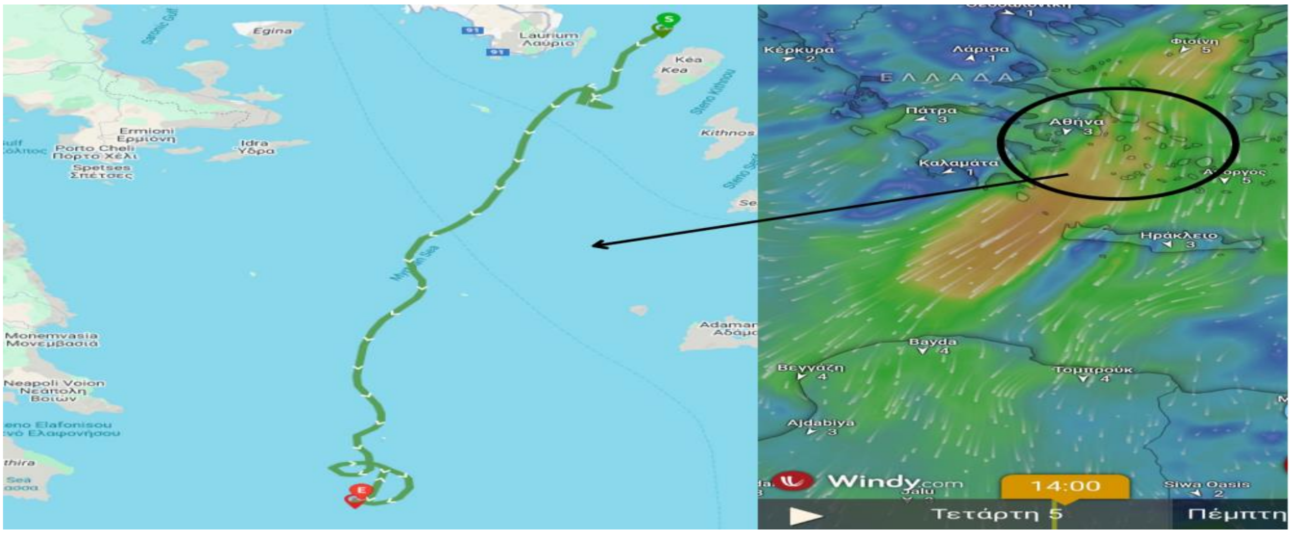

Figure 100. Detailed movement of buoy from Kavo Doro to Crete (part 1) (Source: MCG).

Between March 9th and 10th, as the device approached the area near Kythera, the regional wind pattern shifted. Winds blew from the southeast near southern Crete, and simultaneously from east to west in the northern part of the island. These converging flows appear to have created cyclonic eddies, causing the device to enter a circular trajectory, temporarily stalling its southward progress.

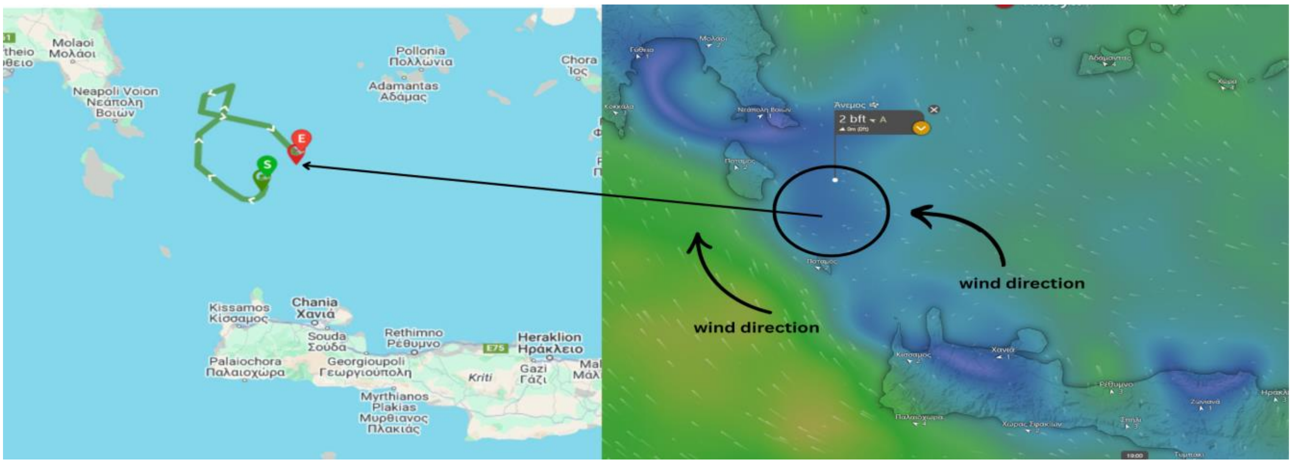

Figure 101. Detailed movement of buoy from Kavo Doro to Crete current direction and influence on device (part 2) (Source: MCG).

The buoy remained within this rotational current system (Figure 101) for several days until March 18th, when northerly winds reasserted themselves. At that point, the device resumed its journey southward, now following the coastal path shaped by a persistent cyclonic current along Crete's western coastline—a pattern likely influenced by the island's complex geomorphology. It eventually reached southern Crete (Figure 102) and, as of the time of this writing, continues its southbound trajectory toward the Libyan coast, covering up to now more than 720 km distance (Figure 103).

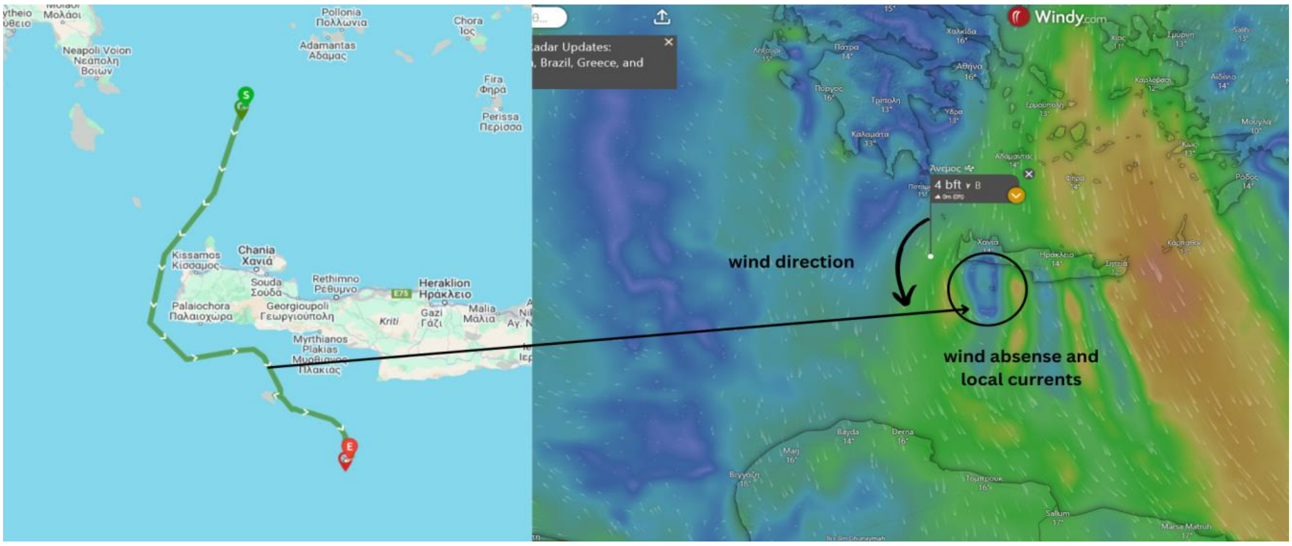

Figure 102. Detailed movement of buoy from Kavo Doro to Crete current direction and final destination (part 3). This Figure indicates the movement that the device follows after the change of weather conditions and the role of the local currents and the geomorphology (Source: MCG).

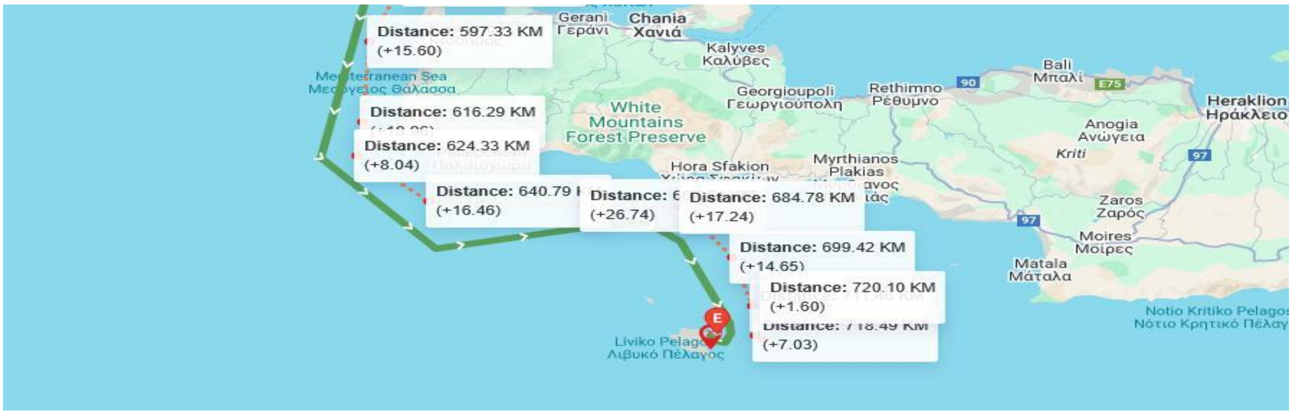

Figure 103. Total distance covered from Kavo doro to Crete (Source: MCG).

This case underscores the sensitivity of long-range transport to both large-scale atmospheric dynamics and mesoscale circulation features. It also highlights the importance of island morphology in shaping retention and redirection zones for floating litter in transitional marine corridors.

Despite this apparent increase in flow continuity, four islands Kea, Kythnos, Ag. Georgios and Makronisos functioned as a physical and hydrodynamic barrier. These islands appear to play a critical role in intercepting and retaining litter transported from the north through the Kavo Doro strait. In our February 2025 deployment, at least 8 devices (Figure 104) were entrained and ultimately trapped along the northern shores of these islands, particularly in zones facing the direct outflow from the strait.

This supports the hypothesis that these Aegean bottleneck points not only facilitate southward litter transport but can also act as localized accumulation zones, depending on the interaction between currents, island topography, and wind conditions at the time of transit.

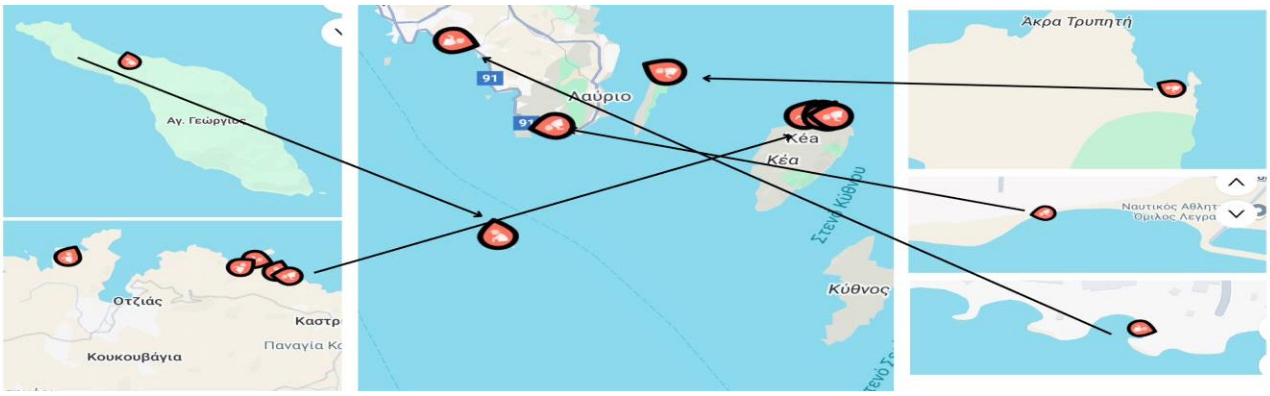

Figure 104. Hotspot near Kavo doro (Source: MCG).

These findings reinforce the idea that island clusters, even in areas of relatively strong current flow, can create selective retention hotspots that affect the spatial distribution and fate of marine litter in the central and southern Aegean basin.

7.5.2 Seasonal Influence on Litter Drift Pathways: Comparing Winter Northerlies and Summer Etesians

As demonstrated above, even during the winter months, in the absence of the persistent summer meltemia (Etesian winds), floating devices (buoys) were still able to travel southward, largely propelled by intermittent northerly winds. This reinforces the notion that, while meltemia are not active year-round, winter wind regimes can still sustain long-range southward transport of floating litter through the Aegean.

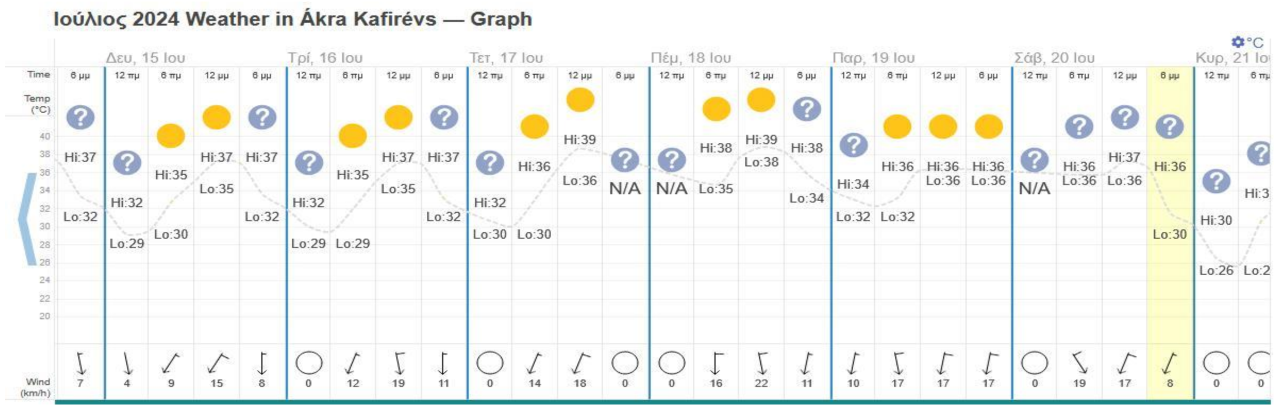

Figure 105. Weather Conditions near Kavo Doro under Etesian wind conditions (Source: MCG).

However, the key distinction lies in the intensity and consistency of the wind. The Etesian winds of summer are typically stronger and more continuous (Figure 105), resulting in more predictable and unidirectional flow patterns. This increases the likelihood that floating litter originating from Kavo Doro will travel south or southeast toward Libya or the Eastern Mediterranean basin during the summer months.

In contrast, during winter, the wind direction tends to alternate more frequently, leading to greater variability in transport pathways (Figure 106). As a result, litter may deviate from its southbound course, ending up along Crete's northern coastline, accumulating in areas such as the Bay of Chania, or being redirected westward toward the Peloponnese.

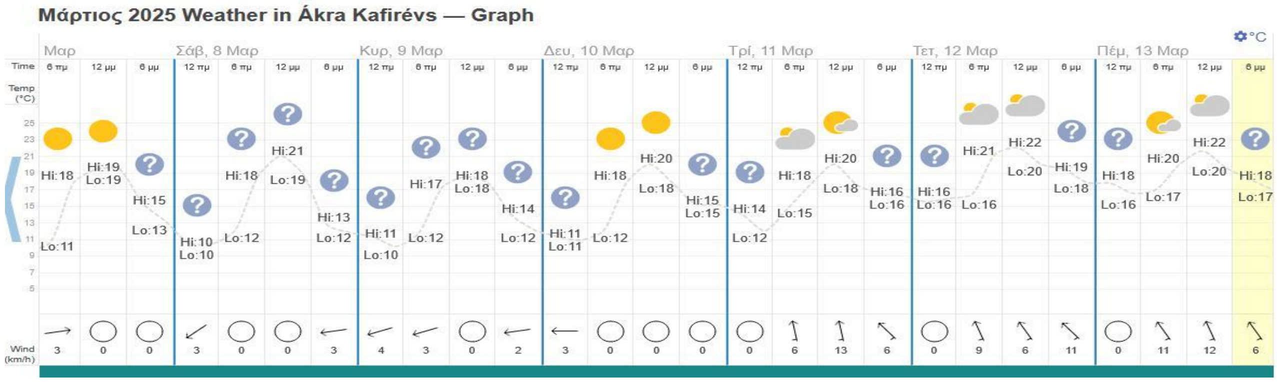

Figure 106. Weather Conditions near Kavo Doro during Research (Source: MCG).

In other cases, as seen in the example in Figure 107, winter wind patterns may even reverse the expected drift direction entirely. For instance, during the March 10th, 2025 deployment, conducted just a few days after a previous release near the same location, the presence of strong southerly winds forced the devices northward, into the Euboean Gulf. There, they became entrapped at various points along the gulf's coastline.

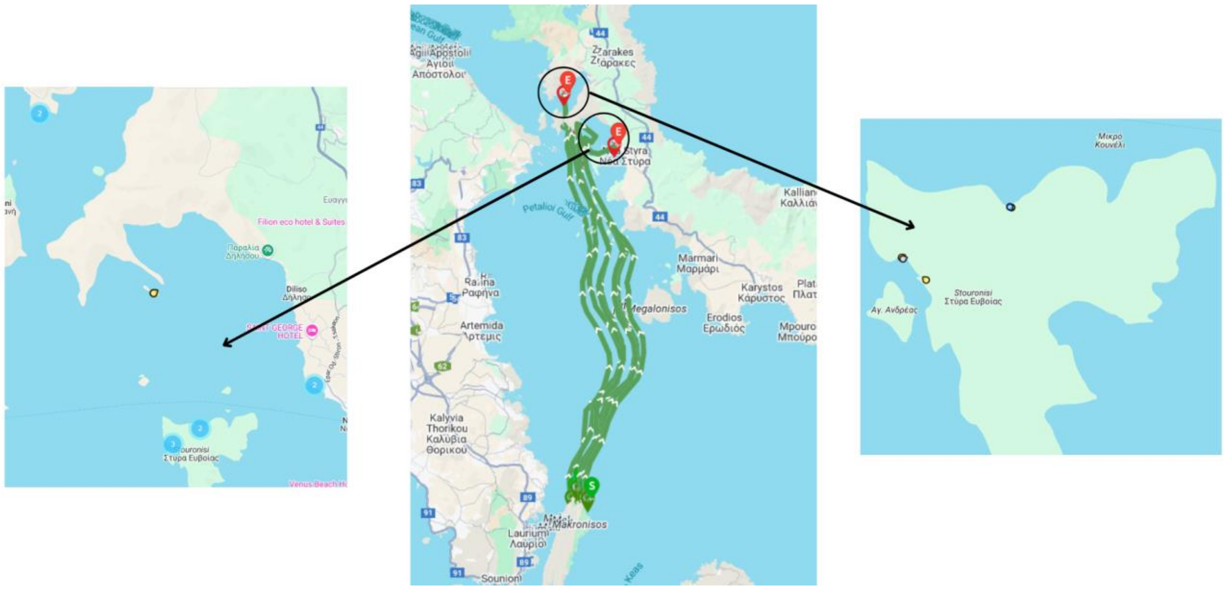

Figure 107. Buoys reverse direction movement under North Winds (Source: MCG).

Such a reversal would be highly unlikely during summer, when the dominance of the meltemia typically prevents northward transport in this region. This example clearly illustrates the significant role of seasonality in shaping litter dispersion dynamics and determining the final destination of floating litter in the Aegean Sea.

7.5.3 Aegean Islands as Natural Barriers to Marine Litter: The "Island Fence" Effect

As noted earlier, the islands of both the Cyclades and the Dodecanese act as natural filters (Figure 108) and barriers for floating marine litter moving between the northern and southern Aegean Sea. These island clusters influence the transport, retention, and eventual fate of floating litter by either intercepting it or redirecting its movement through narrow straits and between landmasses.

During our field deployments, which included multiple islands in the Cyclades such as Mykonos, Tinos, Andros, Serifos, and others, we observed a consistent pattern across both summer and winter seasons. Due to the proximity of many islands in the central Aegean, floating litter tended to remain within localized zones. Most devices released in these areas did not travel far from the point of deployment; instead, they were often washed ashore on the nearest island, which effectively blocked their path.

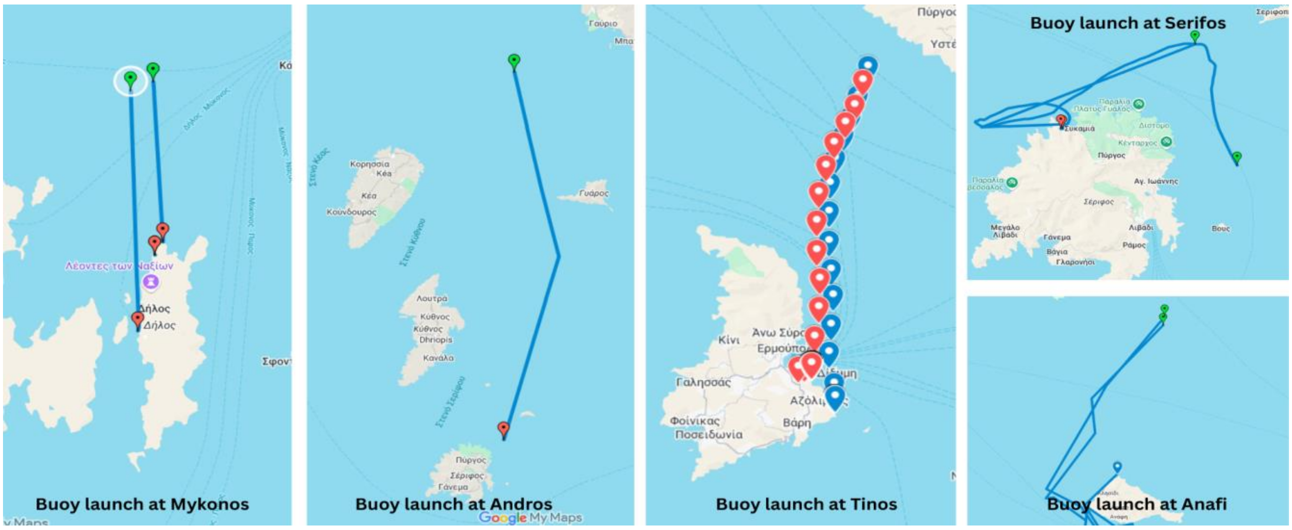

Figure 108. Buoys hotspot in Cyclades (Source: MCG).

The research findings showed that in densely clustered island groups—such as Mykonos, Tinos, Delos, Serifos, and Paros—marine litter was often beached shortly after deployment. This behavior demonstrates that litter originating from one island may directly impact nearby neighbors. For instance, plastic pollution from heavily touristed Mykonos can drift toward Delos, an archaeologically protected site, or toward Tinos and Serifos, which are less developed tourist destinations. Importantly, the litter does not disperse evenly across the Aegean, but tends to accumulate along the northern coasts of these islands, likely due to prevailing northerly wind patterns and local current regimes. These northern shorelines therefore act as seasonal hotspots for marine litter accumulation, especially during summer when the Etesian winds are dominant and tourism-related litter generation peaks.

In contrast, islands that are located farther offshore, such as Anafi and Astypalaia, showed different patterns. Some devices deployed near these islands were able to travel long distances, bypassing immediate coastal retention zones and eventually reaching other regions. These results highlight that the material properties of litter—such as size, weight, and buoyancy—along with island geography, play critical roles in determining whether litter is retained locally or dispersed more widely (Figure 109 and Figure 110).

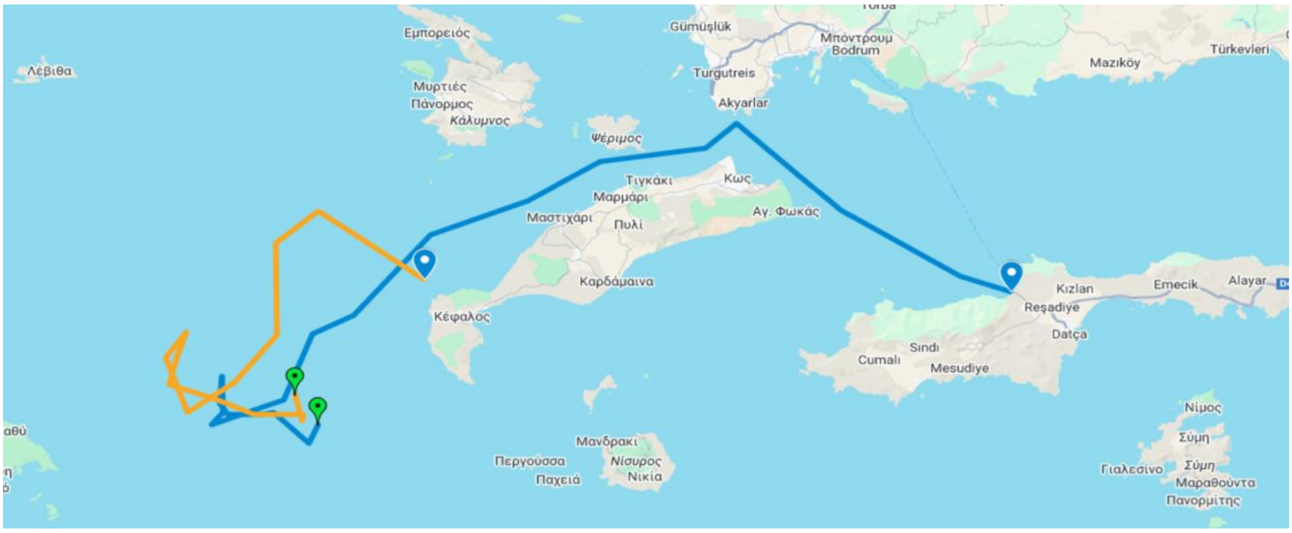

Figure 109. Comparison of a wooden buoy and a plastic on a launch at Dodecanese (Source: MCG).

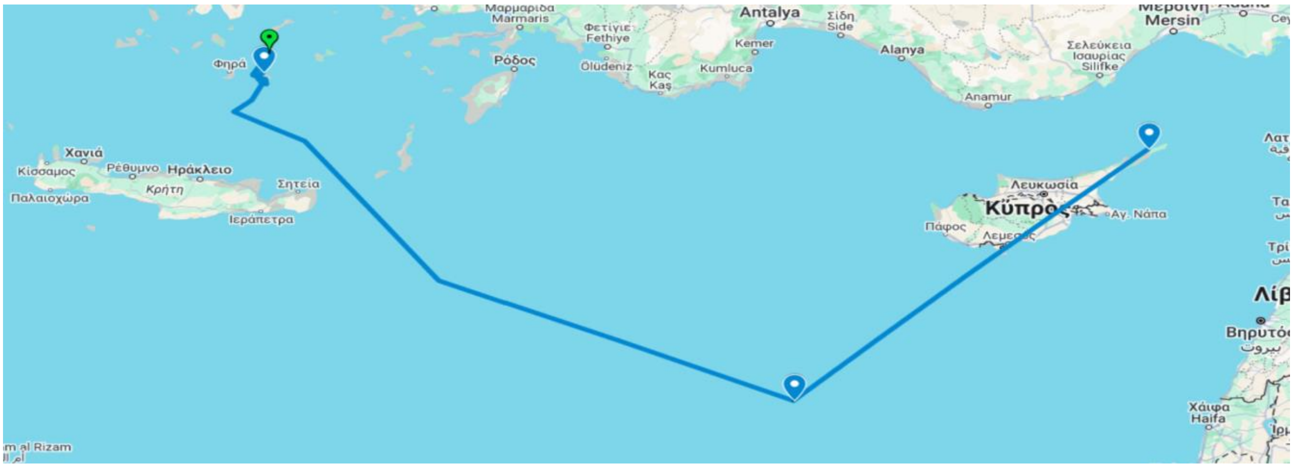

Figure 110. Movement of a buoy from Anafi to Cyprus during summer launch (Source: MCG).

7.6 Overall Summary of findings and Conclusions

Final Synthesis and General Conclusions: Seasonal and Spatial Trends in Litter Transport across the Aegean Sea. As discussed in the previous chapters, this study presents a detailed analysis of the trajectories recorded by GPS-tracked devices (buoys) deployed throughout the Aegean Sea, including the major river mouths of Northern Greece. Deployments were conducted during different seasons to account for the influence of seasonality on litter movement, and in many cases, repeated deployments were performed at the same locations to verify the consistency of results.

The overarching conclusion of this research is that seasonal variability plays a critical role in shaping the transport and distribution patterns of marine litter. During the summer months, floating litter tends to move southward, often exiting the Aegean toward the Eastern Mediterranean, effectively contributing to a temporary "cleansing" of the Aegean basin. This behavior is driven largely by the persistent and strong Etesian winds (meltemia) that dominate the region during summer.

In contrast, during winter and early spring, wind and current regimes are more variable. Southerly winds often lead to northward dispersal of litter toward various Cycladic islands, while occasional northerlies reverse the flow southward.

Two key zones emerged as dominant conduits and control points for litter movement: the Kavo Doro strait and the Mykonos Ikaria corridor. Due to their geomorphology and prevailing hydrodynamic conditions, these narrow regions act as transfer belts, channeling marine litter between the northern and southern Aegean. Islands situated nearby such as Mykonos, Ikaria, Chios, Andros, and Kea appear to receive disproportionate amounts of litter, functioning as barriers to southbound or northbound flows.
The open marine corridors on either side the Ikarian Sea to the east and the Myrtoan Sea to the west represent the main long-distance transport routes, guiding litter either eastward into the Eastern Mediterranean or westward toward the Central Mediterranean.

Main Findings: Absence of Fixed Hotspots

Our results indicate that the concept of permanent plastic hotspots in the Aegean Sea is misleading. The final destination of marine litter is influenced by a complex interaction of seasonal wind patterns, current systems, and geomorphological features. Any of these variables may alter a litter trajectory entirely.

7.6.1 Key Hotspot Categories

River Mouths (Northern Greece)
- Rivers behave as litter accumulation zones during summer, when low flow rates and shallow waters, combined with dense reed beds, trap plastics inland.
- In winter, stronger flows carry litter toward the open sea, but southerly winds at that time tend to push it back onto nearby coasts, polluting bays such as the Thermaic and Strymonian Gulfs.

Northern Aegean (Winter Dynamics)
- During the cold season, water density gradients between the Black Sea inflow and Aegean waters, along with prevailing southerlies, create circulation patterns that block southward movement.
- As a result, litter accumulates along coastal Halkidiki, Katerini, and Platamonas.
- Meanwhile, semi-enclosed bays in the Eastern Aegean (e.g., Oinousses) become effective traps for litter due to inward-directed current flows.

Central Aegean (Mykonos–Ikaria and Kavo Doro)
- These regions are crucial control points where litter is funnelled from distant origins and concentrated.
- Islands such as Kea and Makronisos, particularly on their northern shores, receive large amounts of litter due to strong winds and converging currents.
- In summer, meltemia drive litter away from these islands, effectively clearing them, while winter conditions lead to accumulation.

Crete (Especially Chania Region)
- The northern coast of Crete, and especially the Bay of Chania, emerged as a significant hotspot.
- Several devices reached or remained in the area for extended periods before continuing their journey southward.

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7.6.2 Visual Summary

The following section presents mapped data on the final positions of buoys to illustrate spatial trends and recurring accumulation zones.

Oinousses Sector – Plastic Accumulation Observations

The Oinousses area received more than six GPS-tracked buoy deployments during the monitoring campaign. Remarkably, only one of these devices managed to escape the region and continue its journey southward. This suggests that the marine zone around Oinousses functions as a natural retention basin for floating litter.

The area appears to be a significant hotspot for the accumulation of plastic litter originating from the northern Aegean and surrounding regions, including Lesvos and Chios (Figure 111) The prevailing current systems and geomorphological features of the area seem to favour the entrapment and long-term retention of marine litter. Notably, there is no indication of incoming plastic pollution from the southern Aegean or other areas of Northern Greece. These observations reinforce the importance of Oinousses as a localized convergence zone, heavily influenced by northern inputs and relatively isolated from broader regional inflows.

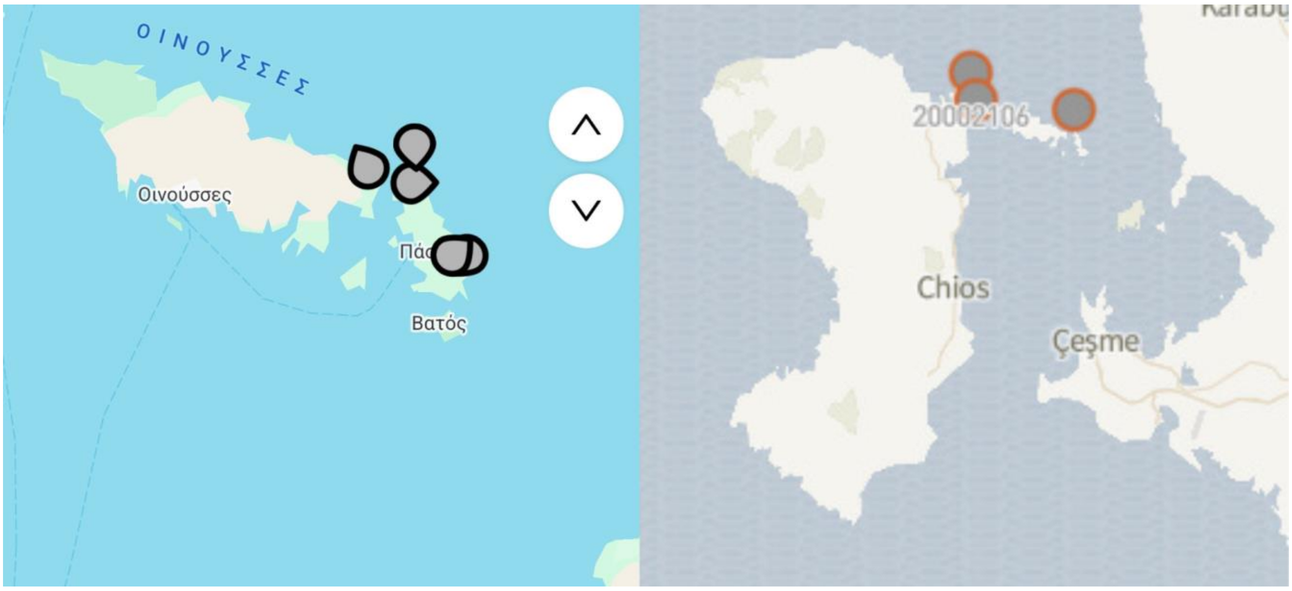

Figure 111. Oinousses Hotspot (Source: MCG).

7.6.3 Amorgos Island – A Key Accumulation and Transit Node

Amorgos appears to be one of the most critical plastic pollution hotspots in the Aegean Sea (Figure 112). Data from the monitoring campaign indicate that the island functions not only as a major receptor but also as a transitional waypoint for floating litter. More than eight GPS-tracked buoys were recorded converging on the island's coastal zone, suggesting that Amorgos receives significant inputs of marine litter potentially originating from various regions in Northern Greece.

In particular, the Aegiali Bay area acted as a temporary accumulation site. Several buoys were observed to either continue their journey southward from this point or reverse direction and disperse northward across the Cyclades. This behavior, especially during the winter monitoring period, highlights Amorgos's role as both a sink and a redistribution hub within the broader drift dynamics of the Aegean. Its strategic position along prevailing current routes makes it highly susceptible to seasonal accumulations and ongoing transit of marine floating litter.

Figure 112. Amorgos Hotspot (Source: MCG).

7.6.4 Crete – Chania Gulf as a Major Accumulation Hotspot

The Gulf of Chania (Figure 113), located on the northwestern coast of Crete, appears to function as a significant accumulation hotspot for floating marine litter. Findings from the GPS-tracked buoy deployments indicate that this enclosed bay effectively traps litter that may originate from distant regions across the Aegean.

In the context of the study, 6 out of 10 buoys (60%) launched from the Kavo Doro strait eventually reached the Chania Gulf and remained within its confines. This high retention rate underscores the bay's geomorphological and hydrodynamic capacity to capture and hold litter. Additionally, 2 other buoys initially entered the gulf but later escaped, continuing their drift either eastward toward Heraklion or southward into the Libyan Sea. These patterns highlight the dual role of the Chania Gulf as both a terminal accumulation zone and a potential transit point in the broader marine litter dispersal system of the eastern Mediterranean.

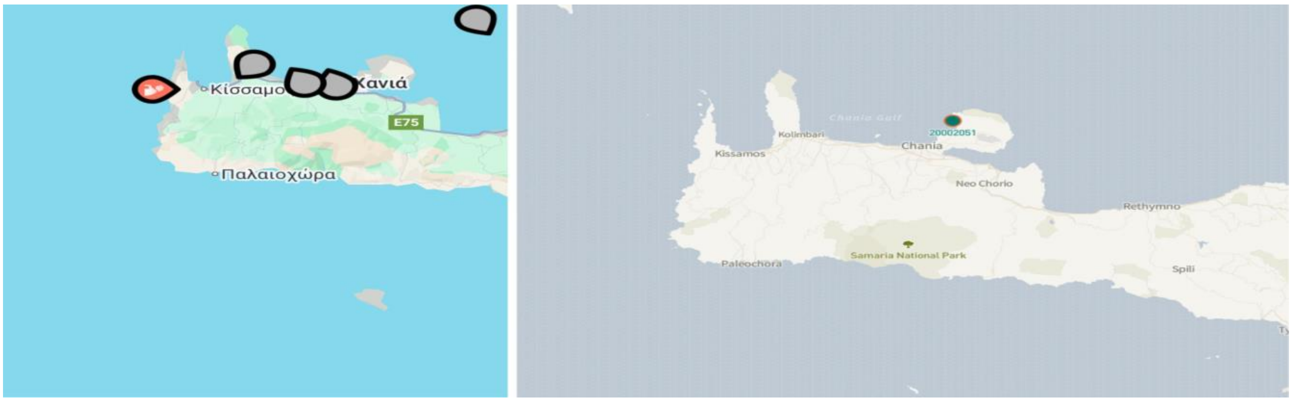

Figure 113. Crete Hotspot (Source: MCG).

7.6.5 Ikaria Island – A Central Aegean Convergence Zone

Ikaria, much like Mykonos (Figure 114), represents a critical hotspot for plastic litter accumulation due to its strategic location in the heart of the central Aegean Sea. Its position makes it a natural convergence zone for floating litter traveling both from the northern Aegean southward and from the southern Aegean northward—particularly during the winter months when current reversals and complex wind systems are more prevalent.

In the context of the REMEDIES research, more than ten GPS-tracked buoys were either temporarily retained or fully trapped in the marine area surrounding Ikaria. Several of these remained near the island for extended

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periods before eventually continuing their drift to other regions. These findings highlight Ikaria's role as a transient accumulation node within the broader marine litter circulation system of the Aegean.

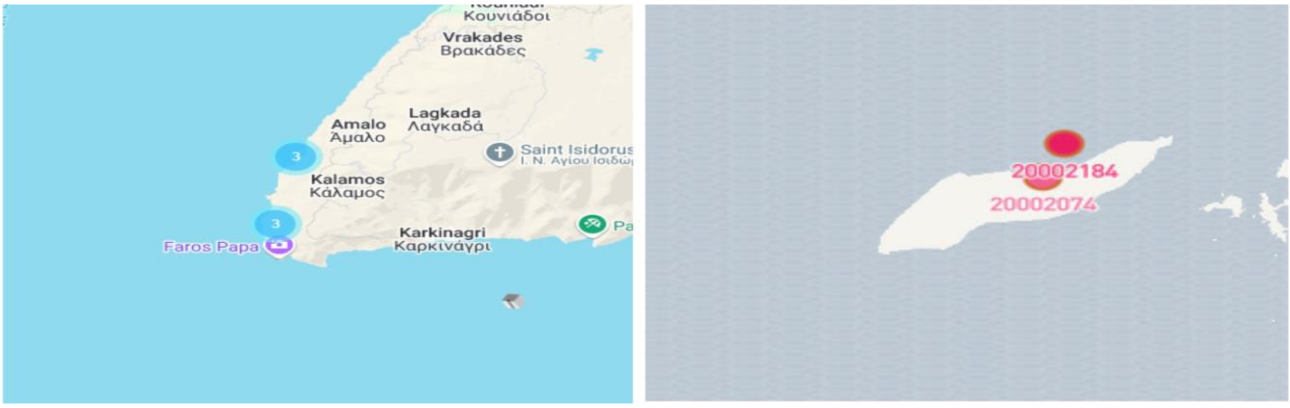

Figure 114. Ikaria Hotspot (Source: MCG).

7.6.6 Euboean Gulf – A Seasonal Retention Zone During Southerly Wind Conditions

The Euboean Gulf has emerged as a significant seasonal hotspot (Figure 115) for marine litter accumulation, particularly during the winter months when strong southerly winds prevail. According to the REMEDIES deployment data, all 12 buoys with GPS released in the Kavo Doro strait during periods of intense southerly winds were subsequently trapped within the Euboean Gulf.

Notably, the buoys were consistently concentrated in specific locations, including the coastal areas of Nea Styra and Petalioi. This pattern suggests that the gulf's semi-enclosed morphology, in combination with wind-driven surface currents, creates a hydrodynamic trap that retains floating litter. These findings highlight the Euboean Gulf as a critical regional retention zone that warrants further monitoring and targeted mitigation efforts during the winter season.

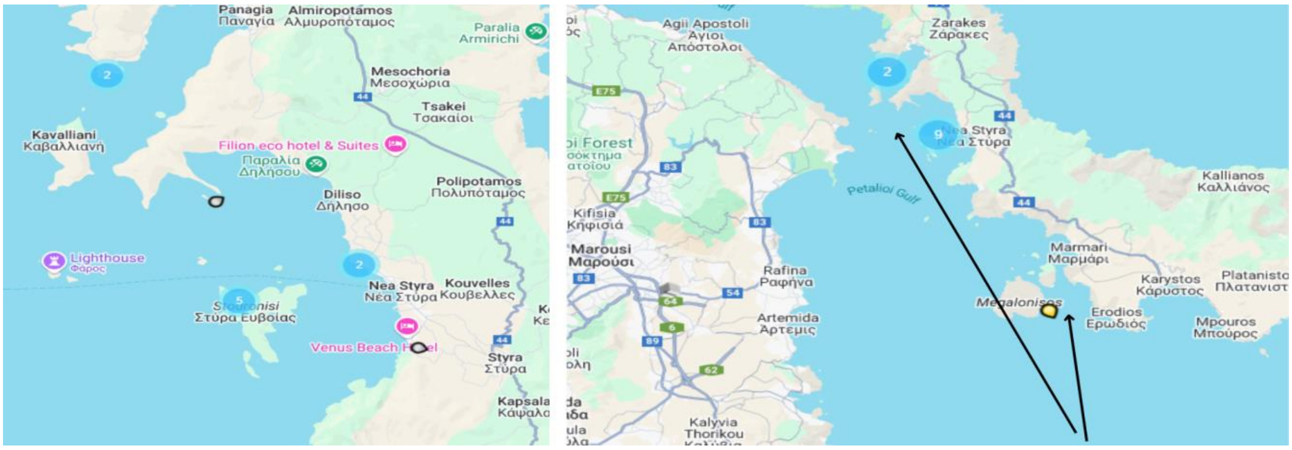

Figure 115. Euboean Hotspot (Source: MCG).

7.6.7 Additional Areas of Interest and Emerging Hotspots

Beyond the key locations already discussed, several other regions demonstrated notable patterns of plastic litter accumulation during the monitoring period. The northern coastline of mainland Greece received multiple GPS buoys that had previously escaped river systems such as the Axios, Aliakmonas, and Strymonas, indicating a strong connection between riverine outflows and nearshore accumulation. Moreover, the northern shores of Kea and Makronisos registered a significant number of buoys arriving from the Kavo Doro strait, particularly during winter deployments. Similarly, the island of Delos—though small in size—received buoys originating from nearby areas such as Tinos and Mykonos, illustrating its role within the local circulation network.

These areas appear to function either as final deposition zones or as temporary transit points depending on the prevailing seasonal conditions, wind regimes, and levels of anthropogenic activity (Figure 116) Their dynamic behavior underscores the complexity of marine litter movement in the Aegean and highlights the need for further long-term research. Extended observation periods, increased buoy density, and seasonally stratified deployments will be essential to better understand the role of these secondary hotspots in the broader regional transport system of plastic pollution.

Figure 116. Hotspot at several islands (Source: MCG).

8. Public Engagement and Awareness

Public engagement and awareness within the framework of this research initiative are of paramount importance, serving as a key pillar for the program's success. The active involvement and education of citizens play a crucial role in three distinct but interconnected areas: raising awareness about the project, fostering behavioral change to prevent plastic pollution, and ensuring the smooth execution of the research activities.

8.1 The Importance of Public Awareness

This chapter describes the three key objectives. The first objective is to provide comprehensive public information about the REMEDIES program—who we are, what we do, and why our research matters. A well-informed public is more likely to engage with and support environmental efforts, creating a sense of collective responsibility. By actively involving communities in the program, we empower individuals to contribute meaningfully to the broader goal of marine conservation. Encouraging a sense of ownership and participation among local populations fosters long-term environmental stewardship, reinforcing the idea that protecting the marine environment is a shared responsibility.

The second objective is to leverage public awareness to promote behavioral change and reduce plastic litter pollution. A key goal of the REMEDIES program is to understand and mitigate the movement of plastic litter in marine and freshwater systems. As highlighted in global scientific literature and confirmed by our research, the Mediterranean is not merely a passive recipient of plastic pollution; instead, it functions as a dynamic system where plastic litter both enters and exits the region. Studies indicate that a relatively small proportion of plastic litter enters the Mediterranean compared to the amount that exits, suggesting that the primary sources of pollution stem from local anthropogenic activities rather than external inputs. The unregulated and excessive use of plastics in tourism, agriculture, and industry, combined with improper litter management practices, has been identified as a primary driver of pollution in the region. Raising awareness about these issues is critical to reducing plastic inputs at their source and fostering a long-term shift towards more sustainable practices.

The third objective is to ensure the uninterrupted and reliable execution of the program's research activities. As outlined in earlier chapters, one of the most significant operational challenges encountered during the first phase of the project was the unintended retrieval of buoys by unaware individuals. A particularly striking example occurred during the summer of 2023, when 18 out of the first 40 deployed buoys were recovered by swimmers, tourists, or fishermen, significantly disrupting the planned tracking and data collection. Without targeted public outreach, such occurrences could have compromised the validity of the results, leading to altered drift trajectories, data inconsistencies, and gaps in monitoring efforts. This highlights the critical need for widespread public awareness to prevent further disruptions and ensure that the scientific integrity of the project remains intact.

8.2 Public Awareness and Engagement Initiatives by MCG

Recognizing the fundamental role of public engagement, MCG implemented a structured outreach strategy from the earliest stages of the program, ensuring that key stakeholders and communities were well-informed and actively involved. At the institutional level, the Greek Ministry of Environment and the Forest and Wetland Protection

Organization in the Evros region were formally notified about the research activities. Their support was instrumental in securing the necessary permits for the buoy deployments in key locations, enabling the research to proceed without regulatory obstacles.

At the maritime industry level, extensive communication was established with major ferry operators, including Blue Star Ferries and Triton Ferries, as well as with crew members, who played an active role in facilitating the deployment of buoys along ferry routes. Their assistance ensured that the buoys were released systematically and accurately, minimizing the risk of immediate retrieval or misplacement.

At the local community level, collaboration with municipal authorities and regional stakeholders (Figure 117) was a key component of the engagement strategy. Municipalities such as the Municipality of Katerini not only provided logistical support but also actively participated in buoy deployment efforts, with members of the local council directly involved in the Aliakmonas River buoy release. Similarly, port authorities, including those in Porto Rafti and Limnos, played a crucial role in coordinating the deployment of tracking devices within their respective jurisdictions.

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Figure 117. Speech about Remedies Program in Marathona (Source: MCG).

8.3 Addressing Public Interaction with the Buoys – Direct Community Engagement

A key part of the outreach strategy involved direct engagement with members of the public who had inadvertently retrieved deployed buoys. A notable case occurred in Astypalaia in summer 2023, where a group of Italian tourists unknowingly collected several buoys, mistaking them for lost objects. Following an educational intervention, they not only returned the devices but also became advocates for the program, sharing their experience with other visitors and raising awareness within their networks. This demonstrates the transformative potential of public education, where one-time interactions can lead to broader awareness and community involvement.

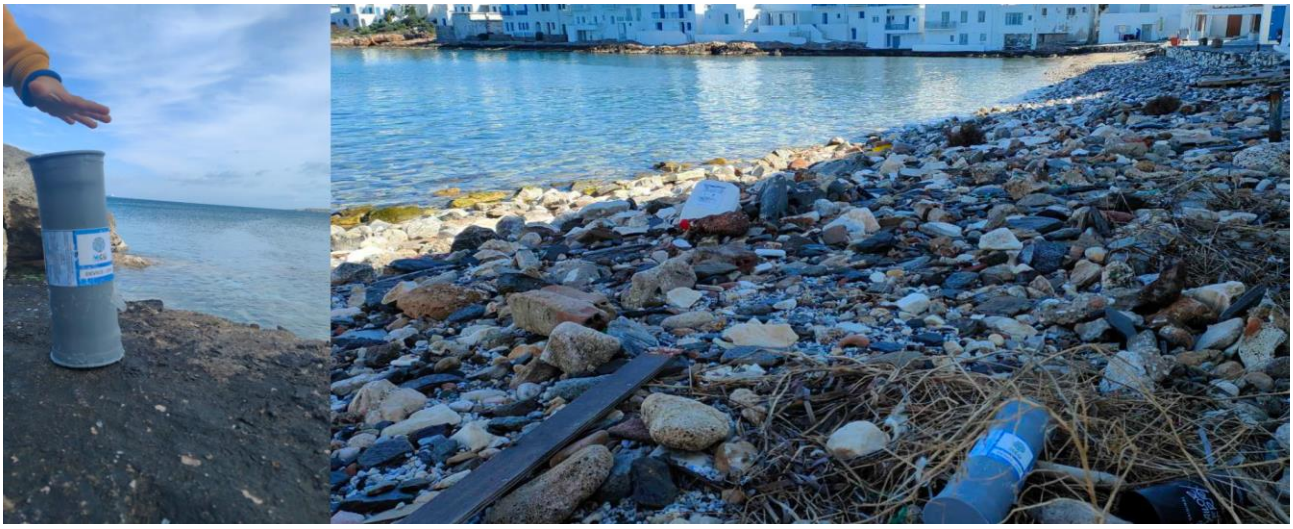

Figure 118. Buoy with GPS retrieve at Paros from Tourists during Winter 2024 (Source: MCG).

8.4 Expanding Public Awareness – Media and Social Media Outreach

Beyond direct community engagement, MCG collaborated with media outlets to ensure that the research program gained widespread visibility. Journalists covering the project published articles (Figure 119) and broadcasted reports on television (Figure 120) and digital platforms Figure 121), extending the program's reach to a broader audience.

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Σκουπίδια: Συσκευές με GPS σε ποτάμια και Αιγαίο θα ανιχνεύουν τη διαδρομή τους

Μέσω του προγράμματος, θα γίνουν 200 ρίψεις, ανά διάφορες χρονικές περιόδους, για τα επόμενα δύο χρόνια προκειμένου να χαρτογραφηθεί η πορεία των απορριμμάτων που βρίσκονται σε διάφορες παραλίες

ΟΙ ΕΙΔΗΣΕΙΣ ΣΕ TAGS: #Πόλεμος στην Ουκρανία #Ντόναλντ Τραμπ #Τέμπη

ΕΛΛΑΔΑ | ΠΟΛΙΤΙΚΗ | ΚΟΣΜΟΣ | ΟΙΚΟΝΟΜΙΑ | ΨΥΧΑΓΩΓΙΑ ΣΚΑΪ ΡΟΗ ΕΙΔΗΣΕΩΝ | ΑΠΟΨΕΙΣ

Συσκευές με GPS «ταξιδεύουν» στο Αιγαίο για να ανιχνεύσουν τη διαδρομή σκουπιδιών

Κάποιες από τις συσκευές είναι πλαστικές και άλλες ξύλινες, είναι όλες αδιάβροχες και έχουν εμφανή διακριτικά και ταμπελάκι με στοιχεία για το ερευνητικό έργο προκειμένου να μη θεωρηθούν σκουπίδια και απομακρυνθούν.

Τη διαδρομή των σκουπιδιών μέσα από τους υδάτινους δρόμους επιχειρεί να χαρτογραφήσει ερευνητική ομάδα στο πλαίσιο προγράμματος, το οποίο ασχολείται με την προστασία των υδάτινων πόρων της ευρύτερης περιοχής της Μεσογείου.

Figure 119. Publication of the program's activities in Greek media (Source: MCG).

Figure 120. Screen capture of the publication of the REMEDIES program's activities in Greek TV (Source: MCG).

Additionally, buoy with GPS deployments were documented and shared on social media through partnerships with influencers and environmental groups boasting thousands of followers. Videos showcasing the buoy releases reached a vast audience, sparking discussions about plastic pollution and marine conservation. This innovative approach to outreach leveraged the power of digital media to amplify the program’s message beyond its immediate geographic scope.

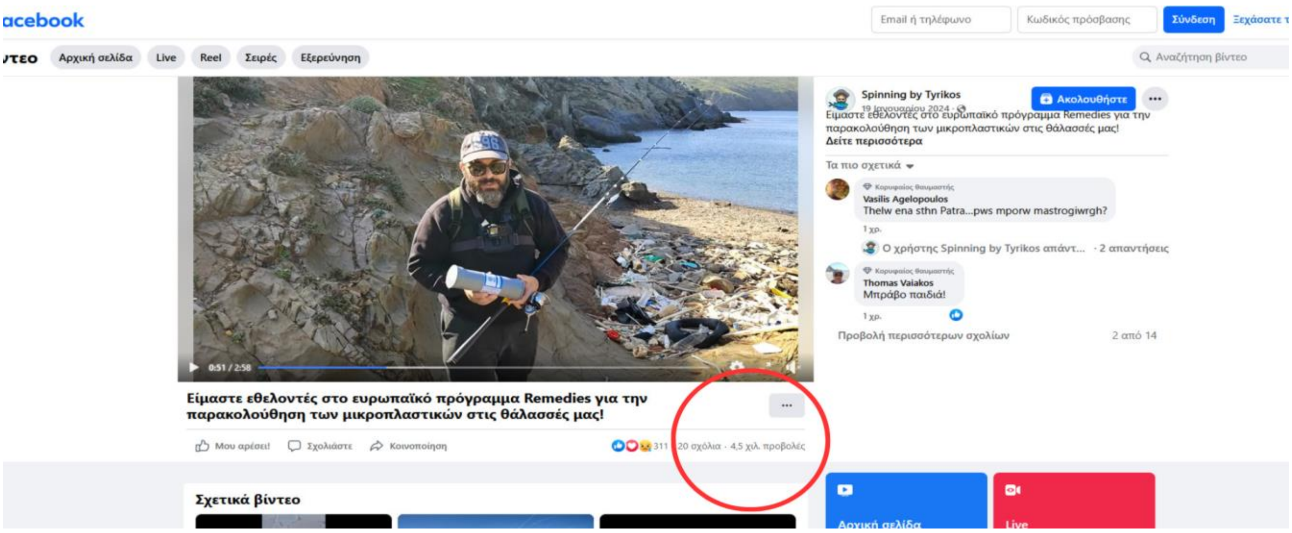

Figure 121. publication of the program's activities in social media (Source: MCG).

8.5 Impact of Public Awareness on Program Effectiveness

With regards to the third challenge—preventing the premature retrieval of buoys—the success of these public engagement initiatives was clearly measurable. Following the implementation of these outreach efforts, the rate of unauthorized buoy retrievals decreased significantly, with only a few isolated incidents recorded thereafter. This substantial reduction in buoy losses directly contributed to the program's ability to collect continuous and uninterrupted data, reinforcing the importance of public awareness in ensuring the accuracy and success of scientific research.

8.6 Conclusion

We strongly believe that these targeted public awareness initiatives have not only been effective in minimizing disruptions to the research program but have also played a crucial role in educating communities about plastic pollution and fostering long-term behavioral change. The integration of public participation, institutional collaboration, and digital outreach has proven to be a powerful tool for promoting environmental responsibility. As the REMEDIES Mission Ocean and waters program moves forward, we anticipate that these engagement strategies will continue to support both scientific progress and real-world environmental impact. Additionally, replication potential to other regions can be envisioned.

9. Final Remarks and Summary

The REMEDIES D1.4 deliverable, titled "Buoys with GPS," outlines an innovative methodology for identifying and monitoring plastic pollution pathways in the Aegean Sea. By deploying approximately 200 GPS-equipped tracking buoys across both marine and riverine environments, the project aimed to visualize the transport, dispersion, and accumulation zones of plastic litter in real-time.

Each buoy incorporated a smart GPS module with an AIS transmitter and extended battery life, enabling reliable, long-duration tracking under harsh marine conditions. The deployment strategy ensured broad spatial coverage throughout the Aegean, including river mouths, narrow straits, and high-energy coastal corridors. Signals from the buoys were collected and used to create spatial and temporal maps of plastic drift trajectories over various seasons.

A core element of the project was citizen engagement. Members of the public were invited to recover buoys via a mobile app interface, contributing underwater and shoreline imagery and helping to locate recovery points. This participatory model fostered public awareness and environmental responsibility while complementing scientific data collection efforts.

Environmental sustainability was prioritized in both the design and lifecycle of the buoys. Initial prototypes used marine plywood and cork but were later replaced with plastic casings from LHDPE due to enhanced buoyancy, durability, and data reliability. All materials used were recyclable, and buoys were designed for recovery and reuse, aligning with circular economy principles.

Despite certain operational constraints—including reduced river discharge during a dry winter, limited device availability, and atypical southerly wind conditions—the project successfully gathered valuable data across more than 10,000 km of total buoy trajectories. Challenges were met with adaptive planning, leading to refinements in both methodology and technology.

The results revealed important insights into the role of natural and anthropogenic factors in shaping plastic litter flows. In dam-regulated rivers (Axios, Aliakmonas, Strymonas), litter movement was minimal, and pollution in the deltas was mostly of domestic origin. By contrast, the free-flowing Evros River transported transboundary litter from Bulgaria and Turkey into the Aegean, with some buoys traveling over 200 km to reach the island of Lemnos. Infrastructure (such as dams), geomorphology, seasonal wind patterns, and salinity gradients were all shown to significantly influence drift behavior.

The REMEDIES project highlights the effectiveness of GPS-based monitoring in understanding plastic pollution transport dynamics. Its conclusions are expected to inform targeted cleanup actions, guide future mitigation strategies, and support transboundary collaboration in managing marine and riverine litter across the Eastern Mediterranean.

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