Project Sentinel: AI-Enabled Underwater Gliders for Real-Time Detection of Illegal Marine Discharges

Legal Notice and Disclaimer
This white paper is published by Hrvoje Mihovilović / ELNAV.AI d.o.o. and placed in the public domain for informational purposes. It describes the Sentinel concept as prior art, ensuring the ideas, methods, and system designs herein are accessible for collaborative development and cannot be patented exclusively by third parties.

No warranty is made as to the accuracy, completeness, or usability of this information; the authors disclaim all liability arising from its use. This document is not legal, engineering, or commercial advice. Parties interested in implementing these concepts should seek professional consultation.

---

1. Introduction

Marine pollution from illegal discharges remains a persistent, yet often overlooked, threat to ocean health and coastal economies. Tankers and cargo ships routinely dump oily wastewater (known as bilge), sludge, ballast water, or other residues directly into the sea—far from public sight. While dramatic tanker spills garner headlines, **chronic, small-scale illegal dumping** can cumulatively surpass the volume of headline-making accidents. Over time, these discharges inflict severe damage on marine life, taint coastal beaches, and impose hefty cleanup costs on governments.

Recent **investigations** by the non-profit newsroom *Lighthouse Reports*—in collaboration with *Jutarnji list*, BIRN, *Deutsche Welle*, *Guardian*, and other European media—have highlighted how often these incidents go **unpunished**. The investigative team, using satellite imagery and Automatic Identification System (AIS) ship-tracking data, documented **330 potential illegal bilge-water dumpings** between July 2020 and December 2021 in European waters, of which 271 occurred within 50 nautical miles of an EU state's coast—areas where discharges are clearly prohibited. Further analysis by the environmental monitor *SkyTruth* suggests that **an additional ~2964 vessels** may dump oil waste in European waters annually, often unseen by satellites. Despite the **sophisticated satellite surveillance** set up by the European Maritime Safety Agency (EMSA), only a small fraction of observed slicks are verified in time, and **prosecutions remain extremely rare**.

This gap between **advanced technology** (e.g., satellites, radar) and **slow or inadequate response** underscores the urgency for better, more persistent monitoring—particularly at sea level or below the surface. **Project Sentinel** proposes an innovative solution: deploying **autonomous underwater gliders** equipped with sensor suites and AI algorithms that continuously patrol the water column, detect pollution events in near-real-time, and automatically relay alerts to authorities. By combining cutting-edge robotics with smart data analytics, Project Sentinel aims to **deter polluters** and ensure that illegal discharges no longer go unnoticed or unpunished.

This white paper overviews the problem of **hidden ship discharges**, explains the concept and technical approach of Project Sentinel, and outlines the potential **cost-benefit** for policymakers in the Adriatic and beyond. It integrates findings from recent investigations to underscore why real-time, in situ monitoring is urgently needed, not only for **oil** but also for **ballast water, grey water, and exhaust scrubber wash-water** discharges, all of which degrade marine ecosystems.

---

2. The Widespread Problem of Illegal Discharges

2.1 Chronic Yet Hidden

Illegal dumping of oily water and other wastes (e.g., sewage, chemical sludge) continues even though international law (MARPOL) explicitly forbids it. Multiple strands of evidence show that:

1. **Increasing Traffic, Increasing Discharges**
   According to the *Lighthouse Reports* investigation, one tanker on **January 9, 2021** released oily water just before midnight in the Adriatic Sea—**inside Croatian territorial waters**, but far offshore, where detection is challenging. This is not an isolated event; it represents one of **hundreds** of such incidents in European seas every year. Local oceanography expert *dr. sc. Mira Morović* notes that **as many as 100,000 vessels** travel through the Adriatic annually, raising serious questions about how many discharge their "dirty" waste en route.
2. **Underreported and Under-Verified**
   Between 2007 and 2019, EMSA recorded **44,383 possible illegal discharges** (mainly oil) from satellite data. Yet investigators found that national authorities typically confirmed only a fraction on-site, and even fewer led to prosecutions. In 2020, EMSA issued 3945 pollution alerts, but **about 30%** were checked, and only in **5%** of those checks was on-site verification done within 3 hours—critical for gathering evidence. Delays mean slicks disperse or drift away, leaving no proof.
3. **Nighttime Dumping and AIS Tricks**
   Ships often release oily waste **at night** or during rough weather—periods when satellites or aerial patrols are less likely to confirm the slick visually. Some vessels also **switch off AIS** (Automatic Identification System) or alter their track to obscure a discharge's origin. The *Lighthouse Reports* team found multiple examples where a vessel's AIS signal mysteriously stopped transmitting shortly before bilge dumping was detected by radar imagery.
4. **Easy Methods for Bypassing Onboard Treatment**
   MARPOL requires vessels over 400 GT to have onboard treatment, limiting oil content to **15 ppm**. However, **whistleblowers** and **inspectors** revealed that many ships use **portable "magic" pumps** to bypass the oily water separator, dumping untreated bilge overboard. Crews also falsify the "oil record book," which is supposed to detail all oil handling. Enforcement of these logs has been inconsistent.
5. **Cumulative Environmental Damage**
   Experts such as ecotoxicologist Kerstin Magnusson emphasize that even small discharges harm planktonic organisms and fish larvae. Over time, repeated discharges create toxic effects in the water column and along coastlines. In the semi-enclosed Adriatic, the risk is amplified by limited water exchange and dense marine traffic.

Overall, investigative reporting and satellite data confirm that **illegal discharges persist on a large scale** due to the **high economic incentive** (saving time and port fees) and **low likelihood of being caught**. As one maritime activist noted, "If you have 10 ships each dumping 15 ppm of oil, that adds up. But there are 5000 ships out there." This mismatch between the scale of the problem and the limited effectiveness of occasional spot checks or delayed satellite alerts is exactly what Project Sentinel aims to fix.

2.2 Why Enforcement Fails

- **Delayed or Insufficient On-Site Response**: The *Lighthouse Reports* investigation shows that only **1.5%** of potential spills in 2019 were checked within 3 hours—the period after which physical evidence dissipates.
- **Jurisdictional and Coordination Gaps**: Many discharges occur near **border zones** (like the Croatia–Italy maritime boundary in the Adriatic) or on the high seas. Tracking a vessel across jurisdictions can be complicated. Even if one country is alerted, the offending ship may dock in another.
- **Limited Patrol Assets**: Traditional methods—coast guard vessels or aircraft—are expensive to operate around the clock. Satellite coverage can miss nighttime or fast-dispersing slicks, and does not always pinpoint a responsible vessel.
- **Lack of Visual Proof**: Courts demand solid evidence (e.g., samples of the polluted water, photos of the discharge). Radar images alone, while strong indicators, are rarely deemed conclusive. By the time a patrol arrives, the slick is often gone or diluted.
- **Underreporting in Official Records**: The *Lighthouse Reports* study underscores that many countries (including Croatia, Italy, the UK, and Romania) report **few or zero confirmed violations** despite frequent satellite alerts. Publicly, authorities claim "no wrongdoing found," yet the raw data suggests otherwise.
- **Cost Pressures**: Treating or unloading oily bilge at port can cost tens of thousands of euros for a single ship. Crews and operators see a strong financial incentive to "dump and go," especially if detection chances are minimal.

Collectively, these factors have enabled an environment where **illegal dumping** is "cheaper than compliance." As *Maja Markovčić Kostelac* of EMSA admitted, "Discharges still happen regularly... the number of prosecutions is low." Addressing this entrenched practice requires **continuous, real-time monitoring** that can produce indisputable evidence and immediate alerts—a gap Project Sentinel can fill.

---

3. Project Sentinel: A Practical Solution

Project Sentinel tackles the core detection and enforcement gaps by **employing autonomous underwater gliders**—small, unmanned submersibles that glide through the sea for months on battery power. Equipped with AI-driven sensors for detecting pollutants (oils, chemicals, etc.) in near-real-time, these gliders surface periodically to transmit alerts. The combination of **persistent underwater presence**, **robust sensor suites**, and **AI-based detection** transforms how authorities can monitor coastal and open-ocean areas.

3.1 Glider-Based Surveillance

- **Long Endurance**: Gliders move by adjusting buoyancy and gliding in a sawtooth pattern. This method consumes minimal energy, allowing multi-month missions without refueling or manual intervention.
- **Sensor Packages:** Each glider can carry oil-fluorescence sensors (detecting petroleum), turbidity sensors (detecting suspended solids), nitrate/chemical sensors, and even hydrocarbon sniffers to identify signature compounds in the water. Depending on mission needs, additional sensors may be integrated. The table below summarizes typical sensor types relevant for real-time pollution detection in Project Sentinel.

Sensor	Application for Project Sentinel
CTD (pumped/unpumped)	Salinity, temperature, depth (for detecting ballast water discharges)
Optical Fluorometers	Detection of oil, petroleum products, and CDOM (Colored Dissolved Organic Matter) from wastewater
Turbidity / Optical Backscatter	Monitoring water clarity (cloudiness), potential wastewater, and fecal contamination
Dissolved Oxygen (DO)	Detecting changes in oxygen levels (indicator of organic waste)
Nitrates (nutrients)	Identifying elevated nitrate levels from wastewater
ADCP (Acoustic Doppler Current Profiler)	Monitoring ocean currents (for predicting the spread or drift of discharges)

- **Adaptive Deployment**: Instead of requiring a large vessel or aircraft to patrol, a single small boat can deploy a glider in strategic waters. The glider autonomously follows a route, submerging and surfacing at intervals (e.g., every few hours) to send data via satellite or cellular link.

3.2 AI-Driven Detection and Real-Time Alerts

- **Onboard Anomaly Detection**: The glider's onboard AI continuously compares sensor readings to baseline water parameters. If it detects a suspicious spike in oil or chemicals, the system flags it as an anomaly.
- **Instant Alert and Localization**: Upon detecting an anomaly, the glider surfaces as soon as practical to relay an alert with exact coordinates, time, and sensor specifics. Shore-based systems can correlate this with real-time AIS data to identify the likely vessel.
- **Evidence Gathering**: Because the glider is directly sampling the water column, the sensor data can serve as **hard evidence** of pollution. While satellite imagery may only show a surface sheen, the glider can measure actual contaminants in the water. This can be critical in legal proceedings.

3.3 Advantages Over Satellite-Only Monitoring

- **Nighttime and Subsurface Detection**: Ships often dump waste at night. Satellites like Sentinel-1 use radar to see slicks even in darkness, but cannot always capture high-

resolution or immediate images of smaller or quickly dispersing spills. Gliders, by contrast, operate beneath the surface, sampling the water itself.

- **Continuous Coverage**: A single glider can patrol 24/7 for months, whereas satellite passes may occur every 2–3 days over a given location (e.g., for the Adriatic).
- **Local Immediate Response**: Because the glider is already in the area, it can "loiter" around a suspected pollution source, taking additional measurements that confirm the event before the slick dissipates. This near-field data is often the missing link for prosecuting offenders.

In essence, **Project Sentinel complements** existing satellite and aerial surveillance with a persistent, on-the-water (or under-the-water) presence. It addresses the common offender strategy of nighttime dumping by offering round-the-clock detection at sea level—a robust deterrent once ships realize they can no longer rely on darkness or distance.

3.4 How Underwater Gliders Move and Collect Data

Underwater gliders are autonomous vehicles that **glide through the ocean in a sawtooth pattern** by controlling their buoyancy. Instead of traditional propellers, gliders change their density (buoyancy) to dive and rise, while wings convert that vertical motion into forward motion. As a glider descends (negative buoyancy) or ascends (positive buoyancy), it moves forward along a gentle slope, typically 15–30° to horizontal. This results in a **zig-zag diving trajectory** that is extremely energy-efficient, allowing gliders to travel for weeks or months on battery power. Multiple dive-and-climb cycles create a **vertical sawtooth path** through the water column. At the sea surface, the glider connects to GPS and satellite networks to upload collected data and download new instructions before diving again.

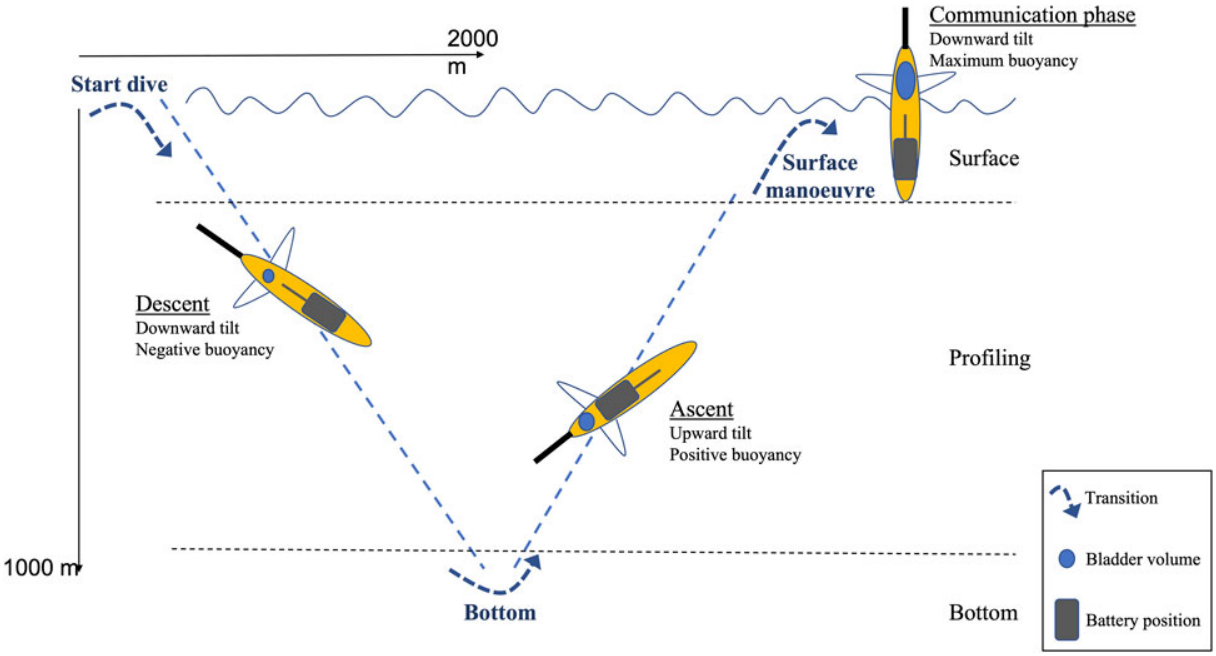

Figure: *Schematic of an underwater glider's dive cycle. Adapted from:Cauchy P., Heywood K.J., Merchant N.D., Risch D., Queste B.Y., and Testor P. (2023), "Gliders for passive acoustic monitoring of the oceanic environment," Frontiers in Remote Sensing, 4:1106533, under CC BY 4.0.*

llustration of an underwater glider's dive cycle, showing its descent and ascent paths (blue dashed line) and surface stops for communication. The glider alternates between negative buoyancy (downward glide) and positive buoyancy (upward glide), following a triangular/sawtooth trajectory through the water. During the surface phase, it obtains a GPS fix and transmits data via satellite before the next dive.

---

4. The Value Proposition: Prevention vs. Cleanup

4.1 Magnitude of the Pollution

The *Lighthouse Reports* team identified **330 potential illegal bilge dumps** in a ~17-month window, but that is likely an underestimate. SkyTruth's extrapolation indicates that **over 2964 vessels** per year may dump oil in European waters. Another investigation by BIRN found repeated discharges near the Croatia-Italy maritime boundary, some up to 100 km² in size. **Even if each discharge is just a few tons**, the aggregate yearly total across all these incidents becomes massive—comparable to major spills.

Such chronic oil presence harms marine ecosystems, fouls beaches, and undermines fisheries. In the Adriatic, a semi-enclosed sea, toxins can accumulate or wash ashore in high concentrations.

4.2 Financial Burdens of Inaction

1. **Cleanup Costs**
    - Cleaning just **1 ton of spilled oil** can cost on average **~$24,000**, including shoreline cleanup.
    - Even a modest 10-ton illegal discharge can rack up nearly **$250k** in cleanup expenses if it reaches sensitive coastal zones.
    - The *Lighthouse* article cites that **EMSA invests ~€7 million** per year just on CleanSeaNet's satellite alerts, yet detection and legal follow-ups are minimal.
2. **Tourism and Fisheries Losses**
    - Oil or chemical pollution near popular beaches can cripple tourism—one major pollutant slick can scare away thousands of visitors, causing multi-million-euro revenue losses for local economies.
    - Fisheries face quarantines or long-term declines in fish stocks if toxins persist in the food chain (especially for species spawning in the polluted area).
3. **Legal and Regulatory Pressures**
    - The EU is revising its directives on illegal ship-source pollution. More robust enforcement is likely imminent, putting pressure on coastal states to **improve detection**.
    - Currently, *only 1.5% of potential spills* are verified quickly, leading to criticism from media and NGOs that governments are not fulfilling MARPOL enforcement duties.

Allowing illegal dumping to continue unchecked can incur **far higher societal and environmental costs** than the investment required for advanced monitoring. Each avoided spill event saves tens or hundreds of thousands of euros in cleanup alone, not to mention intangible ecological benefits.

4.3 Cost-Effective Deterrence via Gliders

By contrast, equipping and deploying a **small fleet of 5–10 underwater gliders** in the Adriatic (or similarly busy maritime region) could cost a few million euros up front and have relatively low operating expenses year-on-year. That sum is **modest** compared to:

- The **€7+ million** EMSA spends annually just for satellite coverage in EU waters.
- The direct cleanup costs of even a handful of moderate spills.
- Potential fines from polluters, which could recoup system costs if enforced. For instance, repeated violators might face multi-million-euro penalties once confronted with hard evidence from glider data.

Real-time glider detection **increases the certainty** that an offender will be caught and fined. Even a 30–50% improvement in detection—and associated prosecutorial success—could be enough to significantly deter routine dumping, thereby **cutting illegal discharges**. Historically, Europe's CleanSeaNet halved observed oil slick frequency over a decade through improved satellite detection alone; **Project Sentinel** can reinforce that trend by closing the enforcement gap at sea level.

---

5. Case Studies and Supporting Examples

Various incidents and investigations illustrate that **persistent monitoring** changes polluters' calculus:

1. **Adriatic Tanker Incident (January 2021)**
    - A tanker near **43°41'59.9" N, 14°31'12.7" E** released oily water, presumably to cut costs on port disposal. Satellite watchers at *SkyTruth* caught the slick, but Croatian authorities did not intercept the vessel in time. In the official records, "no wrongdoing found."
    - Had a glider been patrolling the area, **an immediate alert** could have led to interception. This single event could have faced a large fine, recouping a portion of the monitoring network's cost.
2. **CleanSeaNet's Limited Verification**
    - From 2007–2019, **44,383 possible** illegal discharges were flagged by EMSA's satellite system in EU waters. Yet the *Lighthouse Reports* data shows **less than 2%** resulted in any known legal sanction.
    - Project Sentinel would collect in-water chemical evidence. If correlated with AIS, that is nearly irrefutable proof in court.
3. **Balkans/Adriatic Oil Slicks**
    - Research by *Professor Marko Perković* from the University of Ljubljana documented slicks up to 100 km² within the Adriatic's Exclusive Economic Zones (EEZs). Perković photographed tar residues on remote island beaches—clear signs of chronic pollution.
    - Under a glider-based sentinel system, these slicks would not persist "unnoticed;" repeated events in the same zone would indicate a pattern, prompting targeted action.
4. **SkyTruth "Cerulean" AI**

- SkyTruth's *Cerulean Project* uses machine learning to identify up to **1,000 radar images daily**, linking slicks with AIS vessel data. This technique discovered many unreported discharges, illustrating that **AI-based detection** can yield results.
- Project Sentinel is complementary: while Cerulean scans from above, gliders measure conditions below the surface, confirming the slick's composition and providing real-time data for enforcement.

Together, these examples underscore the urgent need for **continuous, on-site sensors** that can record conclusive evidence. Satellites and AI are crucial, but they must be matched by an in-water system that can provide immediate alerts to cut response times from days to hours.

---

6. Economic Analysis: From Penalties to Environmental Savings

6.1 Balancing Costs and Returns

A typical advanced glider (including sensors) may cost **€200,000–300,000**. If a maritime authority invests in, say, **10 gliders** for strategic coverage, the up-front hardware expense might be **€2–3 million**. Annual operating costs—battery replacement, satellite data fees, maintenance—are relatively modest (perhaps **€50k–100k** per glider). Over five years, total spending could be around **€4–5 million**.

Meanwhile, even **one** medium-scale spill near a coastline can result in **multi-million-euro** cleanup bills, not counting tourism and fisheries losses. Catching one or two major violations per year—and levying fines—could offset or fully cover the operational budget. For instance, a single large fine in the EU or U.S. can exceed **€2 million**, and repeat violators have faced **€5–10 million** in penalties. Thus, in purely financial terms, **Project Sentinel can pay for itself** if properly enforced.

6.2 Prevention Benefits

Beyond direct financial gains from fines, **prevention** reaps the largest reward:

- **Reduced cleanup and restoration**: The less oil or chemical waste in the water, the fewer crises requiring expensive response measures.
- **Safeguarded fisheries and tourism**: Clean beaches, healthy reefs, and safe seafood translate to stable or growing economic activity in coastal regions—particularly vital in the Adriatic, which thrives on marine tourism.
- **Lower satellite/air patrol frequency**: Over time, an effective glider network can reduce the need for constant aerial or satellite missions, freeing resources for other tasks.

Given the scale of **2964+** unmonitored polluters each year (per SkyTruth estimates), even a partial success rate in detecting or deterring them yields **large net savings** for governments and local communities.

---

7. Conclusion

Investigations by *Lighthouse Reports* and partners expose how **illegal discharges** persist across European waters, including the Adriatic, despite state-of-the-art satellite surveillance. Factors like **nocturnal dumping**, AIS manipulation, slow national responses, and legal hurdles enable ships to offload oily bilge or other pollutants with near impunity. The overall toll—from tar-littered beaches to long-term ecological harm—reveals an enforcement gap that conventional patrols, delayed satellite checks, and underfunded inspections have not managed to close.

Project Sentinel offers a **practical, high-impact solution**:

- **Autonomous underwater gliders** patrol continuously, are cost-effective, and can stay at sea for months.
- **AI-based onboard sensors** detect and flag pollution in real time, a critical improvement over after-the-fact or infrequent observations.
- **Immediate alerts** allow authorities to intercept vessels or gather fresh evidence, vastly improving prosecution odds and deterring further illegal dumping.
- **Cost-benefit analysis** shows that preventing even a handful of medium-sized oil slicks or prosecuting a few violators can recoup the system's investment and yield net gains in environmental protection.

By shifting from sporadic detection to **continuous monitoring**, Project Sentinel addresses the "blind spots" currently exploited by polluters. It closes the enforcement gap highlighted by the *Lighthouse Reports* investigation, ensuring that discharges no longer go unnoticed just because they occur far offshore, in the dark, or between satellite overflights. For policymakers seeking a tangible, technology-driven approach to protect national waters and meet international obligations (MARPOL, EU Directives), Sentinel provides a **scalable and impactful** solution.

From a **cost-benefit perspective**, the initial investment in a glider network is modest compared to the **potential environmental and economic gains**—deterring most routine polluters, saving on cleanup, preserving tourism revenues, and securing marine biodiversity. Fines from a handful of proven violations could recover large portions of operational costs, reinforcing the program's sustainability.

Through integrated data sharing, a glider-based sentinel system could **work in tandem** with EMSA's satellite alerts (CleanSeaNet), port-state inspections, and the existing BWMC framework. This synergy offers a robust approach to maritime environmental protection: satellites provide broad coverage, while gliders deliver **continuous in situ** sampling that can detect smaller or subsurface discharges of oil, grey water, sewage, or scrubber effluents. Policymakers committed to **safeguarding the Adriatic** (or any marine zone) will find in Project Sentinel a **practical, high-impact** solution to modernize enforcement, reduce pollution, and ensure accountability at sea.

By enhancing real-time detection, we can finally **level the playing field**, letting responsible shipping lines operate fairly and forcing would-be polluters to adhere to regulations. **Project Sentinel** thus paves the way toward a cleaner, healthier Adriatic—and, by extension, sets a model for all semi-enclosed seas grappling with hidden maritime pollution.

Authored by:
Hrvoje Mihovilović
Founder & CEO, ELNAV.AI d.o.o., Split, Croatia

Date: 13.03.2025

Public Disclosure and Prior Art Statement:
All concepts, methods, and designs related to the project Sentinel described herein are openly disclosed as prior art, effective 13.03.2025, to prevent exclusive patent claims by third parties. Collaboration and further innovation are welcomed.

References (Select)

1. Lighthouse Reports Investigations.
2. European Maritime Safety Agency (EMSA) CleanSeaNet – Annual Activity Reports.
3. BIRN and Jutarnji List joint investigation on bilge dumping in the Adriatic (2021).
4. SkyTruth "Cerulean" Project (satellite-based detection of maritime oil slicks).
5. International Maritime Organization (IMO) – MARPOL 73/78 Conventions.
6. Perić, T. (2016). *Evaluation model of sanitary wastewater pollution from cruise ships in the Adriatic Sea* (Doctoral dissertation, University of Rijeka).
7. Friends of the Earth – Cruise Ship Pollution Reports.
8. US National Academy of Sciences – *Oil in the Sea III: Inputs, Fates, and Effects*.
9. National Oceanic and Atmospheric Administration (NOAA) – Slocum Glider Program.