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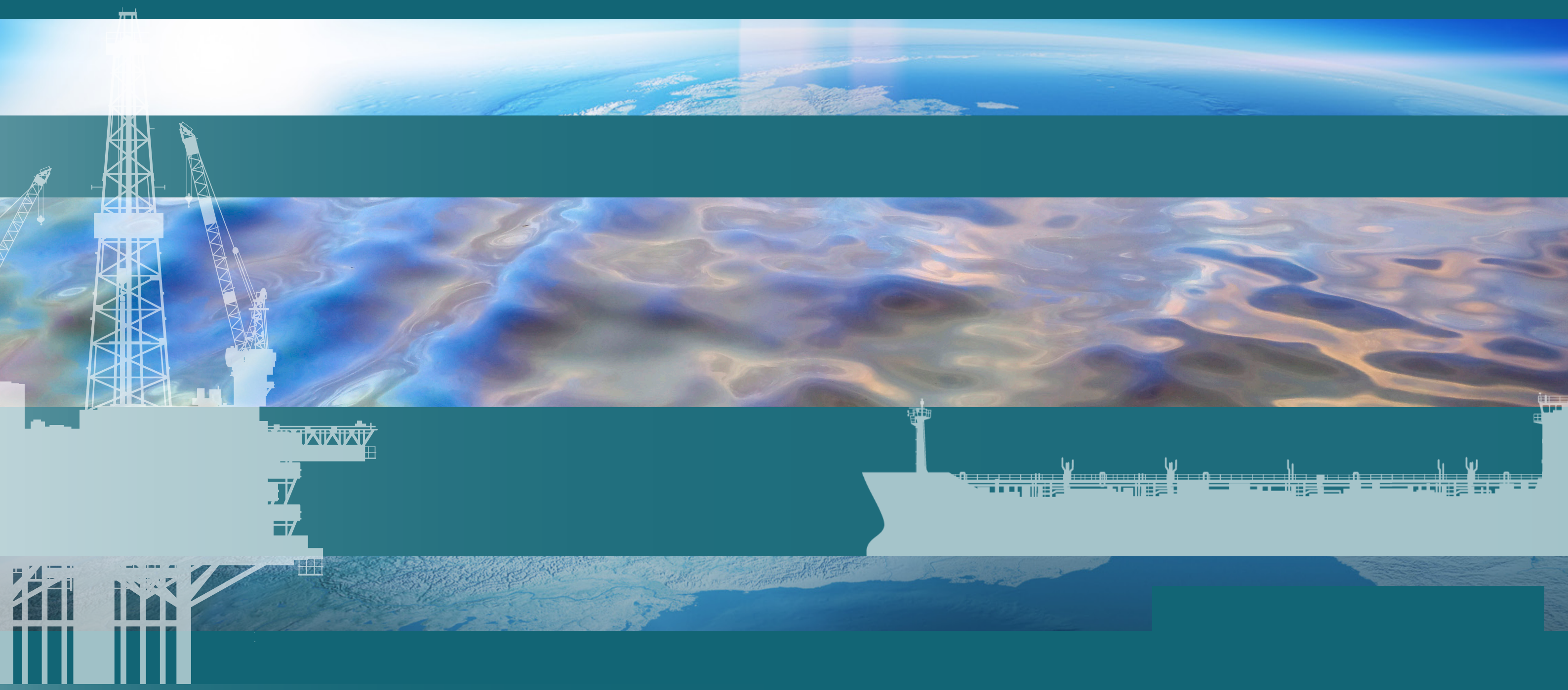
Satellite monitoring of oil spills

Advanced techniques to support detection and clean-up



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The Challenge

Oil spills have devastating impacts on our ecosystems, wildlife, and economies. These catastrophic events occur when extracted crude oil or refined petroleum products are released into the environment, typically in water bodies like oceans and rivers. The consequences of oil spills are multifaceted, making them a grave problem that demands immediate attention and comprehensive solutions.

First and foremost, oil spills can have major effects on marine life, from smothering by fresh crude oils to sub-lethal effects caused by some of the inherent low molecular weight components. Different shoreline and sub-tidal habitats respond to varying degrees from oil exposure/contamination as a function of sensitivity and vulnerability.

Disturbances in the marine food chain can lead to a decline in fish populations, affecting not just aquatic life but also the millions of people who rely on fishing as a primary source of food and income.

Furthermore, oil can impact some particulary sensitive coastal habitats - such as mangroves - leading to reduced erosion resilience and wave defence capability, and impacting biodiversity. Mangroves, coral reefs, seagrass beds and marshes are delicate environments that provide essential services like shoreline protection and habitats for various species. Such ecosystems can take decades, if not longer, to recover fully.

The effects of oil spills also extend far beyond aquatic environments. When oil reaches the shore, it contaminates beaches, making them hazardous for both humans and animals. Tourism, a significant source of income for many coastal regions, takes a severe hit as tourists avoid oil-soaked beaches. Cleanup efforts are costly and often insufficient, leaving many affected areas in a state of environmental disarray.

In addition, oil spills have dire consequences for bird populations. Birds that come into contact with oil suffer from impaired waterproofing and insulation, leading to hypothermia and death. Many species are also poisoned when they ingest oil while preening their feathers. These losses disrupt the delicate balance of ecosystems and can lead to population declines and fluctuations.

Preventing and mitigating these disasters requires stringent regulations and a collective global effort to transition towards cleaner and more sustainable energy sources.

It also requires the use of innovative technologies and methods to better identify oil spills and forecast their potential impacts.

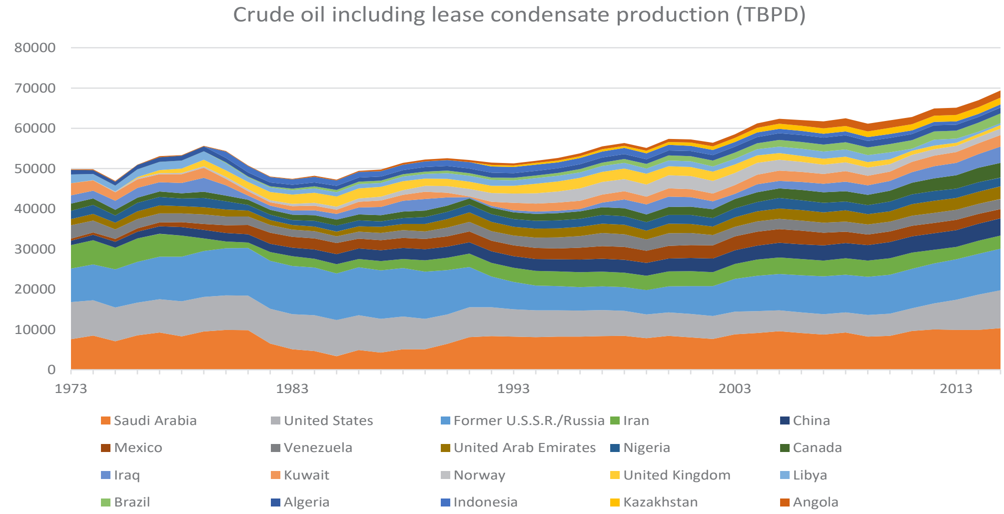


Figure 1: Crude oil production, less condensate production, in trillion barrels per day (TBPD) from 1973 through to 2015, for the top 20 oil producing countries worldwide.

Global oil production is expanding and at an ever-increasing rate (Fig. 1). In more than 30% of all oil-producing countries globally, crude oil production has grown by more than 50% over the last decade as compared with 2000-2010.

Some regions of the globe have operational monitoring systems in place that incorporate satellite remote sensing products (Fig 2), which primarily cover affluent Global North countries.

Coverage contrasts to the location of many countries with increasing crude oil production over the past decade (Fig 3), many of which are located in the Global South.

Oil production is increasing in those areas receiving some of the least operational oil spill monitoring.

Based on satellite remote sensing of global coastal waters, anthropogenic caused spills have been found to contribute a much higher proportion to surface oil slick area than previously estimated (94%, versus earlier calculations of only 6%)[1]. Furthermore, 90% of detected slicks occur within 160 km of the shore.

Coastal shelf zones represent less than one fifth of the planet's surface but provide up to 90% of the global fishery catch and 25% the world's primary production[2]. The impact of oil on the environment can include the introduction of toxicity to the food chain and loss of ecological biodiversity. Oil weakens a habitat's sustainable development capacity by reducing its resilience to climate change impacts and other anthropogenic stressors to coastal waters.

Repeated chronic spills can lead to accumulation within the environment, as some high molecular weight hydrocarbons can persist for a long time following a spill event (depending on oil type, the receiving habitat and the meteorological and ocean state conditions).

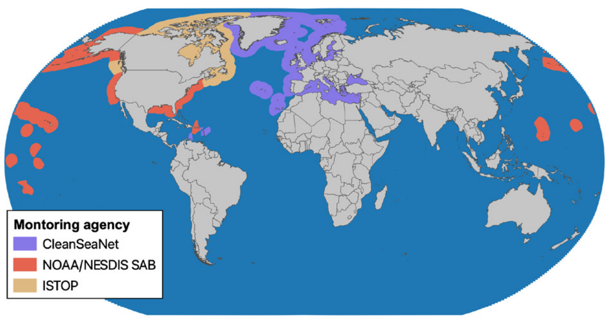


Figure 2: Operational oil spill monitoring agencies which incorporate satellite remote sensing products to their system.

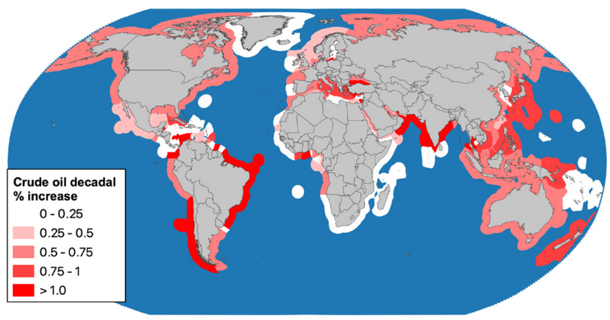
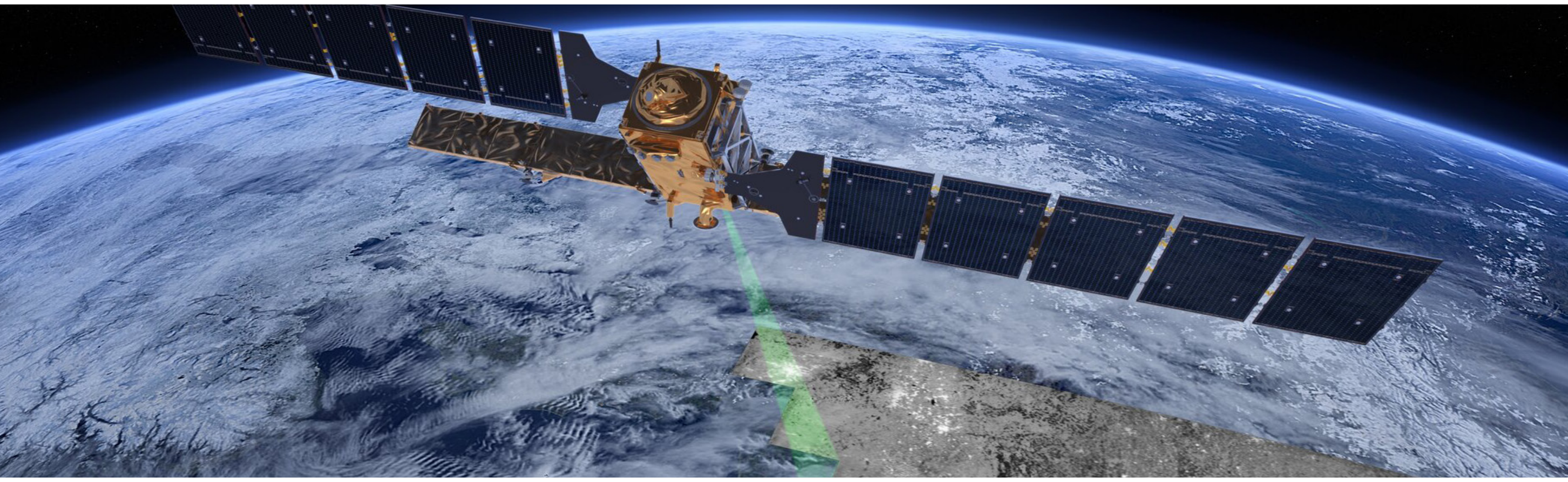


Figure 3: Increase in crude oil production from 2001-2010 to 2011-2020, ranging from white being very little change in decadal crude oil production amount to red representing over a 100% increase in 2010's. Rates are represented over a countries Exclusive Economic Zone (EEZ).

[1] Dong, Y., Liu, Y., Hu, C., MacDonald, I. R. & Lu, Y. Chronic oiling in global oceans. Science 376, 1300–1304 (2022).
[2] Robinson, I.S.; Antoine, D.; Darecki, M.; Gorringe, P.; Pettersson, L.; Ruddick, K.; Santoleri, R.; Siegel, H.; Vincent, P.; Wernand, M.; et al. Remote Sensing of Shelf Sea Ecosystems—State of the Art and Perspective (Vol. 12); European Science Foundation Marine Board: Ostend, Belgium, 2008; pp. 9–18.



How PML can support

PML led the development of a service for observing illegal oil discharge from commercial vessels in the Malacca strait as part of the UK Space Agency-funded EASOS project.

This provided the basis for developing an application able to deliver unparalleled insight into the presence of oil in the marine environment. Whether created by accident (through collisions, sinking or mechanical failure) or via illegal practices (bilge cleaning), the tool offers wide area monitoring for oil presence on a pervasive basis.

Using the latest open-source satellite imagery, the solution delivers a cost-effective approach to monitoring large marine areas in the support of environmental and regulatory management.

The service comprises:

- **Fast and efficient systematic monitoring** of large areas for detection of oil slicks by analysis of microwave and optical satellite images
- **Identification of ship locations from satellite data**, regardless of whether they are using AIS
- **Ship detection and location using AIS data and EO-based methods** together with backwards modelling* of an oil spill to associate a vessel to a pollution event
- **Communication and alert to the user** through an **interactive dashboard**, including in-situ measurements
- **Forward modelling of observed oil spills*** in order to provide warning and guidance for pollution mitigation activities, notably to protect vulnerable coastal regions
- **Integrated data management* allows sharing of intelligence** between agencies improving coordinated response

*In collaboration with RiskAware

Patterns in oil spill occurrence over time

Analysis of oil spill occurrence over time is seldom focussed upon in the wider oil spill detection community, particularly in those regions not receiving consistent operational oil spill monitoring.

Inspection of oil spill distribution trends over time using an **EO-based, regionally-validated operational monitoring tool** can reveal patterns in occurrence tied to particular activities, such as shipping sectors or petroleum extraction.

Dissemination of analyses in **a co-developed reporting structure that supports national coastline risk assessment** allows national decision-making structures to design informed legislation around sustainable development of marine resources.

The toolbox can provide a **low-cost dispersal modelling solution** for countries unable to afford expensive commercial platforms. The hydrodynamic modelling tools are simpler than commercial equivalents and may produce less accurate results, but they are fit for the intended purpose: to analyse the location of oil spill dispersal pathways over time as part of national coastline risk assessment activities.

Detections based on **freely available data in combination with cutting-edge scientific capability** can thus be scaled up in a relatively inexpensive manner to fulfil coastal observation monitoring goals and activities for countries that would otherwise struggle to produce such analyses.

With **tailored training**, national coastal monitoring teams would be able to independently implement these tools.

Sub-daily detection of oil spill dispersal

Taking advantage of recent advances in **EO Synthetic Aperture Radar (SAR) systems**, offering very high resolution imagery (i.e. on a scale <5m) from multi-platform constellations capable of providing multiple acquisitions in a single day, **it is now possible to design a system able to monitor directly how oil slicks are dispersing in the nearshore environment over a timescale of hours**, regardless of cloud conditions.

Oil Spill Response vessel

Despite these technical advances, demonstration of automated SAR-based oil slick detection with very high-resolution data and based on multiple separate acquisitions per day has not yet been demonstrated. PML researchers are working to overcome this challenge.

Space-based platforms allow for global coverage, including regions that may not have the national resources to acquire airborne or ship-based data over the large-scale area necessary for proper design of remediation and clean-up efforts directly following an incident.

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How it works

Synthetic Aperture Radar (SAR) transmits a pulse and measures response scattered back towards the sensor.

For Earth Observation (EO) sensors onboard satellites, the wavelength used for the pulse is sufficiently long that it can penetrate through clouds, fog and precipitation, thus making it the best option for collecting data over areas with frequent cloud cover.

As SAR is an 'active' sensor, that is it provides its own source of illumination rather than relying on an external source (typically the sun), it is able to operate during the day and night.

When collecting SAR data over the ocean, the rough sea surface scatters the SAR signal in all directions, some of which goes back towards the sensor. When there is a slick on the surface, capillary wave formation due to forcing like wind is reduced and results in the surface being smoother, causing most of the signal to be scattered away from the sensor.

Due to the lack of signal from slicks, they appear as dark patches in SAR imagery (Fig 4).

When the sea is very calm and flat, for instance in low wind conditions, the surface will also reflect most of the signal away, thus reducing the contrast between an oil slick and surrounding waters.

Conversely when the sea is very rough, the slick does not sufficiently dampen waves to cause significant reduction in signal reflection, thus can also reduce contrast. In addition to oil slicks, there are a number of other things which could reduce the SAR signal from water and cause dark patches (such as algal blooms, wind shadow from land, pools of fresh water from heavy rainfall or melting ice). These 'look-alikes' must be separated from true slicks.

Manual indentification of slicks from SAR data can be performed to provide information on known events, such as that following a large shipping accident.

However, to go through a regular stream of data covering a large area it is necessary to automate the process. Automatically detecting oil slicks from SAR data typically involves two stages:

1. **Identification of dark objects in the SAR scene**
2. **Separation of true oil slicks from look-alikes**

The first stage is well established and involves identifying the normal signal level from SAR data, then determining a threshold below which pixels are considered 'dark'.

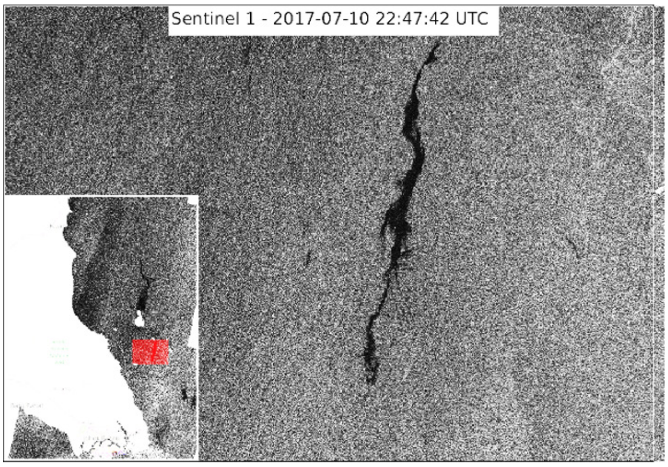

Figure 4: Potential oil slick in a Synthetic Aperture Radar (SAR) scene of the coast of Malaysia. The smooth oil on water, scattering the signal away from the sensor, appears dark in contrast to the rougher surrounding sea scattering signal in all directions.

Various approaches have been tried for the second stage but most involve building 'training' data of true oil slicks and look-alikes, then using an algorithm to compare dark objects (all of which can be considered potential slicks) to each other and assign how likely each object is to be a true oil slick or a look-alike.

The accuracy of differentiating true oil slicks from look-alikes is largely down to two factors: a) the training data (both number and quality of samples) and b) the algorithm used to compare each potential slick to the training data.

The PML method uses three advanced machine learning classification algorithms and a number of features to compare each potential slick to the training data.

The features used are based on how an expert human interpreter would differentiate slicks from look-alikes, using characteristics such as contrast, size and shape. Each classification algorithm provides a confidence of how similar the potential slick is to the training data, and then an average is taken over scores from all three models.

Because the three algorithms use different criteria to compare to the training data, combining scores makes the detection more robust. The output is a confidence value between 0 – 1, identifying how similar the potential slick is to the training data.

This value can be used to sort all potential slicks from highest to lowest confidence, and provide a cut-off point where all potential slicks with a confidence below a given value are ignored.

Case Study: Support of spill response and clean-up efforts

On 14th June, 2017, information was received that an Equatorial Guinea registered tanker, Putri Sea, had reported that her engine room had exploded and the vessel was going to sink. The Malaysian Marine Department (MMD) requested input from the PML-led EASOS project on the incident.

The operational oil spill monitoring and remediation tool was able to augment the existing 'help line' system with regular monitoring, prediction of oil slick dispersal pathway and likely impact to coastlines, and provide information to multiple partners.

In close coordination with MMD, satellite imagery (Fig 5) and modelling was used to predict slick dispersal. Authorities considered products extremely useful for clean-up activity planning.

Support of national coastal resource reporting framework

PML worked closely with the with the Senegalese coordinators of the West Africa West African coastal Observatory Mission (WACOM) to provide input to the 2020 West African State of the Coast Report (coined BILAN).

The report grew out of an update to the West African Coastal Master Plan (Schéma Directeur du Littoral d'Afrique de l'Ouestm, SDLAO, in French), which was developed in 2011 by the IUCN on behalf of West African Economic and Monetary Union within the framework of its Regional Program for Coastal Erosion Control.

The first BILAN report was published in 2016 by WACOM with the support of IUCN. Implementation of the recommended actions within the report falls to the West Africa Coastal Resilience Investment Project, particularly the WACOM coordination office at CSE (the Senegal Ecological Monitoring Centre, or Centre de Suivi Ecologique in French) is responsible for the subcomponent task focussing on regional coastal observation.

These two publications (BILAN and SDLAO) have supported coastal risk management across West African countries, in particular supporting mobilization of funding for blue development of coastal system.

CSE has further pushed to incorporate the PML oil spill detection product into reporting by HASSMAR (Haute Autorité chargée de la Coordination de la Sécurité maritime, de la Sûreté maritime et de la Protection de l'Environnement marin; the Senegalese government entity responsible for maritime safety and security, protection of the marine environment) on risks to sensitive coastal environments within the country.

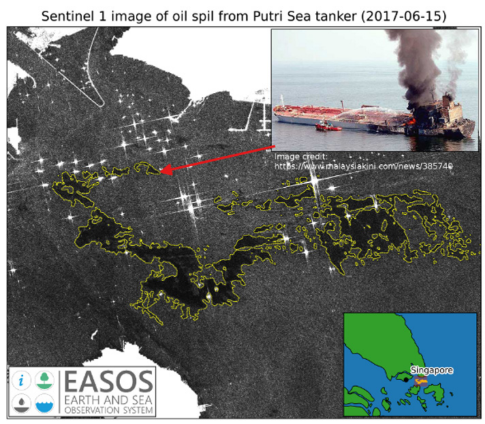

Figure 5: Detection of oil spill coming from Putri Sea tanker using Sentinel-1 data. Yellow lines show EASOS delineation of slick which was used as input to the dispersion model.

Testimonial

"The detection of oil spills on the West African coast is of great importance in the fight against marine pollution, especially in a context where the exploitation of oil will develop with new discoveries of deposits in certain countries and also with the densification of maritime traffic.

The technical support provided by the Plymouth Marine Laboratory (PML), under EO4SD-Marine & Coastal Resource Management, in the use of satellite images for this purpose, is capitalized through capacity building sessions for the network of experts in the sub-region. The forthcoming establishment of the regional observatory and national observatories will, in the medium and long term, make it possible to tackle the issue in a sustainable manner at the local level. Provision of marine pollution indicators can thus be retained in the monitoring program of the regional observatory.

The information produced will be made available at the level of the regional observatory platform and will also be capitalized upon in the regional alert network.

All this will contribute to improving knowledge on coastal risks and help in decision-making in the management of the West African marine and coastal area."

Dr Moussa Sall, Coordinator of the regional unit of the West African Coast Observation Mission

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About Plymouth Marine Laboratory (PML)

A world leader in the field of marine research, Plymouth Marine Laboratory (PML) is committed to the delivery of impactful, cutting-edge environmental and social science in support of a healthy and sustainable ocean.

Our research is globally recognised. We work with a broad range of partners internationally through research projects and wider initiatives, combining observational, experimental and modelling activity to provide a greater understanding of the dynamic and complex marine environment to inform knowledge-based solutions.

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PML's commercial arm - PML Applications - delivers exceptional and environmentally responsible marine consultancy services and products to a global client base.

Proudly a truly social business, all profits are reinvested into funding PML's world-leading and cutting edge research.

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