NET4MPLASTIC PROJECT

Activity 3.1

D 3.1.1 e

LITERATURE REVIEW:

NEW TECHNOLOGIES FOR MARINE LITTER AND MICROPLASTICS IDENTIFICATION:

REMOTE SENSING POSSIBILITIES

September, 30, 2019 - Version 1.0.

CONTRIBUTING PARTNERS	UNIFE AND UNITS

INDEX

1 Introduction

Remote sensing of ocean plastic litter by multispectral and hyperspectral sensors has been investigated by many scholars within the last years. Potentially, remote sensing provides the necessary spatial and temporal coverage of ocean surface in order to estimate the abundance of sea harvested plastics [Garaba and Diersen, 2018]. One of the most common applications is represented by the detection of ocean floating plastics. In fact, macroplastics are one of the major sources of microplastics and larger ocean plastics could be theoretically removed once they have been located using remote sensing [Goddijn-Murphy et al, 2018].

Remote sensing images acquired by multispectral sensors, such as the widely used Landsat Thematic Mapper (TM) sensor, have shown their usefulness in numerous earth observation (EO) applications. A relatively small number of acquisition channels, BUT their discrimination capability is very limited when different types (or conditions) of the same species (e.g., different types of forest) are to be recognized. Hyperspectral sensors can be used to deal with this problem. The sensors are characterized by a very high spectral resolution that usually results in hundreds of observation channels (Melgani & Bruzzone, 2004).

Hyperspectral Imaging (HSI) provides very high dimensional data with hundreds of spectral channels ranging from the visible to the short wave-infrared region of the electromagnetic spectrum. Although HSI enables a detailed separation of similar surface materials, the spectral features are correlated especially in adjacent bands, thus providing redundant information. The redundant and correlated features also increase both the time and memory requirements making the classification computationally inefficient.

Proof-of-concept research [Garaba et al., 2018] and experimental works in the literature involve short wave infrared (SWIR) wavelengths from 1.1 to 3 µm in addition to the visible wavelengths (ranging from 400 to 780 nm) and the near infrared (NIR) that is comprised between VIS and SWIR. However, Garaba and Diersen [2018] affirm that even though the reflectance in the VIS to NIR spectrum has been measured on selected pieces of macroplastics, the are not aware of any studies characterizing the spectral properties of marine-harvested plastics from the VIS to the SWIR wavelengths. Despite this, there is a rising interest in remote sensing due to absorption features in the ultra-violet to longwave infrared spectrum for the detection of hydrocarbons such as oil, methane and plastics. Additionally, other important issues for the characterization and detection of plastic marine litter are the different chemical composition that affect the actual spectral response of the plastic itself and the degree of degradation. The latter is a long-term process comprising discoloration, degradation by photo-oxidation UV exposure and fragmentation into smaller pieces, including microplastics. Although spectral signatures of each polymer can be characterized in laboratory, their subsequent use with in-field images may thus be particularly challenging.

An attempt to model coastal accumulation of microplastic particles (1-5 mm) emitted by the Po river over 1.5 years through hydrodynamic-based modelling and remote sensing-based modelling has been made by Atwood et al. [2019]. For the latter approach, Landsat 8 and Sentinel 2 imageries were used. The use of satellite imagery with higher spatial resolution (World-View 3) and supervised classifications (Random Forest, Linear Discriminant Analysis and Support Vector Machine) has been investigated also by Acuña-Ruz et al. [2018]. Spectral characterization of Anthropogenic Marine Debris (AMD) in laboratory was carried out in VNIR, SWIR and TIR.

Ultrahigh-resolution surveys of marine plastic debris conducted through airborne remote sensing and UAV platforms allows the reconstruction of centimeter-level orthomosaics. Moy et al. [2018] have used a Cessna 206 flying at an altitude of 610 m along the coastlines of the main Hawaiian Islands to produce orthorectified imagery mosaics at 2 cm ground sample distance (GSD). Eight categorical classifications were developed for macro-debris and area measurements were performed for each item. Martin et al. [2018] have proposed a method to assess marine beach litter loads using Unmanned Aerial Vehicles to record marine litter through image acquisition. The develop of machine learning tools for quantifying and categorizing beach litter reduces the processing time of UAV images and requires only one trained person. In addition, the authors also made a comparison between a visual census on selected transects and a visual screening of the aerial image of the same area.

1.1 Summary of Findings

The spectral characterization of plastic litter has shown that common absorption features exist in the VIS to SWIR spectrum. Most of the samples analyzed by Garaba and Dierssen [2018] have highlighted spectral features from 905 to 955 nm, 1160 to 1260 nm, 1380 to 1480 nm and 1715 to 1750 nm. However, the reflectance of wet marine-harvested plastics decreased significantly (by 56 ± 23% on average) if compared to dry particles. In addition, the authors highlight that their results suggest that it is not possible to match natural samples perfectly to raw polymers due to the fact they are blended materials and subject to degradation in nature. Similarly, Acuña-Ruz et al. [2018] found a wide variability among the samples they analyzed throughout the range of VNIR (380-1000 nm) and SWIR which matches with their variability in dirt, color, water content and other environmental weathering processes.

In June 2018, floating artificial targets of common ocean plastics were successfully detected from drones and satellite missions (e.g., PlanetScope Dove, Sentinel, TanDEM-X, WorldView) as part of the "Plastic Litter Project 2018: Drone Mapping and Satellite Testing for Marine Plastic on Aegean Sea" led by a team of researchers at the University of Aegean, Greece. The average debris length and width (±standard deviation) were equal to 1.62 ± 1.20 m and 0.63 ± 0.44 m, respectively (Garaba et al., 2018).

The work presented by Atwood et al. [2018] showed no significant relationship comparing in situ measurements with the nearest cell of the hydrodynamic model, while a moderate negative correlation with the nearest remote sensing model 30m hexagon was found.

Limitations of remote sensing using top-down photography are that (i) only the superficial layer of debris is detectable and (ii) although the detection itself is achievable down to 0.05 m^2, the categorization proved challenging below 0.50 m^2 [Moy et al. 2018].

Martin et al. [2018] reported that in the 56 m^2 transect used as ground assessment, 123 items were detected through visual census and 76 items were recognized by the manual screening of the UAV picture of the same area. The corresponding detection probability of litter identification from 10 m-altitude images was thus 61.8%. An underestimation of beach litter density obtained from aerial pictures can be expected if compared to direct observation, even when using images with a high resolution of < 1 cm. Manual screening of photographs revealed that small items were often hard to detect. Moreover, shadows and vegetation sometimes made also hard to recognize larger items. Automatic image processing showed misdetections due to the small size of some plastic items and the high variability within a same category. False positives and missing objects are common challenges when a machine learning approach is used [Martin et al. 2018].

Moreover, a shot synthesis of the works related to this topic is reported in the following paragraph.

1.2 Annotated Bibliography

Acuña-Ruz, T., Uribe, D., Taylor, R., Amézquita, L., Guzmán, MC., Merrill, J., Martínez, P., Voisin, L., Mattar B., C. 2018. Anthropogenic marine debris over beaches: Spectral characterization for remote sensing applications. Remote Sensing of Environment. 217: 309-322.

Synthesis

The article investigates the use of World-View 3 imageries and supervised classifications (Random Forest, Linear Discriminant Analysis and Support Vector Machine). Spectral characterization of Anthropogenic Marine Debris (AMD) in laboratory was carried out in VNIR, SWIR and TIR. Results showed that it was not possible to spectrally classify all the AMD due to their great variability in the WV3 bands. In general, the accuracies of the different AMD classification models were >75%.

Atwood, E. C., Falcieri, F. M., Piehl, S., Bochow, M., Matthies, M., Franke, J., Carniel, S., Sclavo, M., Laforsch, C., Siegert, F. 2019. Coastal accumulation of microplastic particles emitted from the Po River, Northern Italy: Comparing remote sensing and hydrodynamic modelling with in situ sample collections. Marine Pollution Bulletin 138: 561-574.

Synthesis

The work aims to model coastal accumulation of microplastic particles (1-5 mm) emitted by the Po River over 1.5 years. Hydrodynamic-based modelling and remote sensing-based modelling have been used. Landsat 8 and Sentinel 2 imageries were used. Water microplastic samples analyzed by FT-IR and SWIR spectroscopy ranged from 1 to 84 particles/m3. Highest concentrations were found along the outer river plume edge. The top three contributing polymers were PE, stryne-based ones and PP. No significant relationship was found comparing in situ measurements with the nearest cell of the hydrodynamic model, while a moderate negative correlation with the nearest remote sensing model 30m hexagon.

Diesing M., Green S.L., Stephens D., Lark R.M., Stewart H.A., Dove D. 2014. Mapping seabed sediments: Comparison of manual, geostatistical, object-based image analysis and machine learning approaches. Continental Shelf Research 84:107–119.

Synthesis

Although multibeam echo sounders allow us to map the seabed with high resolution and spatial precision, there is still a lack of fit-for-purpose seabed charts mainly due to the high costs and validation procedures. The Authors compared a high number of approaches including manual interpretation, geo statistics, object-based image analysis and machine-learning to gain more information about the accuracy and comparability of approaches based on multibeam echosounder data and seabed samples with the aim to derive seabed substrate maps. Overall thematic classification accuracy ranged from 67% to 76%. Inaccurate classifications were mainly associated with uncommon classes, which were rarely sampled. Map outputs were between 68% and 87% identical. To improve classification accuracy in seabed mapping, the Authors suggest to carry out more studies on the effects of factors affecting the classification performance as well as comparative studies testing the performance of different approaches.

Garaba, S. P., Aitken, J., Slat, B., Dierssen, H. M., Lebreton, L., Zielinski, O., & Reisser, J. (2018). Sensing Ocean Plastics with an Airborne Hyperspectral Shortwave Infrared Imager. Environmental Science and Technology, 52(20), 11699–11707. https://doi.org/10.1021/acs.est.8b02855

Synthesis

This paper presents a proof-of-concept on remote sensing of ocean plastics using airborne short wave infrared (SWIR) imagery. The authors captured red, green, and blue (RGB) and hyperspectral SWIR imagery using a high-performance state-of-the-art ITRES SAAI-600 push broom line scanning imager with 100 wavebands ranging from 950 to 2450 nm in the SWIR region (with a 15 nm spectral resolution) surveying the "Great Pacific Garbage Patch" at a height of 400 m and a speed of 140 knots. It is recorded the position, size, color, and type (container, float, ghost net, rope, and unknown) of every plastic piece identified in the RGB mosaics. Then it was selected the top 30 largest items within each of our plastic type categories (0.6−6.8 m in length) to investigate SWIR spectral information.

Authors also remark that spectral shape is an important metric in polymer identification utilizing spectral reference libraries. Results from simulations agree well with prior results suggesting that 1215nm and 1732 nm features have potential in estimating ocean plastic pollution levels. The derived continuum band depth indexes suggest that the 1732nm feature might not be appropriate for detecting ocean plastics at 5% pixel coverage.

Garaba S.P, Dierssen, H. M. 2018. An airborne remote sensing case study of synthetic hydrocarbon detection using short wave infrared absorption features identified from marine-harvested macro- and microplastics. Remote Sensing of Environment, 205, 224-235.

Synthesis

The article investigates the optical properties of dry and wet marine-harvested plastic debris. Notable absorption features at approximately 931, 1215, 1417 and 1732 nm for dry plastics. Wet particles show a decreasing of reflectance.

Goddijn-Murphy, L., Dufaur J. 2018. Proof of concept for a model of light reflectance of plastics floating on natural waters. Marine Pollution Bulletin 135: 1145-1157.

Synthesis

Hyperspectral RS for buoyant macroplastic (as major and increasing source of microplastics) in VIS, NIR and SWIR has been studied in this article. Spectroradiometer measurements were carried out both in the field and in the laboratory to determine spectral coefficients. Three surveys were performed in a boating pond in October 2017. Detection results in the field of EPS, HDPE and PET showed that the reflectance of floating items in natural daylight conditions loosely corresponded with the reflectance coefficients obtained in the laboratory. A general RS algorithm for estimating surface fraction of plastic litter floating on natural waters can therefore not been proposed by this research.

Goddijn-Murphy, L., Peters, S., van Sebille, E., James, N. A., Gibb, S. 2018. Concept for a hyperspectral remote sensing algorithm for floating marine macro plastics. 126: 255-262.

Synthesis

The research presents an optical reflectance model that can be used as a first step towards a remote sensing algorithm for marine plastic litter. A suggestion is to select a wavelength for which water leaving light is minor and plastic reflectance is high, for example around 750nm.

Haarr M.L., Westerveld L., Fabres J., Iversen K.R., Eline K., Busch T. 2019. A novel GIS-based tool for predicting coastal litter accumulation and optimising coastal cleanup actions. Marine Pollution Bulletin. 139:117–126.

Synthesis

The study tested a GIS-based predictive model to recognize marine litter hotspots in Lofoten, Norway based on shoreline gradient and shape. Litter density was recorded at about thirty randomly selected locations with 5 transects sampled in each. The greatest litter concentrations were found in small inlets located on larger headlands. A parsimonious model scoring sites on a scale of 1–5 based on shoreline slope and shape had the highest validation success. Locations unlikely to have high litter concentrations were successfully identified and could be avoided. The precision of hotspot identifications was more variable, and presumably more parameters influencing litter deposition (i.e. shoreline aspect relative to prevailing winds) should be integrated.

Hasituya, Chen Z., Li F., Hongmei. 2017. Mapping Plastic-Mulched Farmland with C-Band Full Polarization SAR Remote Sensing Data. Remote sensing. 9, 1264. doi:10.3390/rs9121264

Synthesis

Plastic mulching is a significant technology in agricultural production. In spite of its help of increasing crop yields, the booming expansion of the plastic mulching area has been affecting the environment. Correct and effective mapping of PMF (Plastic-Mulched Farmland) can provide useful information for evaluating its pros and cons. Mapping the PMF with remote sensing is still complex owing to its varying spectral characteristics with the crop growth and geographic spatial division. The Authors investigated the potential of Radarsat-2 data for mapping PMF using Random Forest (RF) and Support Vector Machine (SVM) classifiers. The results indicated that the layouts from Radarsat-2 data have great potential for mapping PMF with an overall accuracy close to 75%. The RF classifier performed better than the SVM classifier. However, it is expected that the classification accuracy of PMF with SAR remote sensing data can be enhanced by combining SAR remote sensing data with optical remote sensing data.

Lu L., Tao Y., Di L. 2018. Object-Based Plastic-Mulched Landcover Extraction using Integrated Sentinel-1 and Sentinel-2 Data Remote sensing, 10, 1820; doi:10.3390/rs10111820.

Synthesis

Plastic mulching on farmland has been increasing worldwide due to its advantages for improving crop yields. Monitoring Plastic-Mulched Land-cover (PML) can provide important information for making agricultural management choices and reducing PML's eco-environmental impacts. However, mapping PML with remote sensing data is still challenging due to its complicated and mixed features. In this study, a new Object-Based Image Analysis (OBIA) approach has been suggested to analyze the potential for combined use of Sentinel-1 (S1) SAR and Sentinel-2 (S2) Multi-spectral data to extract PML. Spectral and backscattering features, index features and texture features from the two types of Sentinels are adopted in classifying PML and other land-cover types. Three different machine-learning classifiers are carried out and compared in this study. The best classification result with an overall accuracy of more than 90% is achieved by using spectral, backscattering, index and textural information from integrated S1 and S2 data with the SVM classifier. Texture information is also demonstrated to contribute positively to PML classifications. PML mapping using SAR information alone has been improved by the object-based approach to an overall accuracy of almost 88%.

Marcello J., Eugenio F., Martín J., Marqués F. 2018. Seabed Mapping in Coastal Shallow Waters Using High Resolution Multispectral and Hyperspectral Imagery Remote sensing, 10, 1208; doi:10.3390/rs10081208

Synthesis

Satellite and airborne multispectral and hyperspectral representations were used to map benthic habitats in a composite ecosystem. A mapping methodology has been identified after an analysis of different corrections, feature extraction, and classification approaches. Atmospheric, sunlight, and water column adjustments were tested. The Authors assessed the use of derived information from rotation transforms, texture parameters, and abundance maps produced by linear unmixing algorithms. Maximum likelihood (ML), spectral angle mapper (SAM), and support vector machine (SVM) classification algorithms were contemplated at the pixel and object levels. Results demonstrate the better performance of SVM but the higher robustness of ML to the nature of information and the number of bands examined. Hyperspectral data increases the overall precision with respect to the multispectral bands but the inclusion of additional traits, in general, did not significantly improve the seabed map quality.

Martin, C., Parkes, S., Zhang, Q., Zhang, X., McCabe, M. F., Duarte, C. M., 2018. Use of unmanned aerial vehicles for efficient beach litter monitoring. Marine Pollution Bulletin. 131: 662-673.

Synthesis

Litter has been recorded through UAV image acquisitions and machine learning was used for debris detection and classification. DJI Phantom 3 Advanced was used for aerial flights. A preliminary test on a cleaned beach was conducted to select best gimbal angle and altitude for beach surveys, then the system was flown at 5, 10 and 20m AGL altitude with camera gimbal angled 45° and 90°. Best results were obtained at a 10m altitude and 90° gimbal angle. Ground assessment showed that only 76 items were detected by manual screening of 10m-altitude UAV pictures while 123 items were detected through a visual census. Small items (<4cm in length) are those mainly not recorded by remote survey. Accuracy of random forest was found to be around 40%.

Maximenko N., Corradi P., Law K.L., Van Sebille E., Garaba S.P., Lampitt R.S., et al. 2019. Toward the Integrated Marine Debris Observing System. Front. Mar. Sci. 6:447.

Synthesis

The Authors discussed the structure of the future integrated marine debris observing system (IMDOS) to provide long-term monitoring of the state of pollution and support actions to mitigate impacts on the ecosystem and maritime activity. The suggested observing system integrates remote sensing and in situ observations. Models are used to optimize the design of the system and, in turn, they will be gradually improved using the products of the system. Remote sensing technologies offer spatially coherent coverage and consistent surveying time series at local to global scale. Optical sensors, including high-resolution imaging, multi and hyperspectral, fluorescence, and Raman technologies, as well as SAR are used to measure many types of marine debris. They will be implemented in a variety of platforms, from hand-held tools to ship, buoy, aircraft, and satellite-based sensors. A network of in situ observations will be developed to provide data for calibration/validation of remote sensors and to monitor the diffusion of plastic pollution and other marine debris. IMDOS will interact with other observing systems and the synthesized data will support advanced multi-disciplinary research and serve a diverse community of users.

Melgani, F., & Bruzzone, L. (2004). Classification of Hyperspectral Remote Sensing. IEEE Trans. Geosci. Remote Sens., 42(8), 1778–1790.
Synthesis
This paper addresses the problem of the classification of hyperspectral remote sensing images by support vector machines (SVMs).

Millera R.L., McKeeb B.A. 2004. Using MODIS Terra 250 m imagery to map concentrations of total suspended matter in coastal waters. Remote Sensing of Environment. 93:259–266.
Synthesis
The concentration of suspended sediments derived from bottom sediment resuspension or discharge of rivers is highly variable overtime and space. Although there has been great commitment to use remotely sensed images to offer synoptic maps of suspended particulate matter, there are limited routine applications of this technology due in part to the low spatial resolution and cost of most remotely sensed data. In contrast, near daily coverage of medium resolution data is available from the Moderate-resolution Imaging Spectroradiometer (MODIS) Terra instrument without charge from numerous data distribution sources. The utility of MODIS 250 m data for analysing the concentration of Total Suspended Matter in coastal waters was examined in the Northern Gulf of Mexico A robust linear relationship was established between MODIS Terra data and in situ measurements. This study demonstrated that the moderately high resolution of MODIS 250 m data alongside with the operating characteristics of the instrument provided data suitable for examining the transport and fate of materials in coastal environment.

Moy, K., Neilson, B., Chung, A., Meadows, A., Castrence, M., Ambagis, S., Davidson, K. 2018. Mapping coastal marine debris using aerial imagery and spatial analysis. Marine Pollution Bulletin. 132: 52-59.
Synthesis
Aerial surveys were conducted over the coastlines of the main Hawaiian Islands using a Cessna with an altitude of 610 m. This produced an orthorectified imagery mosaics at 2 cm GSD and covered a swath of 300 m. Finally, the imagery was color balanced. Eight categorical classifications were developed for macro-debris. Also, area measurements were performed for each item. Methods used in this study advanced the ability of researchers to systematically quantify macro-debris over an expansive coastline. Authors say that low-altitude monitoring systems (UAS) offer ultra-high resolution imagery but their use is hampered by FAA restrictions to fly under 122m AGL. Limitations of aerial surveys consist in detecting only the superficial layer of debris. However, focused reassessment of hotspots could help study debris accumulation over time.

Stephens D., Diesing M. (2015) Towards Quantitative Spatial Models of Seabed Sediment Composition. Composition. PLoS ONE 10(11): e0142502. doi:10.1371/journal.pone.0142502

<u>Synthesis</u>

The aim of this study was to determine if it is possible to predict substrate structure across a large area of seabed using legacy grain-size data and environmental predictors in the North Sea, in the Celtic Seas and in the English Channel. The analysis matched outputs from hydrodynamic models as well as optical remote sensing data from satellite platforms and bathymetric variables. The Authors built a statistical regression model to make quantitative predictions of sediment structure (fractions of mud, sand and gravel) using the random forest algorithm. The compositional data was analysed on the additive log-ratio scale. A substrate model achieved an overall accuracy of 83%. The Authors demonstrated that it is possible to spatially predict the seabed sediment composition across a large area of continental shelf.

Topouzelis K., Papakonstantinou A., Garaba S.P. 2019. Detection of floating plastics from satellite and unmanned aerial systems (Plastic Litter Project 2018). Int J Appl Earth Obs Geoinformation. 79:175–183.

<u>Synthesis</u>

This paper presented an innovative exploratory use of unmanned aerial systems (UAS) and open-access satellite imagery of floating plastics in seawater, through an aquatic environment experiment. The Authors aimed to extract meaningful spectral measurements in near-real scenarios and to compare the geospatial information ranging from moderate to very high resolution. A set of three artificial floating litter targets were setup in the waters of Greece. These floating targets were made up of 100 m^2 PET-1 1.5 L water bottles, LDPE plastic bags and nylon fishing ghost nets. By investigating the controlled targets and the surrounding seawater they demonstrated how UAS very high geospatial resolution images can be suitable in improving geo-referencing of satellite images and how UAS can be used to assess the plastic percentage coverage of satellite images. The study proved the importance of very high geo-spatial resolution UAS datasets in validating and enhancing the geo-spatial accuracy of satellite data for monitoring plastics in the aquatic environment.

Veenstra T.S., Churnside J.H. 2012. Airborne sensors for detecting large marine debris at sea. Marine Pollution Bulletin. 65:63–68.

<u>Synthesis</u>

This paper has described a variety of airborne sensors that could be used for detection of marine debris. Each has specific strengths but none is capable of seeing all debris in any type of sea state, light conditions, and turbidity level, so a set of sensors appropriate to survey conditions will offer the best solution for debris detection with minimal false hits even if is more expensive to implement. The most promising general-purpose single sensor would be a filtered multi-spectral camera. The Authors suggested the use of green and red spectral bands, with spectral resolution that can only be defined with hyperspectral measurements of typical nets. Lidar is more expensive and precludes operation from small unmanned aircraft, but adds valuable information. Thus, a practical layout of sensors would include a multi- or hyperspectral imager with an automated detection algorithm operating in real time and a lidar that would be finalized at targets detected by that algorithm. The lidar data would provide verification and help to identify the debris.

Yang Q., Liu M., Zhang Z., Yang S., Ning J., Han W. 2019. Mapping Plastic Mulched Farmland for High Resolution Images of Unmanned Aerial Vehicle Using Deep Semantic Segmentation. Remote sensing. 11, 2008; doi:10.3390/rs11172008

<u>Synthesis</u>

Plastic mulch benefits agriculture by promoting crop quality and yield, but the environmental and soil pollution is raising. Plastic mulched farmland in unmanned aerial vehicle (UAV) remote images, shows a prominent spatial pattern, which brings difficulties to the task of observing PMF. Comparing two deep semantic segmentation methods, SegNet and fully convolutional networks (FCN), and a traditional classification method, Support Vector Machine (SVM), the Authors proposed an end-to-end deep-learning method expected at accurately recognize PMF for UAV remote sensing images from Hetao Irrigation District, Inner Mongolia, China. After trials with single-band, three-band and six-band image data, the Authors found that deep semantic segmentation models built via single-band data which only use the texture pattern of PMF can identify it well. MF identification can be improved by models combining the texture and special features with three visual bands and six-band data. In addition, deep semantic segmentation methods, FCN and SegNet, clearly far exceed the traditional SVM method in precision and speed. Among three classification methods, SegNet model based on three-band and six-band data obtains the optimal average accuracy of nearly 90%.