DATA FUSION OF DRONE AND SATELLITE IMAGERY FOR ALIEN SPECIES CLASSIFICATION ON RIVERDIKE

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ABSTRACT: The management of riverdike vegetation plays a crucial role in the prevention of soil erosion and underscores the importance of detecting alien species as part of ecosystem management. This study aimed to investigate the distribution of native grass and invasive alien species in extensive river dikes using remote-sensing technology. Although high-resolution satellite images provide broad coverage and detailed spatial resolution, they are limited by mixed-pixel issues, that affect the accuracy of alien species mapping. This study focused on enhancing the WorldView-3 satellite-based classification of alien species on river dikes by integrating drone information and employing data fusion techniques. An object-based image analysis of satellite and drone images was conducted to extract vegetation information, which was then integrated on a segment-by-segment basis. Ground-truth data obtained from a drone with 0.01 m resolution were used to supervise the classification model and assess the classification accuracy. The Random Forest (RF) supervised classification method was used to classify alien species based on the extracted information and the predicted classes were compared with the ground truth classes of the target species to assess the model's accuracy. The findings demonstrated that the data from the fusion of satellite-drone data were more accurate than those from individual sources. Notably, the drone-derived information significantly improved the classification accuracy of the fused datasets. This study contributes to the development of techniques for identifying and classifying alien species in wider river dike areas, thereby providing valuable insights into targeted management strategies.

1. INTRODUCTION

1.1 Research Background

Herbaceous vegetation in riverdikes plays a vital role in mitigating soil erosion, which can potentially result in the failure of riverdikes and subsequent instances of severe flooding. Maintaining favorable vegetation conditions, particularly by preserving native grass species, is of utmost importance to river office managers responsible for riverdike structures. The identification of areas where appropriate grass species thrive and unsuitable invasive alien species (IAS) are present across expansive riverdikes would greatly contribute to the effective management of vegetation along these structures (Miura *et al.*, 2021). The classification and quantification of herbaceous vegetation on riverdikes using remote sensing pose a significant challenge. Sufficiently high spatial resolution and accuracy are required to effectively identify small, intricately shaped vegetation on steep river dike slopes (Miura *et al.*, 2021).

Several studies have indicated that high-resolution multispectral satellite imagery can be used to distinguish between different vegetation cover types, such as shrubs and grasslands (Alvarez-Taboada *et al.*, 2017), and quantify invasive plant species (Ragavan & Johnny, 2015). Recently, Nininahazwe *et al.* (2023) utilized WorldView-3 (WV-3) satellite imagery to map invasive alien species. Their findings demonstrated that WV-3 ortho mosaic data are suitable for effectively leveraging texture information to differentiate between invasive alien plant species. However, mixed pixels pose a common challenge in the classification process, affecting the accuracy of image classification (Arif *et al.*, 2015). Even with high-resolution satellite remote sensing, both pure and mixed pixels are still present in vegetation type classification. Pure pixels represent a single feature such as a specific type of vegetation, whereas mixed pixels contain a combination of multiple features, including native and invasive alien species. Overcoming the problem of mixed pixels is essential because it hinders the extraction of meaningful data (Foody, 2006).

Drone technology addresses the issue of mixed pixels because it captures data with significantly higher spatial resolution, often reaching the order of centimeters. Drones and unmanned aerial vehicles (UAVs) can identify IAS (Anderson & Gaston, 2013; Bryson *et al.*, 2014). For example, Akandil *et al.* (2021) developed a methodology that utilizes

UAVs equipped with multispectral sensors to accurately detect and assess the IAS coverage of a Giant Goldenrod. Their research showed high overall accuracy in classifying the presence of giant goldenrods.

Royimani *et al.*, (2019) reviewed multispectral approaches using single sensors to identify invasive alien plants and highlighted various research requirements to overcome financial constraints in long-term and large-scale mapping. A key aspect is the utilization of multi-source datasets, known as data fusion, for the detection of invasive alien plants (Rajah *et al*., 2019). However, the full potential of data fusion to achieve optimal detection and mapping of invasive alien plant species has not yet been thoroughly explored. Moreover, the fusion of data from satellites and UAV platforms is widely regarded as the most powerful agricultural strategy, allowing the extraction of detailed land cover and biophysical vegetation features at a fine resolution. For example, Zhao *et al.*, (2020) employed pixel-level image fusion between UAV and satellite multispectral images to facilitate object-oriented vegetation classification. Their findings revealed that the fusion of these images, when coupled with the object-oriented supervised classification method, resulted in significant enhancements in both overall accuracy and the kappa coefficient. Despite their potential, satellite and UAV data fusion remains underutilized, highlighting the need for further research and development in this area (Alvarez-Vanhard *et al.*, 2021).

1.2 Objectives

This study aimed to improve the classification accuracy of invasive alien species on river dikes by enhancing multi-spectral WorldView-3 high-resolution satellite images. This enhancement was achieved by incorporating drone data and applying data fusion techniques to integrate information from satellite and drone imagery datasets. The data sources were combined to improve the accuracy and effectiveness of classifying and mapping invasive alien species on river dikes.

2. METHODOLOGY

Figure 1 illustrates the methodology used in this study. The process began by targeting a specific study area. Subsequently, essential materials were collected, including high-resolution satellite images, drone images, and ground-truth data. Both satellite and drone images underwent preliminary processing before conducting object-based image analysis. After extracting data from the images, a data fusion procedure combines data from both satellite and drone sources. A pre-processing drone with a 0.01m resolution served as the ground truth data in this study. Ground truth classes were determined using ground truth data to supervise the classification model and compared with the groups predicted by the model to assess the accuracy.

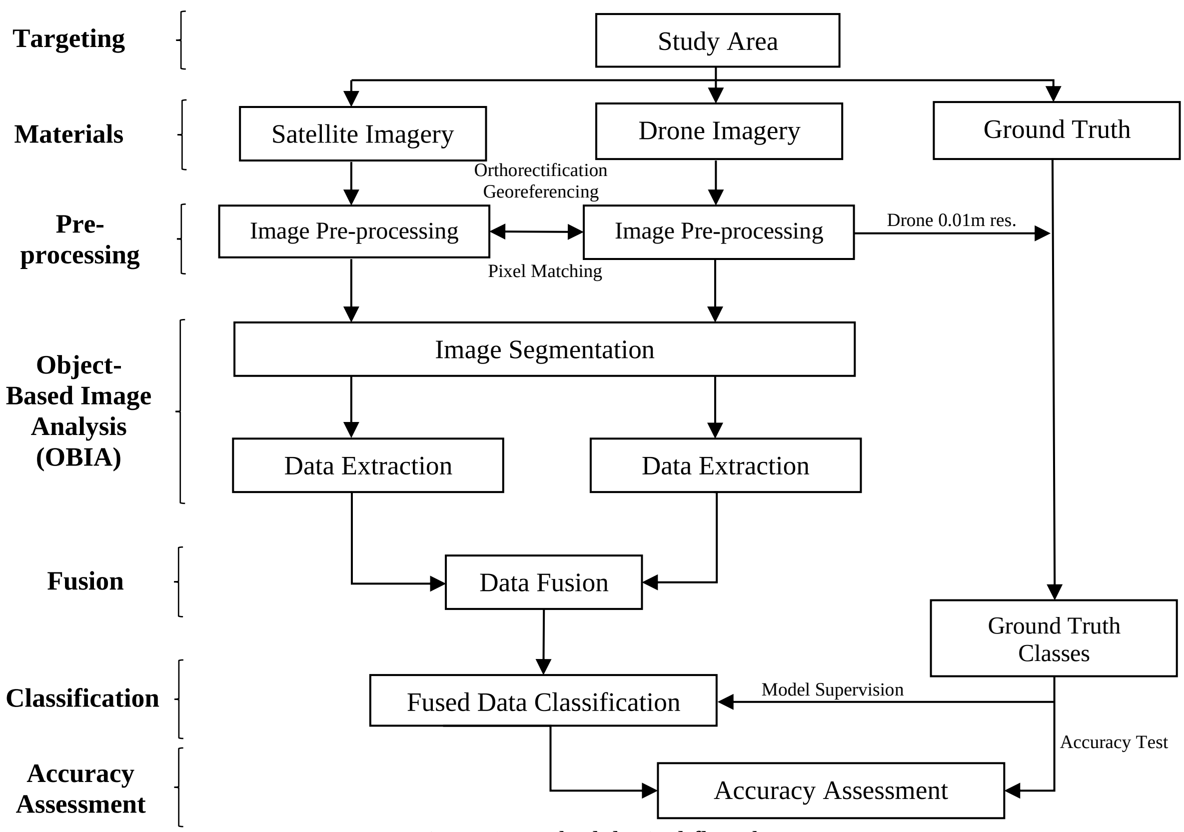

Figure 1. Methodological flowchart

2.1 Study Area

2.1.1 Section of Riverdike

The studied section of the riverdike (Figure 2) is situated in the middle stream of the Tone River in Ibaraki Prefecture, Japan. The selected section had a length of approximately 1 km, a width of 40 m, and a height of 7 m.

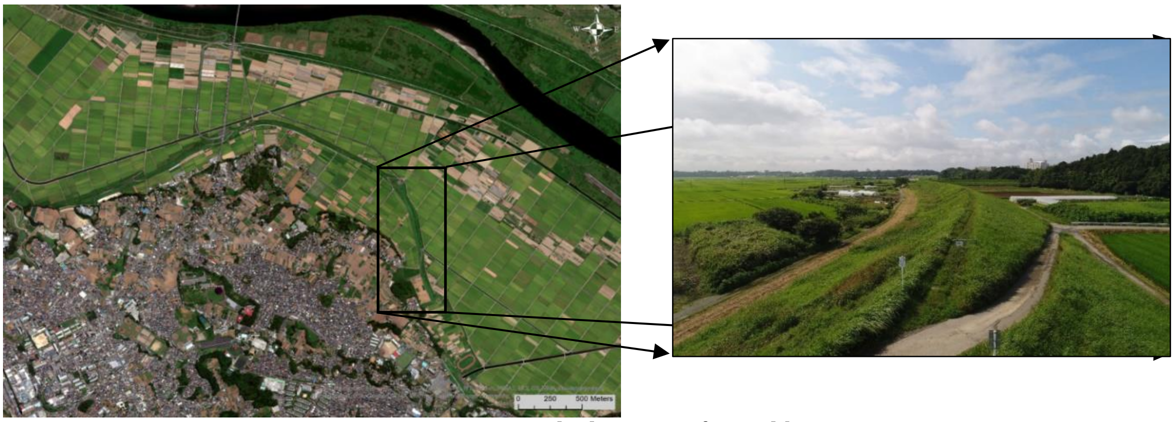

Figure 2. Studied section of riverdike

This segment of the riverdike plays a critical role in safeguarding human lives and urban assets from potential flooding and overflow of the Tone River during flood occurrences. Ensuring the structural integrity of this dike section is of paramount importance, necessitating precise and effective management of vegetation growth along its edges. This approach to vegetation management is significant because it conserves native ecosystems and actively contributes to the prevention of soil erosion along the dike. Furthermore, the dike segment is encircled by rice fields, farmland, and other agricultural areas. Hence, it is essential to prevent the proliferation of harmful non-native plant species from dikes into neighboring regions. These plants can damage crops and other agricultural products grown by local farmers.

2.1.2 Target Alien Species

The slopes of the river dikes in the study area are predominantly covered by herbaceous vegetation, which comprises various plant species, such as native grass species, and non-native species, including two dominant alien species, *Solidago altissima*, and *Sorghum halepense* (Figure 3). Unfortunately, owing to budget constraints, the management of river dike vegetation has become increasingly challenging, resulting in the spread of invasive alien species. *Solidago altissima* species grow over one meter tall, have broad leaves that block sunlight from the native species, and physically obstruct the visibility of the riverdike (Yamada & Nemoto, 2016). Moreover, *Sorghum halepense* species demonstrate vigorous growth, rapidly extending across the river dikes and forming dense clusters that can outcompete both native vegetation and crops (Shimizu *et al.*, 2001).

Figure 3. Target alien species
Solidago altissima (left) and *Sorghum halepense* (right)

2.2 Materials

2.2.1 Satellite Imagery

The satellite imagery used in this study was obtained from WorldView-3 (WorldView-3 - Earth Online (esa.int)), a high-resolution imaging and environment-monitoring satellite operated by Maxar Technologies (USA). The WorldView-3 satellite imagery used in this study was acquired on August 22, 2018. This date was chosen because it was closely aligned with the aerial survey conducted using drones over the studied section of the river dike. This satellite imagery offers high spatial resolution (1.6m resolution) and includes eight spectral bands, capturing specific information about the Earth's surface. Table 1 provides a breakdown of the spectral bands present in WorldView-3 imagery.

Table 1. WorldView-3 multi-spectral bands

Band Number	Band Name	Spectral Band
1	Coastal Blue	400 – 450 nm
2	Blue	450 – 510 nm
3	Green	510 – 580 nm
4	Yellow	585 – 625 nm
5	Red	630 – 690 nm
6	Red edge	705 – 745 nm
7	Near-IR1	770 – 895 nm
8	Near-IR2	860 – 1040 nm

2.2.2 Drone Images Acquisition

This study utilized a Phantom 4 advanced drone equipped with an RGB camera for aerial surveys of the study area. A total of 1210 original drone images were captured, providing comprehensive coverage of the entire study area. The drone flight conditions are listed in Table 2.

Table 2. Drone flight conditions

Height	35 meters
Speed	12.9 kilometers/hour
Angle	90 degrees
Image Overlap	X 75%, Y 80%
Shutter Interval	2 seconds
Acquisition Date	20th August 2018

2.2.3 Ground truth

A high-resolution drone imagery resolution (0.01m) derived from pre-processing drone images was utilized to establish the ground truth data for this study. The target alien species in the imagery can clearly be identified at this resolution.

2.3 Image Pre-processing

For the pre-processing of WorldView-3 satellite images shown in Figure 4, a band composition of 7-5-3 (False-Color Infrared) was employed to enable vegetation analysis (Persello *et al*., 2019). The Normalized Difference Vegetation Index (NDVI) proposed by Johansen *et al*. (2020) was also computed to indicate the presence of vegetation.

$$NDVI = \frac{NIR2 - Red}{NIR2 + Red} \qquad (1)$$

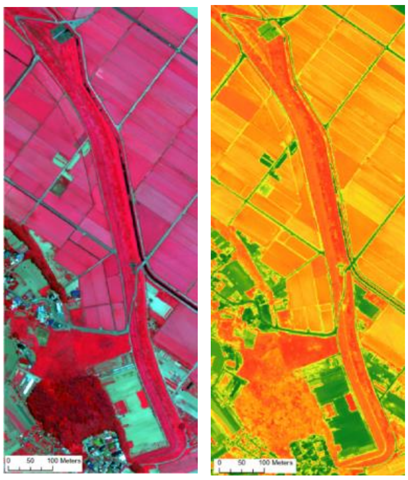

Figure 4. Pre-processing satellite imagery
Band composition 7-5-3 (left) and NDVI (right)

The preprocessing of the drone imagery is shown in Figure 5. Pix4Dmapper software, assisted by eight ground control points (GCPs), was used to generate 3D models, and create an orthomosaic incorporating three multispectral bands for the drone images. Additionally, drone data were leveraged to derive crucial features, including a Digital Surface Model (DSM), Digital Terrain Model (DTM), and height raster, computed as the disparity between the DSM and DTM. The vegetation index, an important vegetation indicator, was calculated using the square red–blue normalized difference vegetation index (NDVI) formula (Lee *et al.*, 2021).

$$Square\ Red - Blue\ NDVI = \frac{NIR^2 - Red * Blue}{NIR^2 + Red * Blue} \qquad (2)$$

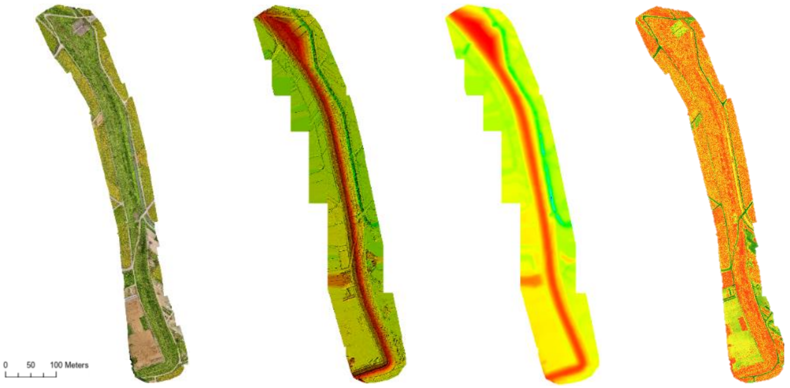

Figure 5. Pre-processing drone imagery: Orthomosaic, DSM, DTM, Square Red-Blue NDVI (left to right)

To ensure the geometric alignment and compatibility between the satellite and drone images, image orthorectification was performed using ArcGIS Pro. This process involved the integration of the 7-5-3-NDVI satellite image and the drone DTM with a resolution of 1.6m. Georeferencing of both the satellite and drone images was performed using ArcGIS Pro to establish a consistent spatial resolution within a shared coordinate system. Furthermore, Datum Workstation Geospatial software was used to facilitate pixel matching and enable fitness between satellite images with a resolution of 1.6m and drone images with a resolution of 0.1m.

Moreover, Datum Workstation Geospatial software was also employed to generate a resampled drone orthomosaic with a resolution of 0.01m, which served as the ground truth data in this study.

2.4 Object-based Image Analysis

An object-based image analysis was conducted to partition the pre-processed images into homogeneous objects. Definiens Professional 5.0, which incorporates advanced image segmentation techniques and data extraction tools, was used to accomplish this task.

2.4.1 Image Segmentation

Only multi-spectral satellite images were utilized for the segmentation process using Definiens Professional 5.0. The segmentation parameters are listed in Table 3.

Table 3. Segmentation parameters

Scale parameter	5.0
Segmentation mode	Multiresolution segmentation
Color	0.9
Shape	0.1
Compactness	0.5
Smoothness	0.5

2.4.2 Data Extraction

The segmented images obtained in the previous step were further processed to extract information related to vegetation objects. The specific data extracted from these image sources are listed in Table 4.

Information on the vegetation objects such as descriptive statistics and generic shapes were extracted from multi-spectral satellite images, including false color infrared and NDVI, using Definiens professional 5.0 software. Furthermore, the information extraction process involved the integration of drone images with the corresponding segmented satellite images. To extract the segmented information from the drone images, specifically descriptive statistics, the Zonal Statistics tool in QGIS software was used. This tool enables the statistical analysis of defined segments from an orthomosaic, height raster, and square red-blue NDVI derived from the drone image.

Table 4. Types of extracted data from image sources

Descriptive Statistics	**Generic Shape**
Mean, Median, Standard deviation, Minimum, Maximum	Borderline, Area, Roundness, Radius, Brightness, Compactness, Rectangular, Shape index, Main direct, Length/Width, Length, Density, Elliptic, Asymmetry, Width, Border length

2.5 Data Fusion

A data fusion process is carried out to combine information derived from satellite and drone imagery. This integration was performed on a segment-by-segment basis using a feature concatenation approach, where the features from the satellite and drone images were combined horizontally to create a unified feature vector encompassing all the features for each segment as illustrated in Table 5.

Table 5. Data fusion dataset

Segment ID	Satellite Information		Drone Information		
	False color infrared (7-5-3)	NDVI	Orthomosaic	Height raster	Square red-blue NDVI
First segment	Borderinde, Area, Roundness, Radiusofsm, Brightness, Compactnes, Rectangula, Shapeindex, MeanLayer1, MeanLayer2, MeanLayer3, MeanLayer4, Standardde, Standard_1, Standard_2, Standard_3, Maindirect, Radiusofla, Length/Wid, Length, Rectangu_1, Max.diff., Radiusof_1, Roundness(, Density, EllipticFi, Radiusof_2, Asymmetry, Elliptic_1, Width, Borderleng		_mean, _median, _stdev, _min, _max, _mean2, _median2, _stdev2, _min2, _max2, _mean3, _median3, _stdev3, _min3, _max3		
…	…		…		
Last segment	Borderinde, Area, Roundness, Radiusofsm, Brightness, Compactnes, Rectangula, Shapeindex, MeanLayer1, MeanLayer2, MeanLayer3, MeanLayer4, Standardde, Standard_1, Standard_2, Standard_3, Maindirect, Radiusofla, Length/Wid, Length, Rectangu_1, Max.diff., Radiusof_1, Roundness(, Density, EllipticFi, Radiusof_2, Asymmetry, Elliptic_1, Width, Borderleng		_mean, _median, _stdev, _min, _max, _mean2, _median2, _stdev2, _min2, _max2, _mean3, _median3, _stdev3, _min3, _max3		

Note: The numbering of variables follows the order of the image bands shown in the top row

2.6 Ground Truth Classes

Using ground truth imagery, 351 polygons were manually created to represent areas containing the target alien species. The percentage of the target alien species is also indicated within each polygon. The created polygons were merged with the segmentation image obtained in the previous steps to determine the percentage of the target alien species in each segment. The percentages of alien target species within the segments were divided into five distinct classes (Table 6). The ground-truth class of the target alien species served as reference material to supervise the classification model and assess the level of agreement and accuracy of the classification model predictions.

Table 6. Classes of target species percentage in the segment

Class Label	Description
Class 0	0% target species
Class 1	0 - 25% target species
Class 2	25 - 50% target species
Class 3	50 - 75% target species
Class 4	75 – 100% target species

2.7 Classification

Analysis of reports on the identification of invasive species indicates that Random Forest (RF) algorithms have consistently demonstrated superior performance in terms of statistical accuracy (Lawrence *et al.*, 2006) and classification time (Sluiter & Pabesma, 2010) compared to others. In this study, RF classification was employed to assign vegetation types and identify alien species based on their spectral signatures and spatial patterns using the IBM SPSS Modeler. The imagery dataset was split into training and testing sets at a ratio of 80% for training and 20% for testing to implement the RF algorithm. The training set was used to train the RF model supervised by the ground-truth classes of the target alien species percentage, utilizing the extracted information from both satellite and drone images as predictor variables, whereas the predicted classes of the target alien species percentage served as the target variable. Once the model was trained, the testing set was used to test the trained RF model to determine how well the classification model was trained.

For the configuration of the RF model, a classification model was created by adjusting various parameters within the model. These adjustments were made to attain an accuracy level for the supervised classification model that would be deemed satisfactory for application to a novel dataset. The specific parameters used in this configuration are listed in Table 7.

Table 7. Random Forest model setting

Model Building	Number of Trees to Build	100
Tree Growth	Specify Max depth	10
	Minimum leaf node size	1
	Number of Features to use for splitting	auto

Furthermore, the developed Random Forest classification model was applied to the entire fused imagery dataset and separately to the satellite and drone imagery datasets. This allowed a comparative analysis of the classification results obtained from each dataset.

2.8 Accuracy Assessment

Following the application of the developed RF classification model to each dataset, the resulting classification outcomes were compared with the ground truth classes of the target alien species. This comparison was conducted to assess the accuracy of the classification results derived from each input dataset.

3. RESULTS

Following the image segmentation process adhering to the segmentation parameter specified in Table 3, 6462 segments were produced. These segments represent discrete and consistent objects in the image. These segmented elements served as fundamental building blocks for subsequent analysis and interpretation in this study.

By utilizing ground truth data and following the ground truth class process, this study yielded both the percentage of target alien species within each segment and the number of segments containing the target alien species. The results are shown in Figures 6 and 7.

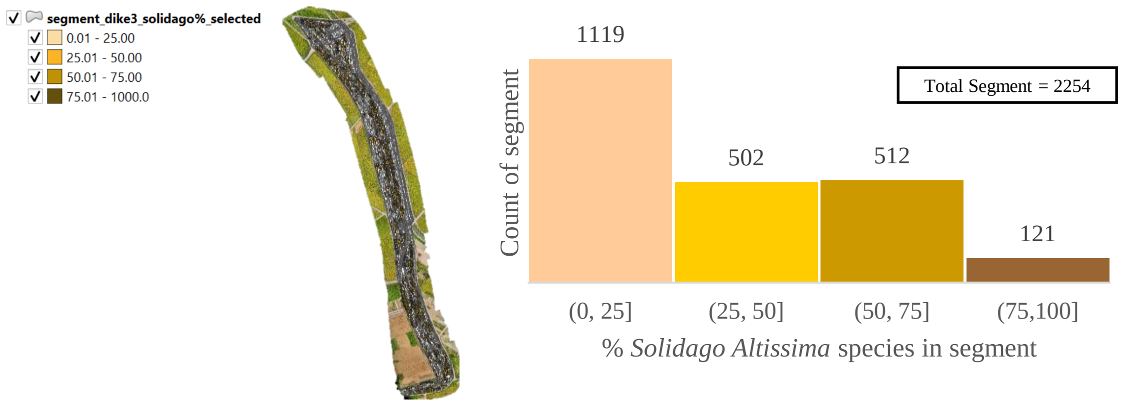

Figure 6. Ground truth classes of *Solidago altissima* species

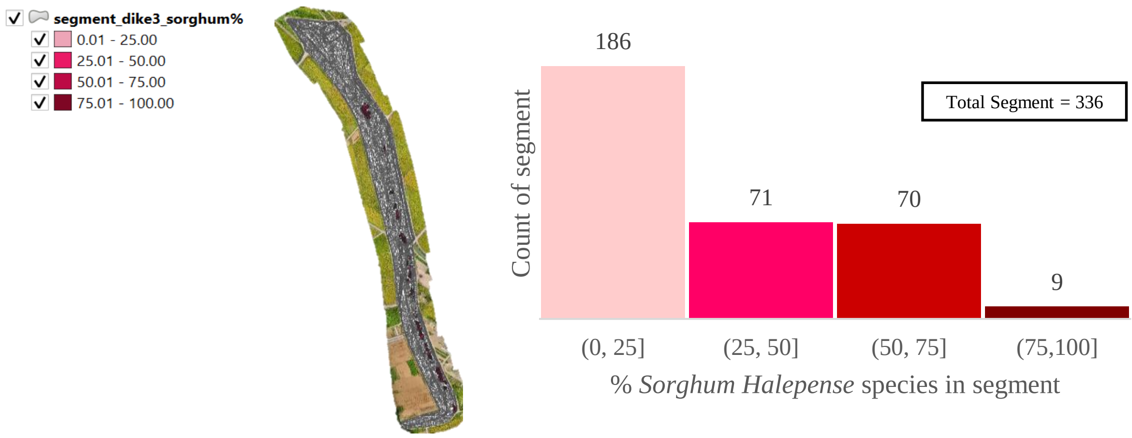

Figure 7. Ground truth classes of *Sorghum halepense* species

Figures 6 and 7 illustrate that 2254 out of 6462 segments contained the *Solidago altissima* species, and 336 out of 6462 segments encompassed the *Sorghum halepense* species. As indicated in Table 6, the proportion of the target alien species within each segment was categorized into the respective classes. Based on the ground truth data, these classes served as the basis for supervising the classification model. A subsequent comparison of these classes with the classification results is shown in Figure 8.

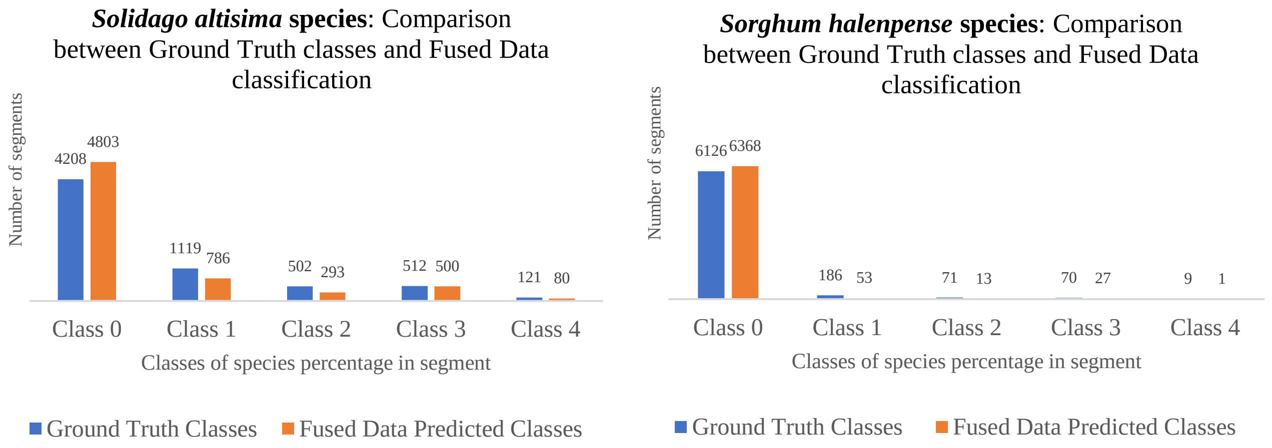

Figure 8. Comparison between Ground Truth classes and Fused Data classification.

By applying the developed RF classification model across the fused imagery dataset, as well as individually on the satellite and drone imagery datasets, and by comparing the classification model's prediction with established ground-truth target alien species classes, a comparative accuracy assessment of the classification outcomes from each input dataset was achieved. A comparative assessment of the accuracy is shown in Figure 9.

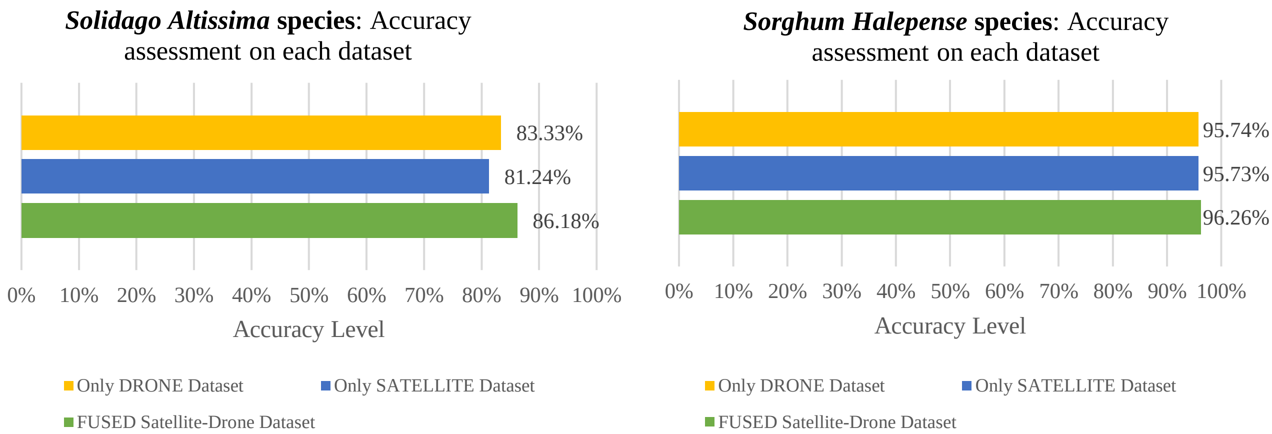

Figure 9. Accuracy assessment results

Figure 9 demonstrates that the combination of satellite and drone data has substantially improved classification accuracy compared to using either dataset alone. In particular, when classifying the *Solidago altissima* species, the accuracy of classification using the fused dataset surpasses that of the drone dataset by approximately 3%, and significantly exceeds the accuracy of the high-resolution satellite dataset by approximately 5%. Regarding *Sorghum halepense*, the classification accuracy of the fused dataset exhibited a moderate improvement compared with the individual datasets, resulting in comparable classification accuracy.

Figures 10 and 11 highlight the key predictors extracted from each dataset that played a crucial role in classifying the target alien species within the Random Forest classification model. These predictors were automatically generated by the Random Forest model after the completion of the classification process, illustrating the sequence of predictor importance in the model predictions. By considering the top 10 important predictors, it's noteworthy that the essential predictors from the individual datasets, which were used to classify the target alien species, continued to contribute to the target alien species classification when the fused satellite-drone dataset was utilized. This contribution leads to an enhancement in classification accuracy. Additionally, Figures 10(c) and 11(c) verify with Table 5 that among the ten most important predictors joining the satellite and drone dataset, the significant predictors originating from the drone dataset have a more pronounced impact on the accuracy improvement of the fused satellite-drone dataset.

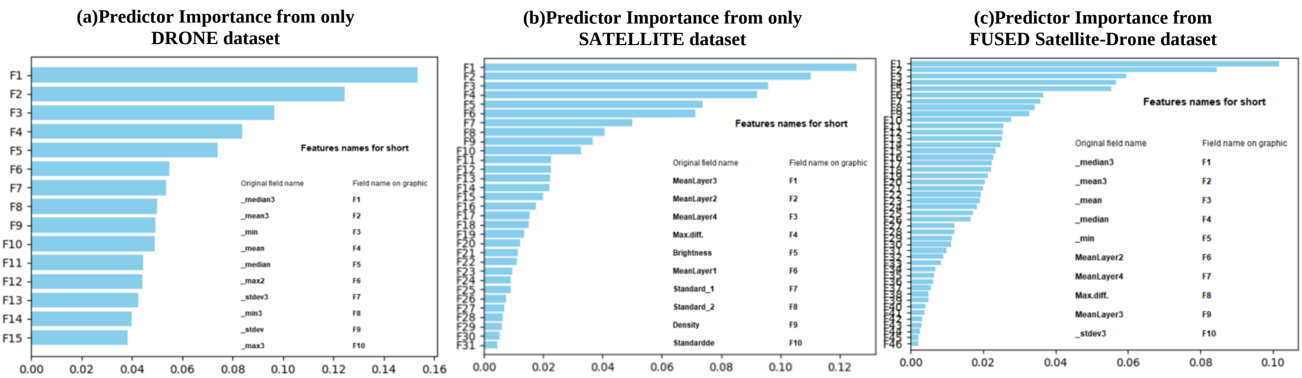

Figure 10. Predictor important for *Solidago altissima* species classification

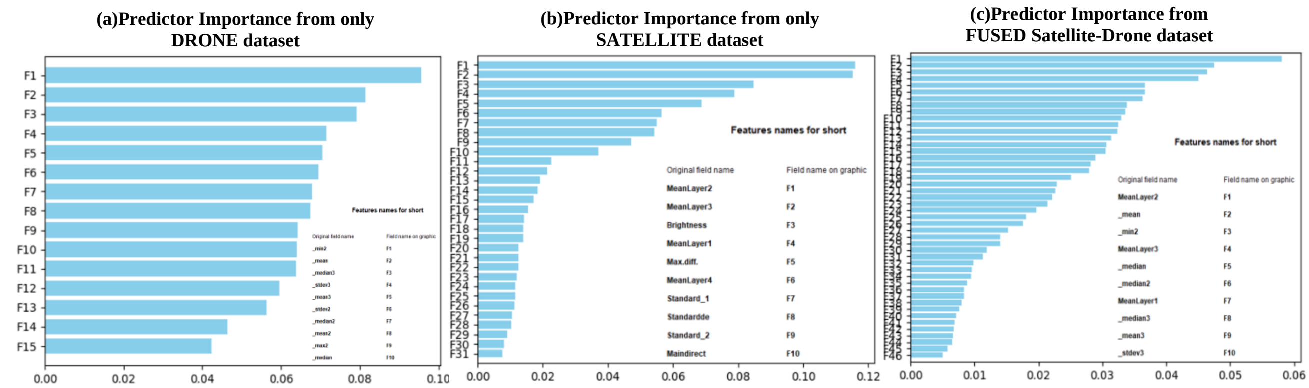

Figure 11. Predictor important for *Sorghum halepense* species classification

4. DISCUSSION

The findings of this study as illustrated in Figure 9 reveal that the fusion of satellite and drone data significantly enhanced classification accuracy compared to using either dataset individually for alien species classification on riverdike. This aligns with the observations made by Alvarez-Vanhard *et al*., (2021), suggesting that the combination of satellite and UAV data facilitates the extraction of intricate land cover and biophysical vegetation characteristics, achieving a refined level of resolution. Royimani *et al.*, (2019) and Rajah *et al*., (2019) mentioned that the utilization of data fusion to attain the utmost efficacy in detecting and mapping invasive alien plant species is lacking. This study demonstrates that data fusion of high-resolution satellite and drone imagery addresses this gap. Especially in the case of the *Solidago altissima* species, it is apparent that exclusively relying on WorldView-3 (WV-3) high-resolution satellite imagery is inadequate for the classification of invasive alien species along river dikes. In this context, it can be asserted that the effectiveness of high-resolution satellite images is constrained by the presence of mixed-pixel problems, which in turn affect the precision of mapping alien species. Hence, this study demonstrates that drone technology has emerged as a viable solution for addressing mixed-pixel issues, potentially circumventing this challenge. In the context of *Sorghum halepense*, the improvement in classification accuracy using a fused dataset was moderate compared to the individual dataset. This phenomenon might be attributed to the limited occurrence of this species in all segments, as indicated in Figure 7 when compared to the absence of the species. Consequently, this balance between the presence and absence could be a contributing factor to comparable classification accuracies.

The RF classifier is a robust and effective supervised classification algorithm. It achieved high accuracy and provided insight into the importance of predictors in determining the labelling classes of the target variables as shown in Figures 10 and 11. Figures 10(c) and 11(c) show that the additional information derived from drone imagery is crucial for enhancing the accuracy of the classification process of the fused dataset. Therefore, combining information extracted from high-resolution satellite images and drones contributes to achieving a higher classification accuracy.

The outcomes of this study offer valuable insights into the advantages of leveraging multiple data sources and the resultant impact on accurate species identification. This approach not only showcases the effectiveness of the methodology but also contributes to a broader understanding of how data fusion can advance remote sensing analysis. As Miura *et al*., (2021) emphasized, achieving precise classification and quantification of herbaceous vegetation on riverdikes requires remote sensing with exceptionally high spatial resolution and accuracy. In alignment with this notion, the study proposes that data fusion of high-resolution satellite and drone imagery represents a promising remote sensing technique capable of fulfilling this objective.

5. CONCLUSION

The fusion of high-resolution satellite and drone data, coupled with the application of advanced classification algorithms, such as Random Forest, yields higher accuracy in classifying vegetation types and identifying alien species on river dikes. This study underscores the importance of integrating multiple data sources, such as satellite imagery and drones, to comprehensively understand ecological patterns. By combining the strengths of the different data modalities, researchers can improve their ability to accurately identify and manage alien species in diverse ecosystems. This knowledge can guide future research and management strategies aimed at addressing the ecological challenges related to alien species in a wider area of river dikes.

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