AUGMENTING THE PHILIPPINES' CENSUS OF AGRICULTURE AND FISHERIES EFFORTS USING SAR SATELLITES

Karl Louie S. Mariano[1*], John Bart Lovern C. Dumalag[1], Neyzielle Ronnicque R. Cadiz[1], Alvin E. Retamar[1], Darius Jude C. Casuga[1], Jonathan Christian F. Aceron[2], John Keithley L. Difuntorum[3]

[1] Department of Science and Technology – Advanced Science and Technology Institute
DOST-ASTI Building, C.P. Garcia Avenue, Diliman, Quezon City, Philippines 1101
Email: (karllouie.mariano, johnbartlovern.dumalag, neyzielle.cadiz, ning, darius.casuga)@asti.dost.gov.ph

[2] Department of Science and Technology – Philippine Institute of Volcanology and Seismology
DOST-PHIVOLCS Building, C.P. Garcia Avenue, Diliman, Quezon City, Philippines 1101
Email: jcfaceron@gmail.com

[3] University of Canterbury
Christchurch, New Zealand
Email: jkd49@uclive.ac.nz

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ABSTRACT: Fishery is one of the important sectors in the Philippines' economic domain. In 2018, the aquaculture subsector contributed to 53% of the total fish production in the Philippines (DA-BFAR, 2018). It is a type of farming of aquatic organisms from fishponds, fish pens, fish cages, as well as the mariculture of oyster, mussel, and seaweed. It has been a vital source of employment, food security, industry, and trade. Continuous monitoring and data collection are essential for the effective management and sustainability of the sector.

The Philippines Statistics Authority (PSA) is responsible for collecting and managing this crucial data. Every 10 years, they conduct the Census on Agriculture and Fisheries (CAF), gathering comprehensive information on farming and fishing activities, which serves as a foundation for policymaking both in the national and local level. Recognizing the need for timely information, the PSA partnered with the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) to leverage Synthetic Aperture Radar (SAR) technology. This collaboration culminated in the Artificial Intelligence for Census on Agriculture and Fisheries (AI4CAF) program, enhancing the industry's sustainable development using emerging technologies such as satellite remote sensing, Geographic Information System (GIS), and Artificial Intelligence (AI).

The AI4CAF program was created to develop convolutional neural networks for rapid detection of fishponds, fish pens and fish cages. The initial models developed by DOST-ASTI, and for further improvement of PSA, exhibited an average accuracy of above 85.86%. The developed workflow was operationalized by PSA on their CAF program, paving the way for a more informed and technologically advanced approach to agriculture and fisheries in the Philippines, with improved accuracy and efficacy in data collection and analysis (PIA, 2023). The AI4CAF activities, efforts, and methodologies can potentially serve as a guide for other countries planning to augment their capabilities in Aquaculture monitoring.

1. INTRODUCTION

1.1. Background of the Study

The fishery industry plays a significant role in the Philippine's economy, contributing to employment, food security, industry, and trade. It is a crucial sector that supports that livelihood of millions of Filipinos, especially in coastal communities, with the industry primarily serving as their main source of income. In addition to traditional fishing, aquaculture has become increasingly important in the country. It involves the cultivation of fish and seafood in controlled environments such as, ponds, pens, and cages. In 2018, the aquaculture subsector contributed to 53% of the total fish production in the country (DA-BFAR, 2018), providing a significant portion of the country's fish supply and helps reduce pressure on wild fish stocks. Due to its impact to the country's economy, there is a need for a system to continuously monitor valuable information that are crucial for the effective management and sustainable development of the sector.

The Philippine Statistics Authority (PSA) is the mandated agency to collect and manage these data, as well as conduct surveys and census that will serve as the official statistics of the Philippines regarding the country's demographics, socio-economic status, among others. The agency is tasked to prepare and conduct the Census of Agriculture and Fisheries (CAF) every 10 years to gather data on structures and characteristics of farms such as size; tenure of holdings; land use and area planted to crops; inventory of livestock and poultry; and distribution and number of households engaged in farming, fishing, and related activities (PSA, 2012).

The data collected and analyzed from this census serve as a foundation for policymaking for the development, management, and utilization of fisheries resources both in the national and local level. It provides comprehensive up-to-date information on the state of the fisheries sector essential in making informed decisions regarding resource management, conservation efforts, and the allocation of fishing rights and quotas. This information is also critical for setting limits and implementing measures if overfishing or unsustainable practices are potentially occurring, which can lead to destructive ecological and socio-economic effects. However, this may be insufficient when rapid delineation is needed for immediate government intervention to determine these unsustainable farming practices.

The PSA sought scientific intervention from the Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) to leverage on Synthetic Aperture Radar (SAR) satellite imagery. SAR technology can be effective in detecting and monitoring aquaculture structures because of their high backscatter values in contrast with the surrounding waters. Through the Synthetic Aperture Radar and Automatic Identification System for Innovative Terrestrial Monitoring and Maritime Surveillance (SARwAIS) Project that gives the Philippines a 10% share of NovaSAR-1 satellite imagery, a workflow was made to delineate existing aquaculture structures in select areas of interest. The PSA and DOST-ASTI collaborated for the sharing of resources for the conduct and completion of the Artificial Intelligence for Census on Agriculture and Fisheries (AI4CAF) program.

1.2. Objectives

The AI4CAF program was created to develop models for automated delineation of selected major crops and aquaculture farms using emerging technologies such as remote sensing, Geographic Information System (GIS), and Artificial Intelligence (AI). The models must produce mapping and area estimation for the aquaculture farms, enabling a regular monitoring and assessment of fishponds, fish pens, and fish cages.

2. METHODOLOGY

The proposed method is to train AI models to detect each aquaculture structures from multiple SAR images. The concept is that since water bodies inherently have lower backscatter coefficients as opposed to land mass, certain areas in coastal communities can be assumed to be fishponds as they have distinct boundaries, separating them from surrounding areas, and have regular man-made shapes and patterns. Likewise, the concept is also applicable to fish pens and fish cages as their boundaries protrude above water bodies, creating a stronger radar reflection and subsequently, further enhancing their visibility. However, this will still be subject to ground-truth validation handled by PSA.

Study Area: The PSA identified key areas to be used for the development of the aquaculture models, such as Laguna de Bay (14.3935° N, 121.1939° E), Buluan Lake (6.6364° N, 124.8403° E), and Bolinao, Pangasinan (16.3881° N, 119.8947° E) (Figure 1). These areas of interest exhibit aquacultures structures of different types and sizes, which can be beneficial when training the AI models.

Figure 1. Images of Laguna de Bay (left), Buluan Lake (middle), and Bolinao, Pangasinan (right) as shown in the latest ArcGIS World Imagery basemap.

Datasets Used: Various NovaSAR captures from 2019 to 2021 were used depending on the aquaculture type (Table 1). These images were used for training the initial prototype models for detecting fishponds, fish pens, and fish cages.

NovaSAR Image	Location	Type
NovaSAR_01_6669_grd_13_190710_144525_HH_1	Pangasinan	Ponds, Pens

NovaSAR_01_8474_grd_13_191028_021301_HH_2	Laguna Lake	Pens
NovaSAR_01_10794_grd_13_200331_143748_HH_3	Nabulao, Negros Occidental	Ponds, Cages
NovaSAR_01_11139_grd_13_200413_141717_HH_2	Panay, Capiz	Ponds
NovaSAR_01_11388_grd_13_200502_142927_HH_2	Pangasinan	Ponds, Cages
NovaSAR_01_12022_grd_13_200605_143500_HH_1	Lake Buhi, Bicol	Cages
NovaSAR_01_12243_grd_13_200617_140948_HH_2	Buluan Lake	Pens
NovaSAR_01_12761_grd_13_200707_142733_HH_2	Quezon	Ponds
NovaSAR_01_18512_grd_13_210102_140600_HH_3	Davao	Ponds

Table 1. Some of the NovaSAR Images used for training the aquaculture models.

The proposed methodology (Figure 2) follows four major steps from training to prediction: image pre-processing, training data generation, AI training, and feature prediction. However, post-processing and accuracy assessment were added to reduce the misclassifications from the prediction and assessed if the model has acceptable accuracy, respectively, subject to the ground-truth validation of the PSA.

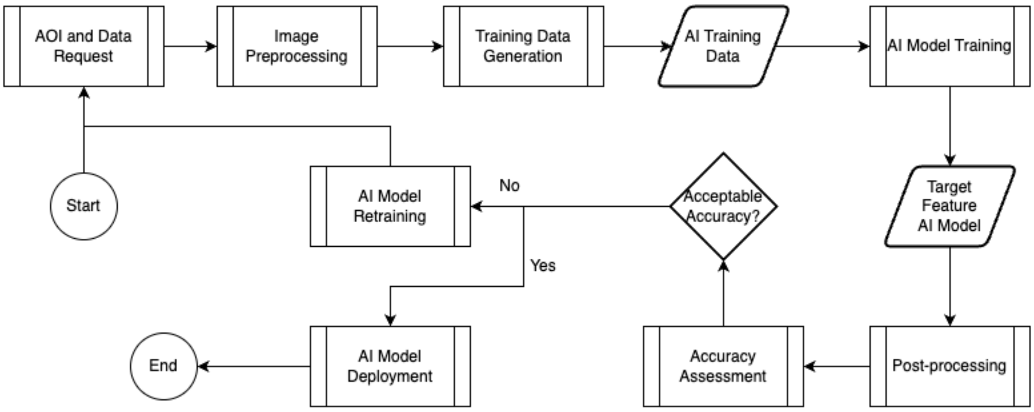


Figure 2. General Workflow of the Aquaculture Detection

2.1 NovaSAR Data Pre-Processing

The NovaSAR-1 products received all require pre-processing before they can be used in the training data generation. This starts with the application of the calibration constant; a value provided in the image metadata and is used to convert the DN values into the actual intensity values. After this step, the image is the geocoded to apply the map coordinates to the image. Lastly, the values in the image are converted into the decibel scale. Figure 3 shows the general workflow of the pre-processing applied to the NovaSAR-1 images. All these steps are applied automatically using Python-based scripts.

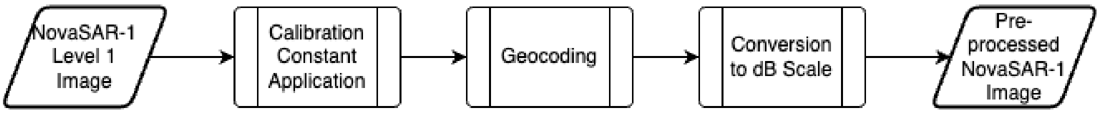


Figure 3. NovaSAR-1 pre-processing Workflow

Figure 4. Fishponds as shown in NovaSAR_01_11139 Image located in Panay, Capiz.

2.2. Training Data Preparation

This process involves identifying the areas of interest from the NovaSAR images. These areas of interest can either be large or small sections of the image, covering the whole extent of the area where the aquaculture features are located or areas showing the different characteristics of the aquaculture feature, i.e., small/large features, isolated/clustered features, etc., respectively.

Then, polygon shapefiles are created to mark the aquacultures within the areas of interest. These polygons can either be the overall shape of the aquaculture structure, or only marking their boundaries (Figure 5). The shapefiles were provided and validated by the PSA as they have prior information to the locations and extents of the aquaculture farms.

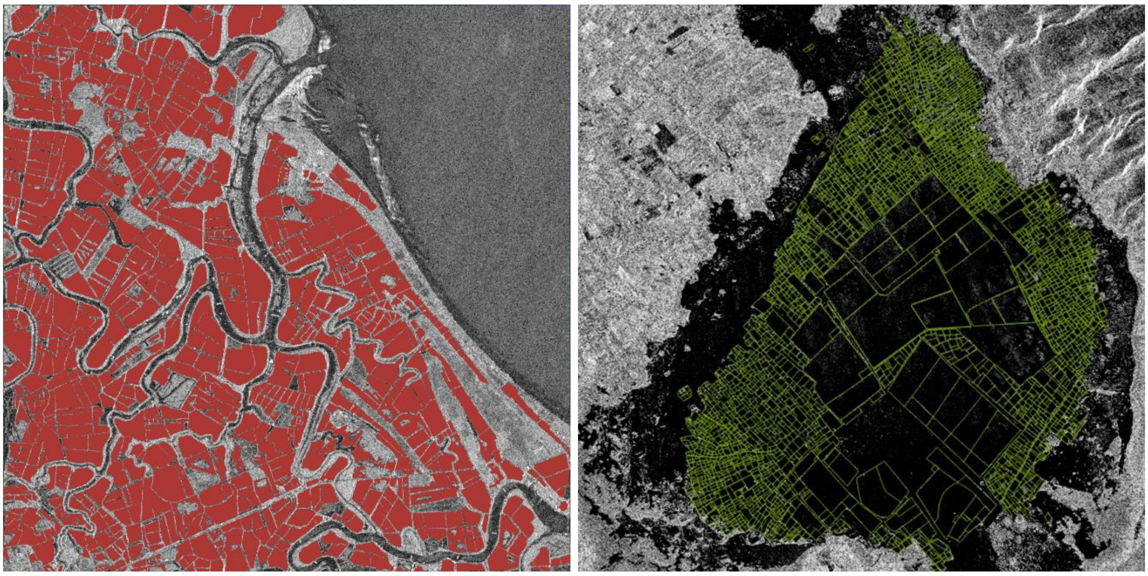


Figure 5. Digitized areas for fishponds (left), and fish pens (right)

The NovaSAR images will then be clipped to the extent of the areas of interest, and once the aquaculture features are marked, the polygon shapefiles will be converted into a raster with values of 0 and 1, corresponding to non-features and features, respectively. The clipped images and their corresponding feature masks are then merged to create stacked images to be used as input in training the aquaculture models.

2.3 AI Training and Prediction

Training: The Keras machine learning framework was used for this activity on the U-Net architecture as it is relatively easy to use and work with. This allows for rapid prototyping and testing of the aquaculture models with minimal changes in the script. Batch normalization was used since it can help improve the performance and stability of the model during both training and prediction. By normalizing the inputs to each layer, it will help the network to converge faster, leading to a significant reduction in training. The activation function used is the exponential linear unit (ELU) as it is found to be noise-robust that leads to higher generality under noisy conditions (G.Jin et al, 2020).

The binary cross entropy was used as the loss function since its logarithmic nature heavily penalizes predictions that are confidently wrong. This can help the model to focus on improving predictions for challenging examples, ensuring that the model's confidence scores reflect the true likelihood of the classes. The Nadam Optimizer (Nesterov-accelerated Adaptive Moment Estimation) was used as the optimizer, and a learning rate of $1e^{-3}$. The models were trained for 50 epochs for each feature, and for each iteration/improvement of the models.

Also, an experimental design was conducted to further improve the aquaculture models and see the effects of setting different window and batch sizes, introducing buffer sizes on the shapefiles marking only the boundaries, and scaling the backscatter coefficients of the images.

Prediction: The aquaculture models output a raster mask with values of 0 and 1: 0 for non-aquaculture features and 1 for aquaculture features. As part of the post-processing steps, the raster mask is adjusted to remove isolated noise predictions using a land mask and vectorized using a GIS software (Figure 6). For the models that only predict the boundaries of the aquacultures, further steps were done by transforming the shapefile containing the predicted boundaries into a polygon shapefile marking the inner extent of the aquaculture structure (Figure 7).

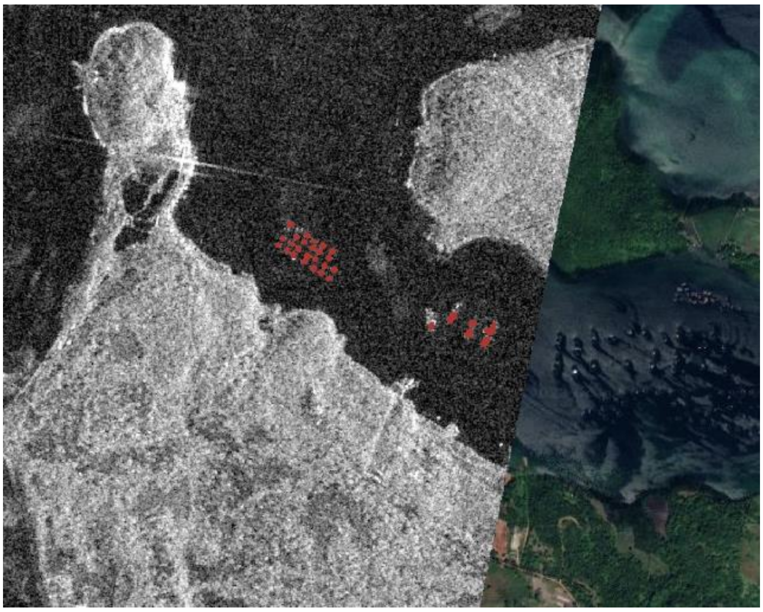


Figure 6. Post-processed Fish Cages prediction in Masinloc, Zambales

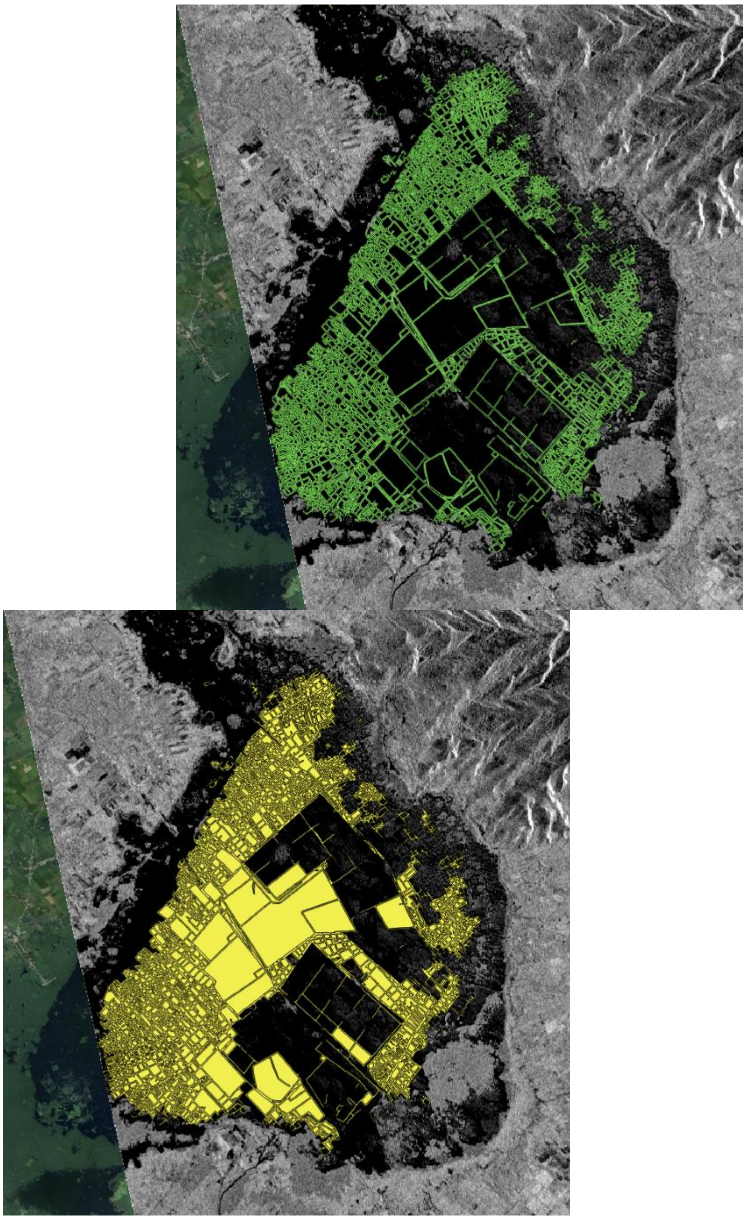
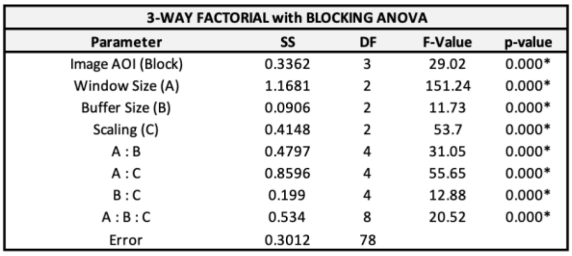


Figure 7. Post-processed Fish Pens from boundary predictions (left) to polygon extent (right).

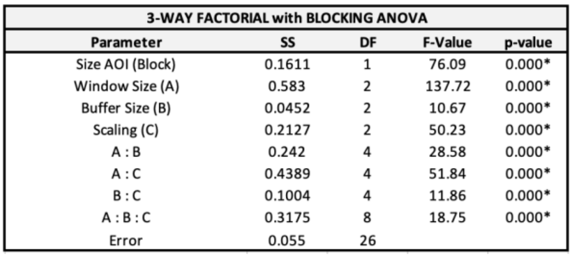
The result of the experimental design also showed that the window size, buffer size, and scaling main-effect parameter estimates as well as their interaction-effect parameters were found to be significant. Despite being tagged as a nuance factor, both the selected areas of interest and sizes of the aquaculture types have a significant impact on the performance of the models as shown in Tables 2 and 3. Over 20 models were compared, just for detecting fish pens alone, to see each model's overall performance and identify which set of parameters are best suited in detecting the aquaculture type.



3-WAY FACTORIAL with BLOCKING ANOVA

Parameter	SS	DF	F-Value	p-value
Image AOI (Block)	0.3362	3	29.02	0.000*
Window Size (A)	1.1681	2	151.24	0.000*
Buffer Size (B)	0.0906	2	11.73	0.000*
Scaling (C)	0.4148	2	53.7	0.000*
A : B	0.4797	4	31.05	0.000*
A : C	0.8596	4	55.65	0.000*
B : C	0.199	4	12.88	0.000*
A : B : C	0.534	8	20.52	0.000*
Error	0.3012	78		

Table 2. 3-Way Factorial ANOVA with Blocking (areas of interest) for fish pen models



3-WAY FACTORIAL with BLOCKING ANOVA				
Parameter	**SS**	**DF**	**F-Value**	**p-value**
Size AOI (Block)	0.1611	1	76.09	0.000*
Window Size (A)	0.583	2	137.72	0.000*
Buffer Size (B)	0.0452	2	10.67	0.000*
Scaling (C)	0.2127	2	50.23	0.000*
A : B	0.242	4	28.58	0.000*
A : C	0.4389	4	51.84	0.000*
B : C	0.1004	4	11.86	0.000*
A : B : C	0.3175	8	18.75	0.000*
Error	0.055	26		

Table 3. 3-Way Factorial ANOVA with Blocking (aquaculture size) for fish pen models

3. RESULTS AND DISCUSSION

To quantify the actual ground accuracy of the aquaculture models, the best models were first used to predict the aquaculture structures from a different set of processed NovaSAR images on areas determined by PSA for their pilot ground-truthing activity: (1) San Mateo, Isabela, (2) Talibon, Bohol, (3) Socorro, Surigao Del Norte, and (4) Brgy. Tambler, Gen. Santos City.

PSA generated random points (n=99) in the validation areas and classified them according to the aquaculture type. A confusion matrix was then generated to calculate the overall accuracies of the models. The method achieved a producer's accuracy of 95.00%, a user's accuracy of 76%, and an overall accuracy of 85.86% with a 0.70 Kappa statistic as shown in Table 4.

	Aquaculture	Not Aquaculture	User's Accuracy
Aquaculture	38	12	**76.00**
Not Aquaculture	2	47	95.92
Producer's Accuracy	**95.00**	79.66	**85.86**

Table 4. Confusion Matrix (n=99)

4. CONCLUSION

The proposed workflow in detecting aquaculture structures using remote sensing, GIS, and artificial intelligence was developed to augment the efforts of the Philippine Statistics Authority in their Census on Agriculture and Fisheries (CAF). This will not replace their process in conducting the census however, this can help provide a comprehensive coverage of the areas used and potentially unused areas in the fishery sector. With the initial prototype models reaching an accuracy of 86%, it has shown promise in providing added value for mapping and monitoring fisheries and can potentially improve further with additional training data.

5. ACKNOWLEDGEMENT

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