A DEEP LEARNING MODEL FOR GREEN TIDE DETECTION BASED ON SAR IMAGES

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Abstract

This study developed a textural-enhanced deep learning (DL) model based on the classic U-net framework for green algae detection in Sentinel-1 synthetic aperture radar (SAR) imagery. Four special modifications are made in the framework: texture-fused input dataset, texture concatenation to effectively use the texture information, weighted loss function to settle the imbalance of algae–seawater samples, and an attention module to facilitate model focus on the discriminative features efficiently. To build the proposed model, we collected 119 Sentinel-1 SAR images acquired in the Yellow Sea and manually labeled 8441 samples, among which 4421/1896/2124 were used as the training/validation/testing dataset, respectively. Experiments show that the classification achieves the mean intersection over union (mIOU) of 86.31%, outperforming previous DL methods. Moreover, we monitored green tide in the Yellow Sea from 2019 to 2021 using the proposed model and analyzed the relationship between green tide interannual variation and two primary environmental factors: nitrate concentration and sea surface temperature (SST). The interannual variation is characterized via three crucial indexes: bloom duration, coverage area, and nearshore damage. The detection results reveal that the bloom duration is the longest (shortest) in 2019 (2020), corresponding to the biggest (smallest) coverage area in 2019 (2020). In addition, the nearshore damage is the heaviest (lightest) in 2021 (2020). We also found that the interannual variation of green tide scales is partly related to the available nitrate concentration and SST variation in algae-distributed regions.

Introduction

Coastal macroalgae blooms have a profound influence on marine ecosystem balance, tourism, and aquaculture. Since 2008, the western coasts of the Yellow Sea have been damaged every summer by a macroalgae bloom, i.e., green tide, caused by the overgrowth of green algae, mainly *ulva prolifera*. Remote sensing has been the primary tool for monitoring this green tide. With the emergence of more free synthetic aperture radar (SAR) images with high resolution and the ability to image in cloudy conditions, SAR images play an increasingly important role in green tide monitoring. Deep learning is a powerful method in remote sensing images classification.[1] However, current studies mainly focus on the image's backscattering coefficient, while ignoring the morphological characteristics [2]. Moreover, the proportion of algae-pixels and seawater-pixels is significantly unbalanced, which will reduce the learning ability of the deep learning method. Besides, many researches investigated the correlation between green tide scales and environmental factors throughout the study area, whereas green algae are only influenced by surrounding environmental factors.

Objectives

- Propose a deep learning method using both polarized images and texture features to detect green algae.
- Monitor the interannual variations of green tide scales from 2019 to 2021.
- Analyze the relationship between green tide interannual variations and key available environmental factors.

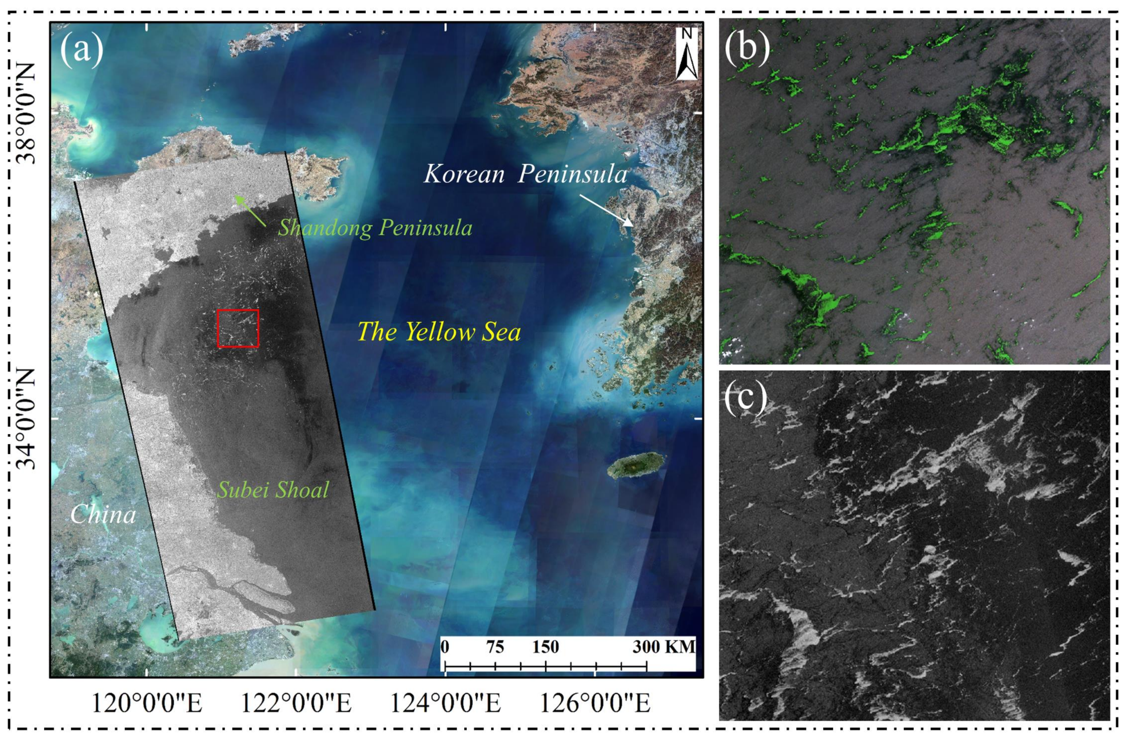

Figure 1. Study area and green algae signatures on SAR and optical images. (a) Map of the Yellow Sea and our study area: the scope of SAR images. The true-color image is Sentinel-2 (Band 4/3/2), and the rectangle box-bounded greyscale image is the Sentinel-1 VV-polarized image. (b) True-color Sentinel-2 image at the red box of (a) on June 23, 2019. The green patches on the sea surface are green algae. (c) Sentinel-1 VV-polarized SAR image at the red box of (a) on June 23, 2019. Green algae appear as bright patches.

Data and Dataset

- SAR data: SENTINEL-1 Level-1 ground range detected high-resolution (GRDH) in interferometric wide (IW) mode
- Nutrient data: Copernicus Marine Environment Monitoring Service (CMEMS)
- Seawater surface temperature data: Operational SST and Sea Ice Analysis (OSTIA) on CMEMS
- Dataset:

  4421 / 1896 / 2124 groups of patches as the training / validation / testing dataset

Methodology

The green tide detection model is constructed based on well-known segmentation model U-net, with four tailored modifications:

- Adopt a texture-fused input strategy
- Build a texture-enhanced path in the model
- Design a weighted loss function
- Embed the convolutional block attention module (CBAM)

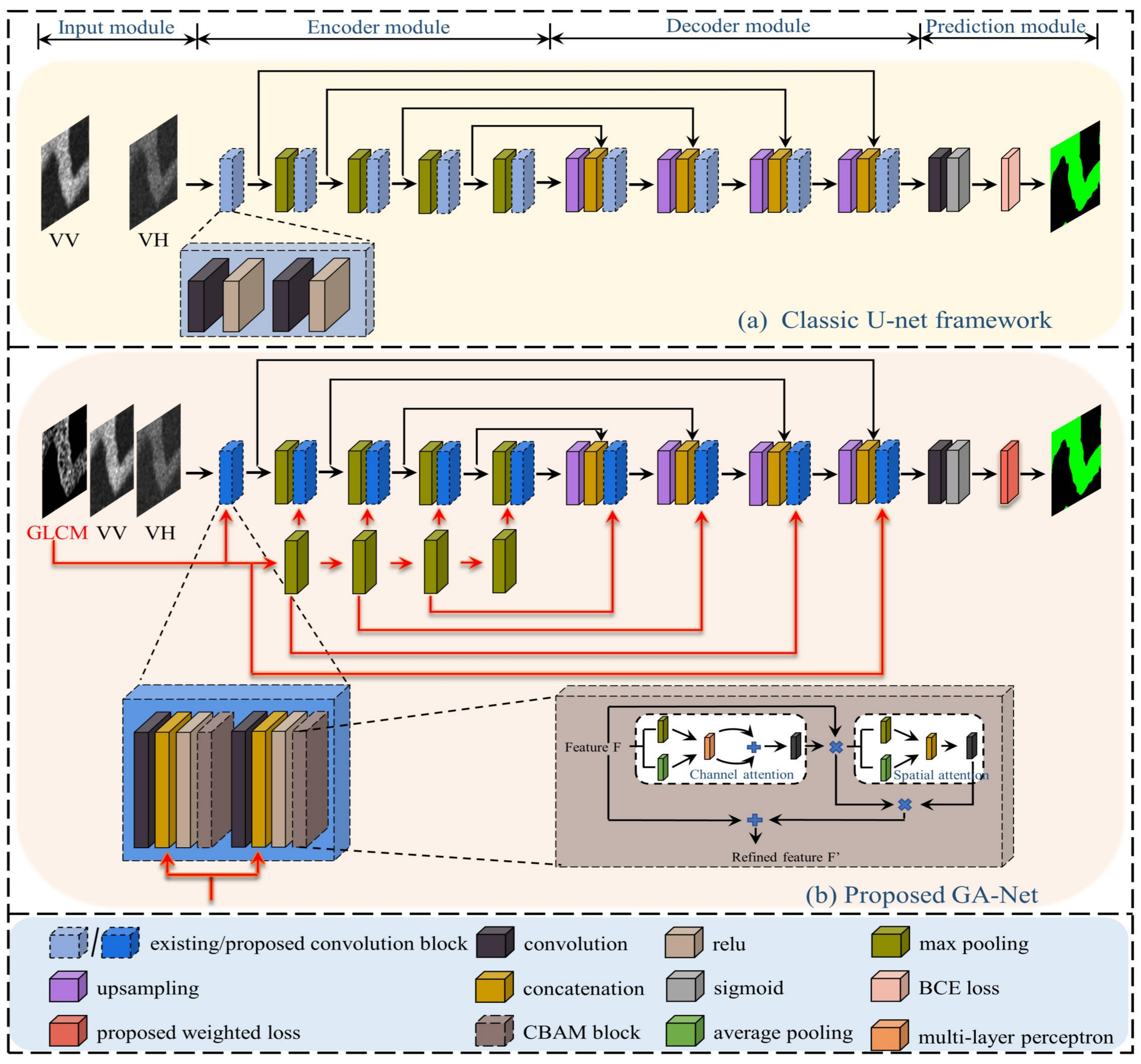

Figure 2. GA-Net with considering textural features and algae–seawater imbalance based on the U-Net framework. GLCM represents the texture set, including mean, angular second moment (ASM), entropy, and correlation.

Results

Model performance

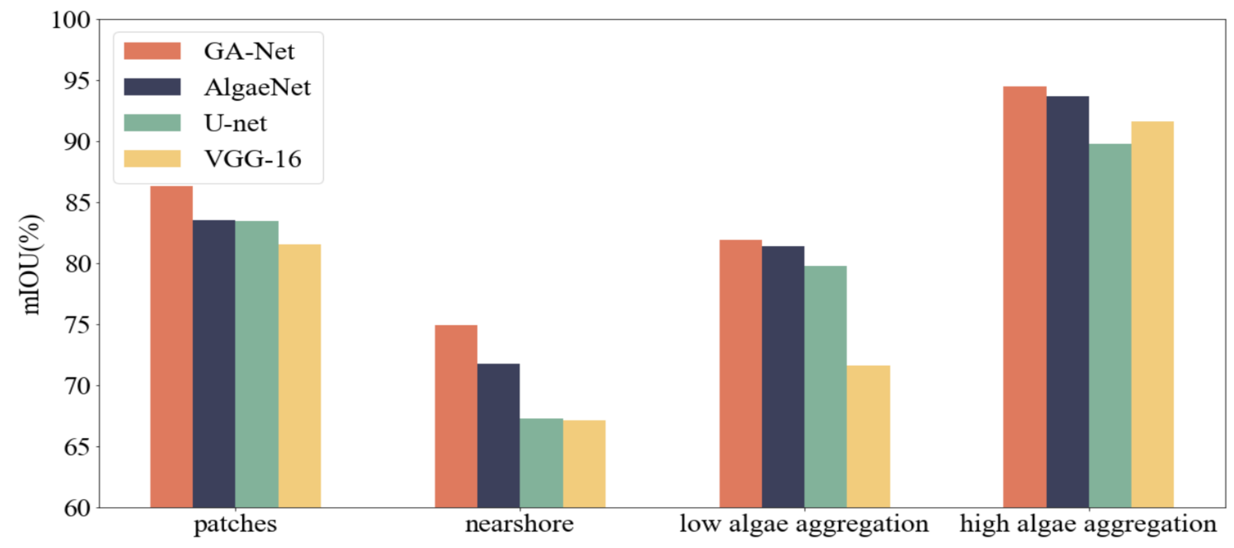

Figure 3. The performance of different detection models.

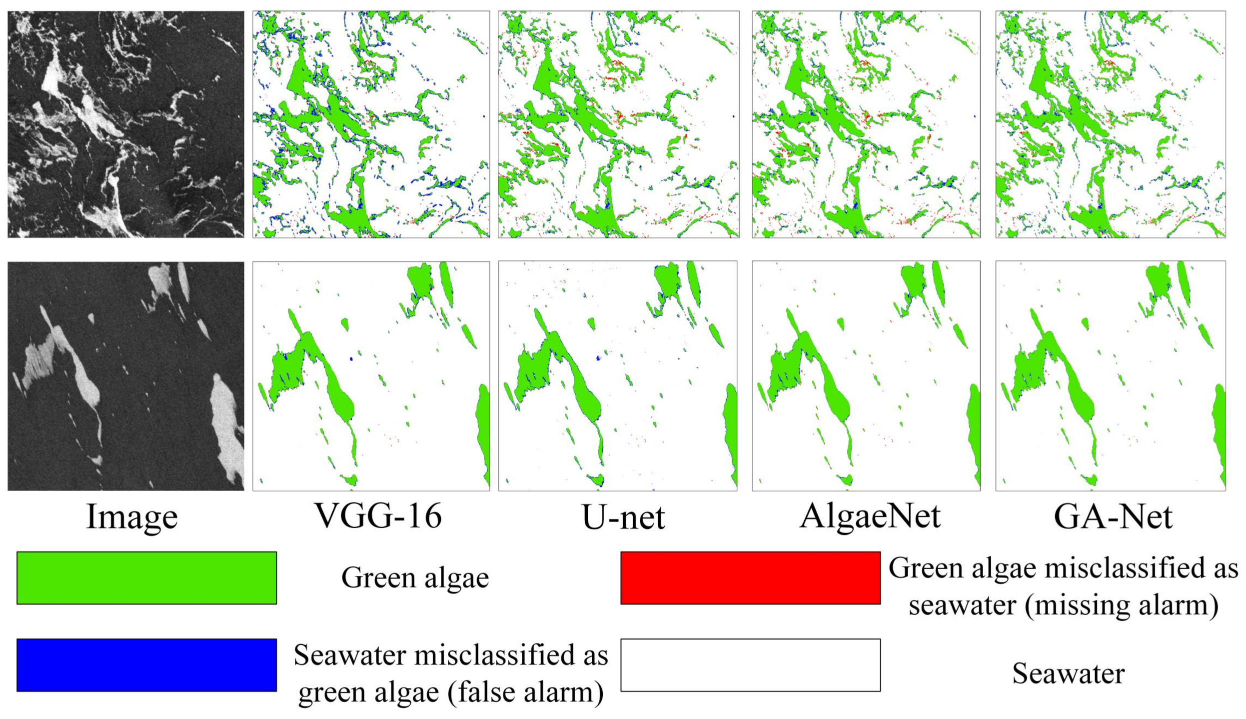

Figure 4. Green algae detection result in two typical scenarios.

Green tide interannual variations

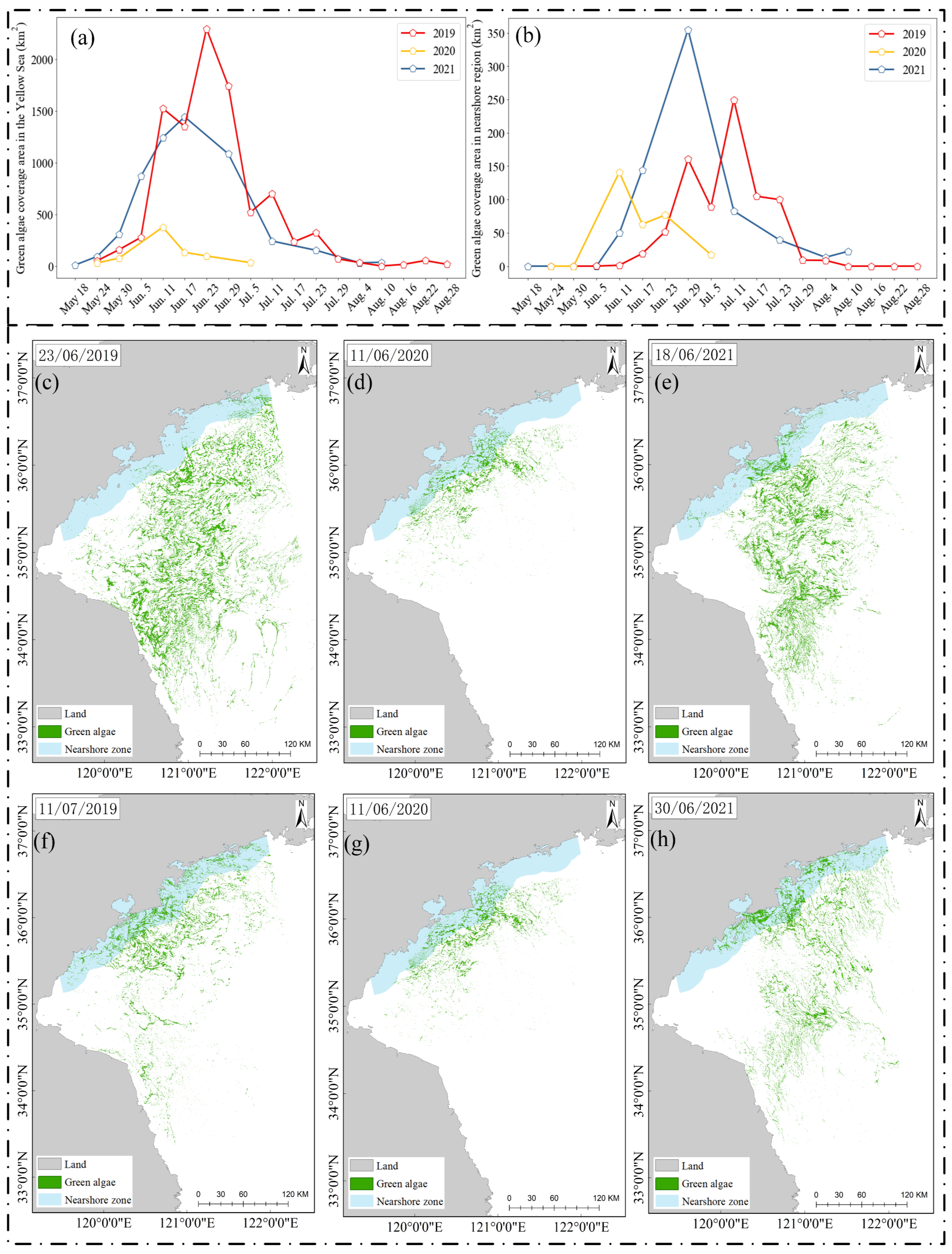

Figure 5. Coverage area in (a) Yellow Sea and (b) nearshore zone. (c)–(e) and (f)–(h) are algae distributions on the maximum coverage area day in the whole research area and the nearshore zone, respectively.

Environmental factors in algae-distributed regions

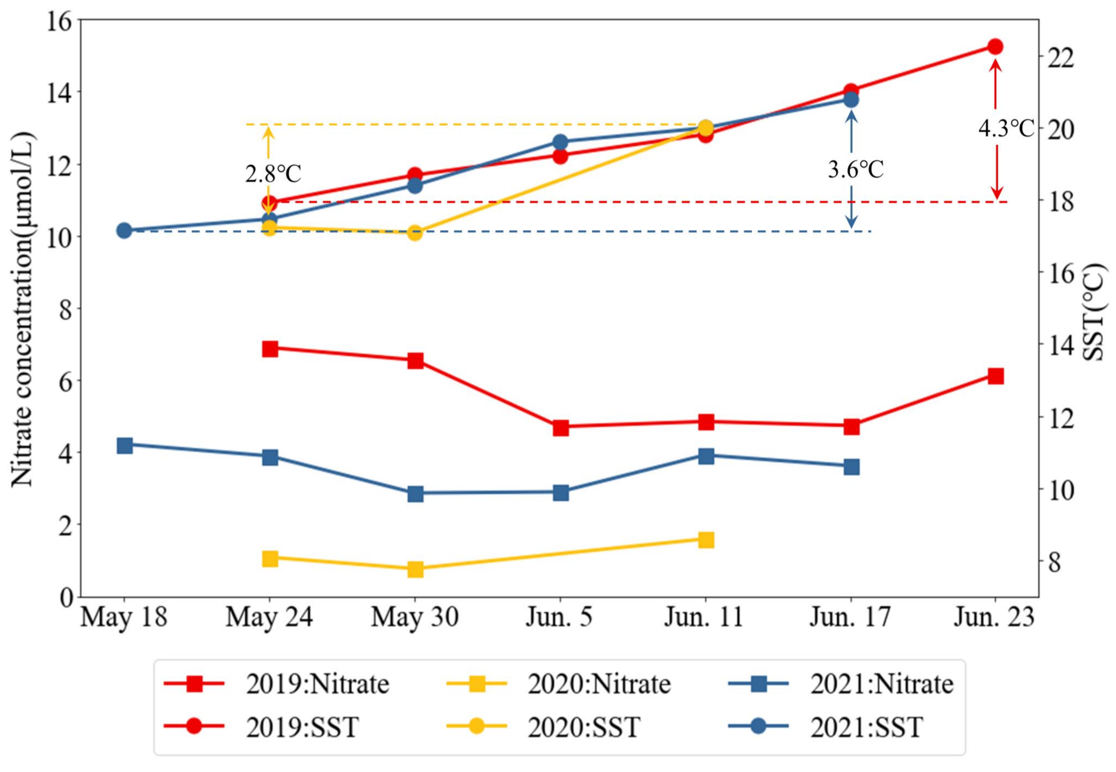

Figure 6. Mean nitrate concentration and mean SST in the green algae distributed regions during the algal-growth period. For the convenience of drawing, the images acquired time in 2021 are one day in advance.

Conclusions

- ✓ The proposed textual enhanced segmentation model can detect green algae more accurately.
- ✓ 2019 (2020) has the longest (shortest) bloom duration and biggest (smallest) coverage area.
- ✓ 2021(2020) has the biggest (smallest) nearshore damage to the southern coastlines of the Shandong Peninsula.
- ✓ The tendency of available nitrate concentration (variation of available SST) in the algae-distributed regions has the same trend as the maximum coverage area in 2019-2021.

References

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[2] Le Gao; Xiaofeng Li*; Fanzhou Kong; Rencheng Yu; Yuan Guo; Yibin Ren; AlgaeNet: A Deep-Learning Framework to Detect Floating Green Algae From Optical and SAR Imagery, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 2022, 15: 2782-2796

[3] Yuan Guo; Le Gao; Xiaofeng Li*; A Deep Learning Model for Green Algae Detection on SAR Images; IEEE Transactions on Geoscience and Remote Sensing,2022, 60: 4210914.