Remote Sensing Estimation for Aquacultural Algae Yield of Sea Area Based on Water Spectral Analysis

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Abstract. Mariculture yield estimation has an important significance in scientific planning and management of aquaculture scale. This study focused on the algae culture of sea area. The feasibility of constructing a remote sensing quantitative model for estimating the yield of algae culture was investigated through spectral characteristics analysis of sea water. Multi-source remote sensing data were used to analyse the spectral characteristics of sea water for coastal aquaculture. Low-pass filtering and threshold segmentation were used to classify algae culture areas. An estimation model was established based on trend yield and algae index for remote sensing quantitative estimation of the annual yield of algae culture. Results demonstrate that (1) the difference in spectral characteristics is mainly reflected in the blue-green band, the spectral reflectance of cultured shellfish is greater than that of cultured algae and the sensitive growth period is from February to April every year. (2) The total yield of algae culture estimated by counting the area of algae culture in Shandong Province is 520699 tons in 2019. This study shows the high accuracy and feasibility of remote sensing quantitative estimation model of algae culture yield.

1. Introduction

Fishery economy is an important component of marine economy. Mariculture dominates the marine fishery structure and has become the main driving force for the development of marine fishery economy in China. The large-scale development of mariculture has brought great economic benefits. However, the unreasonable distribution of mariculture will affect the production efficiency and ecological environment. Mariculture is widespread and distributed, and accurately determining the status of aquaculture by using the monitoring method of field investigation and measurement is difficult. Remote sensing technology can be used to quickly and accurately monitor and estimate mariculture yield in a large area scale. Accurate estimation of mariculture yield can effectively grasp the production status of mariculture, provide a basis for the adjustment of mariculture industrial structure, and assist the government to formulate reasonable aquaculture policies.

Many researchers have carried out research and experiments on the classification of aquaculture areas to estimate reliably the yield based on hyperspectral remote sensing data. Therefore, it is necessary to perform spectral processing on hyperspectral data to extract effective information. Common spectral processing methods include continuum removal method [1] and spectral derivative method [2]. At present, methods of extracting aquaculture area by remote sensing mainly include visual interpretation, feature index, texture feature, object oriented and deep learning methods [3-7]. No universality exists for the identification and classification of aquaculture areas due to the influence of factors, such as study...
area, time and data source. As such, analysis and research of the spectral characteristics of sea water for different aquacultures on time series and culture type is necessary for classifying algae culture areas.

Compared with the traditional method of yield estimation, remote sensing technology has the characteristics of time and cost saving and provides scientific and effective means for agricultural and fishery yield estimation. Many scholars have made abundant achievements on crop yield estimation [8]. In particular, a remote sensing crop yield estimation model was established based on vegetation index [9]. Quantitative models for predicting crop yield were established using different vegetation indices. However, few models are available for estimating mariculture yield. Estimating mariculture yield by remote sensing, especially with the use of a quantitative model, is of great significance and application value.

This study aims to analyse differences in the spectral curves of different aquaculture sea water. The algae culture area is classified by spectral difference. An estimation model of the yield per unit of algae culture is established to estimate the annual yield of algae culture.

2. Materials and Methods

2.1. Study area and data

The sea area of Shandong Province is distributed in the Bohai Sea and the Yellow Sea with large area and abundant resources. The Shandong sea area is rich in aquaculture types and has a wide range of aquaculture areas and is thus suitable for extraction and yield estimation of algae culture areas. According to the field investigation, the offshore of Yantai (121°7′49″~121°13′36″E, 37°39′20″~37°41′50″N) has an area of about 40km² (Fig.1), has many types of aquaculture seas and is fit for spectral analysis of sea water. Remote sensing data and fishery information used are shown in Table 1.

| Dataset       | Source                                      | Property                                      | Count | Time          | Application                                                                 |
|---------------|---------------------------------------------|-----------------------------------------------|-------|---------------|-----------------------------------------------------------------------------|
| Field data    | SVC HR-1024                                 | channels: 1024, spectrum: 350-2500nm.         | 40    | 2019.04.22    | Analysis of spectral characteristics of aquaculture water.                 |
| GF-5          | China Centre For Resources Satellite Data and Application | spatial resolution: 30m, revisiting period: 51days. | 1     | 2019.03.13    | Analysis of spectral characteristics of aquaculture water.                 |
| Landsat8-OLI  | USGS                                        | spatial resolution: 30m, channels: 8, revisiting period: 16days. | 39    | 2013.04.14    | Time series analysis of aquaculture sea, algae extraction and yield estimation. |
| Statistic data| China Fishery Statistical Yearbook           | Summary of fisheries: aquaculture area, annual yield | 6     | 2013-2018     | Statistics of total yield and area of algae culture in Shandong Province.  |

Fig.1 Offshore area of Yantai.
2.2. Spectral analysis method
Spectral analysis methods include continuum removal method, spectral derivative method and time-series analysis method. Continuum removal and spectral derivative processing can reduce the noise and background influence, so as to extract representative bands, and Normalised Difference Algae Index (NDAI) was constructed in the form of:

\[ \text{NDAI} = \frac{B_1 + B_2 - B_3}{B_1 + B_2 + B_3} \]  

where B1, B2 and B3 are the reflectance of representative bands. Time-series analysis method was used to evaluate time-series differences in different aquaculture types through continuous remote sensing observation in the study area.

2.3. Algae extraction method
Low-pass filtering and threshold segmentation were used to extract algae culture area due to the spectral characteristics of algae. Low-pass filtering adopts mean filtering method, which takes the average value of the target pixel and surrounding pixels and then replaces the target pixel to achieve filtering. After the mean filtering, the brightness of algae and seawater pixels will change accordingly. After subtraction from the original band image, the algae culture area can be extracted by threshold segmentation.

2.4. Yield estimation method
NDAI was constructed according to the spectral characteristics. The correlation between NDAI and unit yield was used to determine whether NDAI can be used as a construction factor. Annual trend yield was determined by time-series trend analysis and linear moving average methods. Trend yield represents the yield determined by the long-term social productivity development level of the study area and is the average of the annual simulated value obtained by linear moving average method. Least square linear regression method was used to construct an algae unit yield prediction model using the NDAI index and the trend yield factor. The form of the model is:

\[ y = a \cdot Y_t + b \cdot \text{NDAI} + c \]  

where y is the predicted unit yield; Yt is the trend yield; and a, b and c are the coefficients.

3. Results and Discussion

3.1. Spectral characteristic analysis
According to the location of the measured site, sample points were collected at the same location in the GF5 image. The spectral curve of the measured data and GF5 data was fitted (Fig. 2(a)). The calculated correlation coefficient was 0.9777, indicating that the GF5 data and the measured data were highly correlated. On the basis of the spectral curves obtained from GF5 data (Fig. 2(b)), the spectral curves of the three types of objects showed a trend of first rising and then falling. The peak reflectance of all three types of objects appeared between 500 and 600 nm and showed a sharp decline trend near 600 nm. Between 600nm and 750nm, the reflectance of shellfish was lower than that of seawater and algae. After 750nm, three reflectance curves were all tended to be the value of 0.

After the continuum removal, the absorption depth curve of GF5 data was obtained (Fig. 2(c)). All three objects had a trough near 800 nm, the difference in the near infrared band was the largest and peaks appeared between 800 and 900 nm. After performing first-order differential processing on the GF5 spectral data (Fig. 2(d)), the inflection point of the spectral curve was clearly found. The three curves coincided at the position of 0, indicating that the peaks of the spectral curves of the three objects were at the same wavelength. The minimum value of the first-order differential curve appeared near 600 nm, indicating that the spectral reflectance decreased fastest near 600 nm.

Combined with the spectral curve, absorption depth curve and first-order differential curve of GF5, it can be concluded that the peak reflectance of the three objects all appears near 560nm. The reflectance value drops rapidly near 600nm, and the minimum value of the first-order differential curve appears due
to the strong absorption of water in the near-infrared band. Between 600 and 750nm, the absorption intensity of shellfish is greater than that of seawater and algae, so the reflectance value of shellfish is the lowest. After 750nm, the absorption intensity of seawater is the highest, while that of algae is the lowest. However, after smoothing the GF5 reflectance curve and the strong absorption effect of water, the reflectance curves of the three objects are close and tend to the value of 0. Nonetheless, it can be seen from the spectral curve that the reflectance of algae is higher than that of seawater and shellfish.

NDAI can be constructed from the blue, green and near infrared bands through analysis of spectral characteristics:

$$NDAI = \frac{B + G - NIR}{B + G + NIR}$$

where B, G and NIR represent blue, green, and near infrared reflectance. Spectral curves of algae and shellfish were constructed by OLI image bands 2–5 (Fig. 2(a)). Although the reflectance was higher than that of GF5, the spectral characteristics were basically similar. Moreover, the revisit time of Landsat8 was shorter; thus, NDAI difference time series was constructed (Fig. 3). February, March and April were the months when algae and shellfish differed greatly from seawater. The difference between algae and seawater was greater than that between shellfish and seawater. In February, March and April, the difference between algae and seawater reached more than the value of 0.1. In other months, the difference was around the value of 0.05, and most of which were close to the value of 0.

Based on the analysis of spectral characteristics, the reflectance of the three kinds of objects all showed a trend of first rising and then falling. The maximum reflectance was reached in the green band. After 600 nm, the reflectance dropped rapidly, and the reflectance of the near-infrared band was close to the value of 0 due to the absorption of water. February to April were the months with the greatest difference in reflectance between algae and seawater. Thus, the optimum period for extraction and yield estimation of algae culture was determined.

![Fig.2](image1)

(a) Relationship between GF5 reflectance and field measured reflectance. (b) Spectral curve of sea water for aquaculture based on GF5 and OLI data. (c) Absorption depth curve of aquaculture sea water. (d) First-order differential curve of aquaculture sea water.
3.2. Algae yield estimation

3.2.1. Algae culture area extraction
The offshore water of Yantai was taken as the study area, and Landsat8-OLI data were used to classify algae culture areas by low-pass filtering and threshold segmentation. The difference between algae and seawater was great in blue-green band, and the peak band appeared on the green band. Thus, the green band was selected for extraction of algae culture area based on Landsat8-OLI image. The original image in the green band was subtracted from the mean filtered image. After difference processing, the brightness values of the algae culture area and seawater were significantly different. As such, the algae culture area was extracted by setting the threshold (Figure 4). A small amount of noise was found in the extracted results. The accuracy of the classification results was evaluated using the generated random points, and the classification accuracy reached 79%. Given that the difference in the spectrum of shellfish and algae was not obvious, the shellfish culture area may be inaccurately extracted in the result, thereby affecting the classification accuracy.

3.2.2. Yield estimation
Shandong’s fishery economy is developing rapidly, and the yield of algae culture ranks among the top in China. A quantitative model was constructed using Landsat8-OLI data to estimate algae yield in Shandong Province.

The regression analysis of NDAI and unit yield showed that the correlation coefficient between NDAI and unit yield was 0.94. The high correlation between the two parameters indicated that NDAI was suitable to be used as the factor of the unit yield estimation model. The annual total yield and annual total culture area of algae in Shandong province in recent years were obtained from the Fishery Statistical Yearbook, and the unit yield of algae was calculated. Given that February–April was the sensitive growth period of algae every year, the sample points of the algae culture area on the image...
from this period were selected. The mean NDAI value of the sample points was calculated and used for yield estimation.

Estimation of the total yield of algae culture required estimation of the area of algae culture and the yield per unit in 2019. The algae culture area in Shandong Province was extracted, and the total area of algae culture in Shandong Province was 18861.21 ha. The estimation of algae yield per unit in 2019 was modelled using least square method based on data from 2013 to 2018. The estimation model for 2019 was as follows:

\[ y = 0.9392 \times Y_t + 1.37553 \times \text{NDAI} - 1.0267 \]  

(4)

The mean value of NDAI in 2019 was 0.5223, and the unit yield of 2019 obtained by linear regression was 27.5359 tons/ha as the trend yield. Thus, the unit yield of algae culture estimated in 2019 was 27.6069 tons/ha. The total area of algae culture in Shandong province in 2019 was 18861.21 hectares. The total yield of algae culture in 2019 can be calculated as 520699.5383 tons.

In order to test the reliability of the modelling approach, the model was built with a certain 5-year data as the sample and the remaining 1-year data were used as the verification data due to the small sample size. The data from 2013 to 2018 were used for verification respectively, and the data of other years were used to establish a yield estimation model (Table 2). In general, the R² of each estimation model is above 0.95, which indicates that the model has a high fitting degree. Compared with the verification relative error of each year, the relative error in 2017 was the largest (12.02%) and the relative error in 2018 was the smallest (0.73%). The relative error gap was large, which may be related to the calculation of NDAI. The calculated mean value of NDAI was affected because the area extracted by algae was not accurate, leading to a large error in the estimation of unit yield. According to the statistical data of algae culture (Table 3), the annual yield of algae continued to increase from 2013 to 2016, and suddenly decreased in 2017, but the total area reached the maximum in 2017, which led to a significant decrease in the yield per unit in 2017, resulting in a relatively large error in 2017. At the same time, according to the scatter distribution of NDAI and unit yield, the distance between the points and the fitting line is far in 2017 and 2013, so it can be concluded that the relative error is large in these two years. Moreover, data adopted in the model were small, thereby affecting the accuracy of the model estimation. The constructed remote sensing estimation model was applied to estimate the unit yield of algae culture. The average error of the obtained results was 5.96%, which proved the reliability of the model. The algae culture area in Shandong province is widely distributed. If the algae yield is estimated in a small area, the precision of the model may be improved greatly.

Table 2  Algae yield estimation model.

| Data Set | (year) | Estimation model | 𝑅² | Statistical result (tons/ha) | Estimation results (tons/ha) | Relative error |
|----------|--------|------------------|-----|-----------------------------|-----------------------------|---------------|
| 2014-2018 | 2013   | \( y = 1.05274Y_t - 1.06308\text{NDAI} - 1.04879 \) | 0.979 | 34.2051 | 37.6317 | 10.02% |
| 2013, 2015-2018 | 2014   | \( y = 1.00903Y_t + 0.50429\text{NDAI} - 0.66678 \) | 0.978 | 33.4402 | 32.1504 | 3.86% |
| 2013-2014, 2016-2018 | 2015   | \( y = 1.07204Y_t - 2.87951\text{NDAI} - 0.37365 \) | 0.952 | 31.8110 | 31.0660 | 2.34% |
| 2013-2015, 2017-2018 | 2016   | \( y = 0.78499Y_t + 8.04988\text{NDAI} + 1.2858 \) | 0.966 | 29.9207 | 27.8987 | 6.76% |
| 2013-2016, 2018 | 2017   | \( y = 1.23728Y_t - 5.54934\text{NDAI} - 3.89701 \) | 0.996 | 24.3297 | 27.2528 | 12.02% |
| 2013-2017 | 2018   | \( y = 1.27481Y_t - 7.28022\text{NDAI} - 3.88866 \) | 0.988 | 26.2595 | 26.0669 | 0.73% |

Table 3  Statistical data of algae culture in Shandong Province

| Year | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|------|------|------|------|------|------|------|
| Total yield (tons) | 588944 | 662784 | 665677 | 673036 | 659286 | 665310 |
| Total area (ha) | 17218 | 19820 | 20926 | 22494 | 27098 | 25336 |
| Unit yield (tons/ha) | 34.2051 | 33.4402 | 31.8110 | 29.9207 | 24.3297 | 26.2595 |
4. Conclusion
In this study, the difference in spectral reflectance between algae and shellfish was analysed through spectral processing of sea water and used to establish algae index NDAI. The sensitive growth period from February to April was determined using the algae index time series. Low-pass filtering and threshold segmentation were used to classify algae culture area. The yield estimation model based on trend yield and NDAI index was established, and the actual statistical results was small. This finding proved the feasibility of remote sensing technology for the estimation of algae culture. Therefore, multi-source remote sensing data have strong application potential for classification of algae culture area and estimation of algae culture yield.

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