An estimation of chlorophyll-a concentration using Landat-8/OLI data in Hiroshima Bay

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Abstract**:** *Hiroshima Bay in Hiroshima Prefecture is a very famous place for oyster farming. In oyster farming, it is very important to correctly grasp marine information such as chlorophyll-a (Chl.a) concentrations and seawater temperatures etc. Previously, we examined a method for estimating Chl.a concentrations using the linear combination index (LCI) of Robert Frouin et al. (2006) using Landsat-8/OLI data observed in the Uwa Sea of Uwajima City and Utsumi inland sea of Ainan Town in Ehime Prefecture. These places are very famous places for the birthplace of a perfect circle pearl. As by an oyster farming, it was very important for a pearl farming to grasp marine information correctly of the Chl.a concentrations and the seawater temperatures etc. Therefore, we applied the previously developed method for estimating Chl.a concentrations to Landsat-8/OLI data observed in Hiroshima Bay. As a result of investigating the correlation between the estimated Chl.a concentrations computed from Landsat-8/OLI and surveyed Chl.a concentrations by the Japan Coast Guard, the coefficients and the exponents of the estimate Equation in Hiroshima Bay weren't that different from those of previously developed in Uwa Sea. The Chl.a concentrations of the Hiroshima Bay approximately from 1 through 4 (mg/m^3), the higher Chl.a concentrations were indicated near the estuary of the river, and the lower Chl.a concentrations were indicated the offshore. Moreover, the good estimation sites of the errors of Chl.a concentrations within 0.5 (mg/m^3) were located the shadows of islands and offshore with loose currents etc. On the other hand, the poor estimation sites of the errors of Chl.a concentrations over 0.5 (mg/m^3) were located near the estuary of the river, the ship routs, and the fast currents etc. And the maximum error of about 4.0 (mg/m^3) had occurred at site on the ship routs.*

Keywords: Linear combination index, Visible, Near infrared, Bio-optical model

Introduction

Hiroshima Prefecture in Japan are very famous places for oyster farming, and the account is about 20,000 ton/year of about 60% of Japan's oyster production. The oysters are farmed and produced mainly Hiroshima Bay located around of Hiroshima City of Hiroshima Prefecture. By an oyster farming, it is very important to grasp marine information correctly of the Seawater Temperatures and Chlorophyll-a (Chl.a) concentrations etc. Especially, the nutrients information such as the Chl.a concentrations are very important in the marine information in oyster farming. On the other hand, there are various methods for the Chl.a analysis using satellite data. Here, it is well known that the estimating method of the Chl.a concentrations via the linear combination index (LCI) proposed by Robert Frouin et al. (2006) can mitigate the atmospheric influence on some extent (Sakuno, 2013, Oguro, 2021). Previously, we have been studied an estimation method of the Chl.a concentrations for the Landsat-8/OLI data observed in the Uwa Sea of Uwajima City and the Utsumi inland sea in Aina Town of Ehime Prefecture in Japan where are very famous places for the birthplace of a perfect circle pearl (Oguro, 2022). From the above, we will apply the previously developed method for estimating Chl.a concentrations to Landsat-8/OLI data observed in Hiroshima Bay, and we will investigate the effects of differences of sea in the precise of estimation in this study.

Background

Here, we introduce the LCI proposed by Robert Frouin et al. (2006), and the estimating method of the Chl.a concentrations via LCI for four-bands combination by Oguro et al. (2022).

a. LCI:

The LCI proposed by Robert Frouin (2006) is defined as the sum of the three or four bands of the aerosol reflectance $R_a(\lambda_i)$ and the water reflectance $R_w(\lambda_i)$ as follows:

$$\mathrm{LCI} = \sum_{i=1}^{k} a_i R_a(\lambda_i) + \sum_{i=1}^{k} a_i R_w(\lambda_i)\,, \tag{1}$$

where to eliminate most of the atmospheric influence on the LCI, we approximate the aerosol reflectance $R_a(\lambda_i)$ as a function of wavelength λ_i and set the sum of $a_iR_a(\lambda_i)$ to zero. That is, the sum of $a_iR_a(\lambda_i)$ on the first term of Eq. (1) replaces as follows:

$$\sum_{i=1}^{k} a_i R_a(\lambda_i) \approx \sum_{i=1}^{k} a_i \lambda_i^{\eta_j} = 0. \tag{2}$$

Consequently, the LCI of Eq. (1) is rewritten as follows:

$$\mathrm{LCI} \approx \sum_{i=1}^{k} a_i R_w(\lambda_i). \tag{3}$$

In additions Eq. (2) and Eq. (3) were solved by the following four steps procedure.

Step 1: From our previous studies (Oguro, 2021), we fixed to the four-bands combination (k=4) in the following analysis, the wavelength λ_i are assumed the following Landsa-8/OLI bands: band 1 (443 nm) which is the absorption band of the Chl.a, band 2 (483 nm) which is the absorption band of the Chl.b, band 3 (561 nm) which is a non-absorption band of the Chl.a and the Chl.b, and band 5 (864 nm) which is the indicating aerosol effect.

Step 2: We approximated the exponent η_j in Eq.(2) with the normalized reflectance of sand, clouds and water. For sand, we measured 20 sites reflectance from the Landsat-8/OLI data at the school ground on fine day. And for water, we measured 20 sites reflectance from the Landsat-8/OLI data over the sea on fine day. After that, the measured sand and water reflectance were divided by the maximum value of that reflectance to obtain the normalized reflectance, respectively. On the other hand, we assumed a perfect white cloud and assumed the normalized reflectance of 1.0 regardless of wavelength since it is difficult to determine the normalized reflectance of clouds. Here, the normalized reflectance of sand, clouds and water in the case of four-bands combination 1, 2, 3 and 5 were shown in Figure 1.

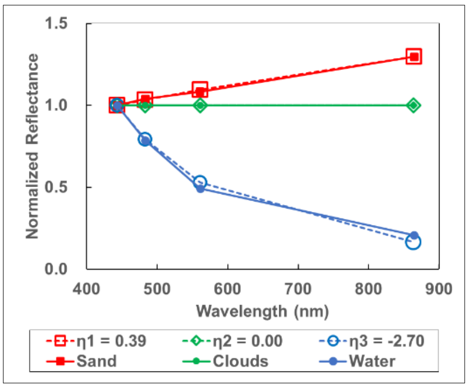


Figure 1: Normalized Reflectance of Sand, Clouds and Water in the case of Four-bands Combination 1, 2, 3 and 5.

Step 3: For the easier calculation, the coefficient a_1 of the shortest wavelength band was fixed to 1, and the remaining coefficients of a_2, a_3 and a_5 were solved by the simultaneous linear equation. The Eq. (4) showed the case of bands combination of 1, 2, 3 and 5 for η_1=0.39 (sand), η_2=0.00 (clouds) and η_3=-2.70 (water).

$$\begin{cases} a_1\lambda_1^{0.39} + a_2\lambda_2^{0.39} + a_3\lambda_3^{0.39} + a_5\lambda_5^{0.39} = 0, \\ a_1\lambda_1^{0.00} + a_2\lambda_2^{0.00} + a_3\lambda_3^{0.00} + a_5\lambda_5^{0.00} = 0, \\ a_1\lambda_1^{-2.70} + a_2\lambda_2^{-2.70} + a_3\lambda_3^{-2.70} + a_5\lambda_5^{-2.70} = 0, \end{cases} \quad (4)$$

where the coefficient a_2, a_3 and a_5 were solved as -1.969193, 1.098359 and 0.129166, respectively.

Step 4: The LCI of Eq. (3) was solved as Eq. (5) in the case of four-bands combination of 1, 2, 3 and 5.

$$LCI \approx R_w(\lambda_1) - 1.969193R_w(\lambda_2) + 1.098359R_w(\lambda_3) - 0.129166R_w(\lambda_5). \quad (5)$$

b. Chl.a concentrations via LCI:

In the area around of the Uwa Sea of Uwajima City and the Utsumi inland sea in Aina Town of Ehime Prefecture in Japan, we compared the LCI in the case of four-bands combination 1, 2, 3 and 5 calculated from Landsat-8/OLI data observed in 2017, and the Chl.a concentration based on the water quality survey (at 0 m depth) measured in 2017. After that, the relation between calculated LCI and survey Chl.a concentration was approximated by exponential function, and we obtained the Chl.a estimation formula of that was shown in Eq. (6). Here, the resulted coefficients of determination R^2 were very low as 0.4187 since the range of the Chl.a concentrations based on the water quality survey was very narrow from 0.37 through 1.33 (mg/m^3).

$$Chl.a \approx 2.1728\ exp(130.1658\ LCI). \quad (6)$$

Therefore, the estimation formula of the Landsat-8/OLI data was modified so that it can correspond to a wide range from 0.1 through 10 mg/m^3 of the Chl.a concentrations using a simulation with the Bio-optical Model proposed by Andre Morel et al. (1988 and 2001). And we obtained the Chl.a estimation formulas of that was shown in Eq. (7). Here, the resulted coefficients of determination R^2 were very high as 0.9949.

$$Chl.a \approx 2.1118\,exp(137.8077\,LCI). \tag{7}$$

Finally, the relation between the LCI in the case of four-bands combination 1, 2, 3 and 5 calculated from Landsat-8/OLI data observed in 2017 and the survey Chl.a concentrations in 2017, and that between the simulated LCI and the simulated Chl.a concentration with the Bio-optical Model were shown in Figure 2.

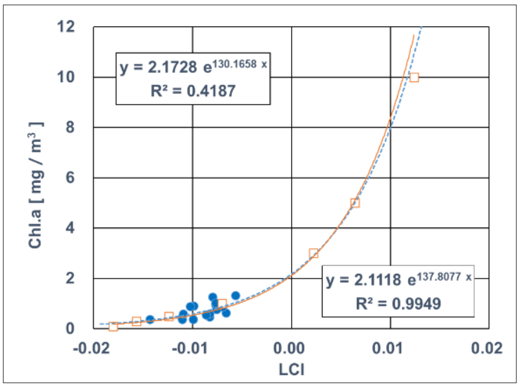
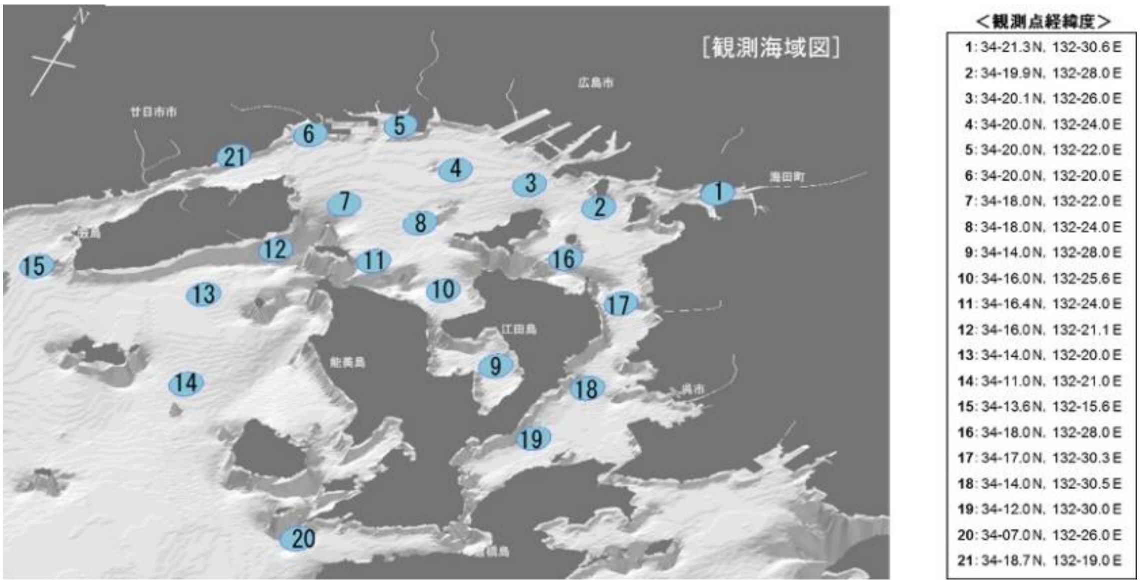


Figure 2: Relation between the LCI and Chl.a concentrations in the case of four-bands combination 1, 2, 3 and 5 by the Landsat-8/OLI data (survey) and the Bio-optical Model (simulation).

Methodology

In here, we will apply the previously developed method for estimating Chl.a concentrations to Landsat-8/OLI data observed in Hiroshima Bay, and we will investigate the effects of differences of place in the precise of estimation. As a satellite data, we used the Landsat-8/OLI data observed over the Hiroshima Prefecture (Path-Row: 112-036) on 11 May in 2023 was used to compute the LCI. The used true-color image was shown in Figure 3. On the other hand, as a reference value of the Chl.a concentration (mg/m^3) at 0 m depth, we used the Hiroshima Bay Environmental Conservation Survey Results in June 2023 measured by 6th Regional Coast Guard Headquarters of the Japan Coast Guard (JCG) on 29 through 31 May in 2023. Figure 3 shows the observations of the Chl.a concentrations (mg/m^3) at 2 m depth and the transparency (m) at 21 sites in Hiroshima Bay measured by the JCG on 29-31 May in 2023. The observations (29 through 31 May 2023) of the chlorophyll-a concentrations (mg/m^3) at 2 m depth and the transparency (m) at 21 sites in Hiroshima Bay measured by the JCG were shown in Figure 4.

Figure 3: The true-color image (R, G, B: 4, 3, 2) of Landssat-8 data (11 May 2023) in Hiroshima Bay (UL: 34 28 N, 132 11 E, LR: 34 06 N, 132 40 E).



(a) Locations (Latitudes and Longitudes) of 21 sites in Hiroshima Bay

(b) Chlorophyll-a Concentration at 2 m depth

(c) Transparency (m)

Source: 6th Regional Coast Guard Headquarters of the Japan Coast Guard

Figure 4: The observations (29 through 31 May 2023) of the chlorophyll-a concentrations (mg/m^3) at 2 m depth and the transparency (m) at 21 sites in Hiroshima Bay measured by the JCG.

Results and Discussion

a. Measured 21 sites:

Firstly, at 21 sites in Hiroshima Bay, we compared the observed Chl.a concentrations (mg/m^3) at 0 m depth measured by the JCG (29-31 May 2023) and the estimated Chl.a concentrations (mg/m^3) in Eq. (6) and Eq. (7) computed from Landsat-8/OLI data (11 May 2023). The comparison's results were shown in Figure 5 and detailed values were shown in Table 1. From the Figure 5, at the sites 4, 11, 14, 15, 17 through 21 had good estimation as the errors of Chl.a concentrations were within 0.5 (mg/m3). Those good estimation sites were located the shadows of islands and offshore with loose currents etc. On the other hand, the sites 1 through 3, 5 through 10, 12, 13, 16 had poor estimation as the errors of Chl.a concentrations were over 0.5 (mg/m^3). Those poor estimation sites were located near the estuary of the river, the ship routs, and the fast currents etc. The maximum error of about 4.0 (mg/m^3) had occurred at site 2 on the ship routs. It is important to note that the observation day of the analyzed satellite data was on 11 May 2023 are different from that of the survey results at 0 m depth by JCG were on 29 through 31 May in 2023. Here, since the Chl.a concentrations are stable in places with loose currents, there was not much adverse effect on the observation day. On the other hand, in places with fast currents, the Chl.a concentrations of the sea surface layer are particularly unstable, so it was susceptible to adverse effects of the observation date.

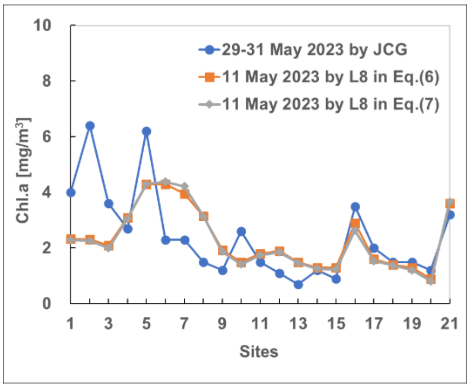


Figure 5: The observed Chl.a concentrations (mg/m^3) at 0 m depth measured by the JCG (29 through 31 May 2023) and the estimated Chl.a concentrations (mg/m^3) computed from Landsat-8/OLI data (11 May 2023) at 21 sites in Hiroshima Bay.

Table 1: The observed Chl.a concentrations (mg/m3) at 0 m depth measured by the JCG (29 through 31 May 2023), computed LCI by Landsat-8/OLI data, and the estimated Chl.a concentrations (mg/m3) in Eq. (6) and Eq. (7) by Landsat-8/OLI data (11 May 2023) at 21 sites in Hiroshima Bay.

Site	**Chl.a of JCG at 0 m depth**	**LCI of L8**	**Chl.a of L8 in Eq. (6)**	**Chl.a of L8 in Eq. (7)**
1	4.0	0.00056330	2.34	2.29
2	6.4	0.00048769	2.32	2.27
3	3.6	-0.00041378	2.10	2.00
4	2.7	0.00266262	3.10	3.05
5	6.2	0.00515573	4.30	4.30
6	2.3	0.00529566	4.30	4.38
7	2.3	0.00502028	3.95	4.22
8	1.5	0.00286558	3.15	3.14
9	1.2	-0.00090801	1.93	1.87
10	2.6	-0.00292220	1.50	1.42
11	1.5	-0.00141432	1.81	1.75
12	1.1	-0.00097754	1.90	1.85
13	0.7	-0.00270285	1.50	1.46
14	1.2	-0.00380501	1.30	1.26
15	0.9	-0.00394706	1.30	1.23
16	3.5	0.00159034	2.90	2.64
17	2.0	-0.00234615	1.60	1.54
18	1.5	-0.00313853	1.40	1.38
19	1.5	-0.00406230	1.30	1.21
20	1.2	-0.00702139	0.90	0.81
21	3.2	0.00397145	3.60	3.65
mean	2.43	-0.00028793	2.31	2.27
S.D.	1.56	0.00340347	1.03	1.08

Source: Chl.a at 0 m depth by 6th Regional Coast Guard Headquarters of the JCG

Secondly, at 21 sites in Hiroshima Bay, we analyzed the LCIs calculated from Landsat-8/OLI data (11 May 2023) and the Chl.a concentrations (mg/m^3) at 0 m depth measured by the JCG (29-31 May 2023). After that, the relation between calculated LCI and measured Chl.a concentration was approximated by exponential function as shown in Figure 6, and we obtained the Chl.a estimation formula of that was shown in Eq. (8).

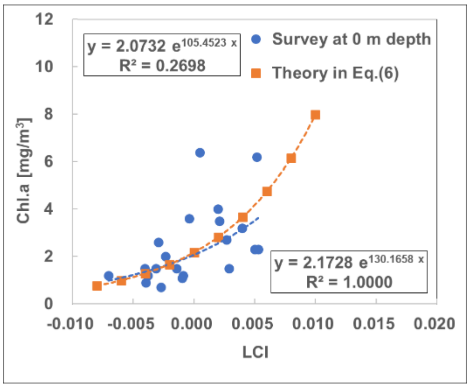


Figure 6: The relation between the LCIs and Chl.a concentrations (mg/m^3) for the survey at 0 m depth by the JCG (29 through 31 May 2023) and the estimation from Landssat-8 data (11 May 2023) at 21 sites in Hiroshima Bay.

$$Chl.a \approx 2.0732\,exp(105.4523\,LCI). \qquad (8)$$

Here, the resulted coefficients of determination R^2 were very low as 0.2698 since the measured day was not a fully simultaneous observation with the analyzed Landsat-8/OLI data. On the other hand, the coefficients and the exponents of Eq. (8) weren't that different from Eq. (6) and Eq. (7).

b. Whole area of Hiroshima Bay:

From the Landsat-8/OLI data (11 May 2023), we made the Chl.a concentrations image as shown in Figure 7. The colors were assigned spectral colors on a logarithmic scale. From the Figure 7, it was confirmed that the Chl.a concentrations of the Hiroshima Bay approximately from 1 through 4 (mg/m^3). The higher Chl.a concentrations were indicated near the estuary of the river, and the lower ones were indicated the offshore.

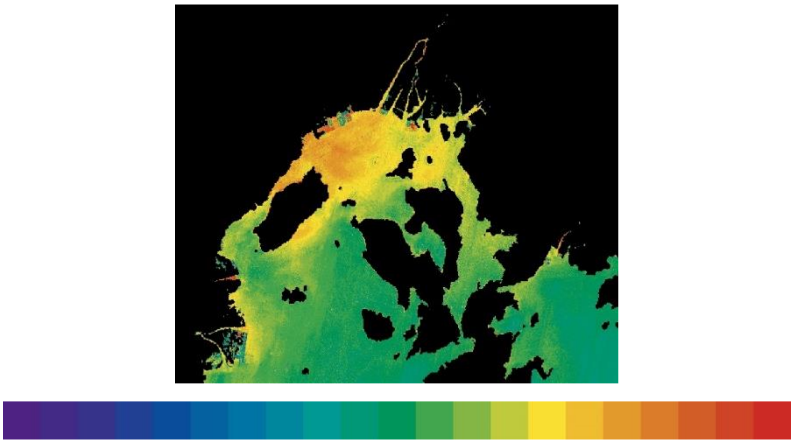


Figure 7: The estimated chlorophyll-a concentration (mg/m^3) computed from Landssat-8 data (11 May 2023) in Hiroshima Bay (UL: 34 28 N, 132 11 E, LR: 34 06 N, 132 40 E).

Conclusion and Recommendation

In this paper, we applied the method previously developed in Uwa Sea for estimating Chl.a concentrations to Landsat-8/OLI data observed in Hiroshima Bay, and we investigated the effects of differences of sea in the precise of estimation in this study. From the above-mentioned analysis, it was clarified that the following:

- The good estimation sites of the errors of Chl.a concentrations within 0.5 (mg/m3) were located the shadows of islands and offshore with loose currents etc.
- The poor estimation sites of the errors of Chl.a concentrations over 0.5 (mg/m^3) were located near the estuary of the river, the ship routs, and the fast currents etc. And the maximum error of about 4.0 (mg/m^3) had occurred at site on the ship routs.
- The coefficients and the exponents of the estimate Equation in Hiroshima Bay weren't that different from those of previously developed in Uwa Sea.
- The Chl.a concentrations of the Hiroshima Bay approximately from 1 through 4 (mg/m^3). And the higher Chl.a concentrations were indicated near the estuary of the river, and the lower Chl.a concentrations were indicated the offshore.

In this analysis, we used as the reference value of the Chl.a concentration (mg/m^3) at 0 m depth by the Hiroshima Bay Environmental Conservation Survey Results, it was not a fully simultaneous observation with the analyzed Landsat-8/OLI data. As the future works, we will perform the measurement of Chl.a concentrations simultaneously with a satellite observation and we will verify this analysis.

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