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Application study of red tide monitoring to desalination plants using chollian (COMS)

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ABSTRACT

Chollian (Communication, Ocean, and Meteorological Satellite (COMS)) is a geostationary satellite developed jointly by the Ministry of Land, Infrastructure, and Transport (MOLIT), the Ministry of Education (MOE), the Korea Communications Commission (KCC), and the Korea Meteorological Administration (KMA). Chollian serves not only as communications and weather satellites but also as a marine observation satellite capable of detecting ocean surface 8 times a day with Geostationary Ocean Color Imager (GOCI). Most of the recent desalination plants use Seawater Reverse Osmosis (SWRO) process, and chlorine cannot be used because the RO membrane in the main SWRO process is made of polyamide (PA). Therefore, it is very vulnerable to biofouling due to the influence of red algae and marine micro-organisms contained in seawater. This study aimed to evaluate the applicability of the "red tide monitoring system" capable of detecting and preventing the influx of red algae adversely affecting operation and maintenance (O & M) of desalination plants using Chollian in advance. The analysis was performed on Gwangyang Bay in the South Sea, South Korea with desalination plants. According to the results, the chlorophyll-a concentration in the observed values of the Ocean Color Imager was highly correlated with Cochlodinium polykrikoides concentration of the experimental values in the analysis of water sampled from a boat at approximately 95% reliability (R^2).

Keywords: Geostationary ocean color imager; Red tide; Desalination; Reverse osmosis

1. Introduction

Global marine observation satellites can include the SeaStar satellite (1997, dedicated S/W entitled SeaDAS) of the National Aeronautics and Space Administration (NASA), the ADEOS (Advanced Earth Observing Satellite) (1996, dedicated S/W entitled SeaDAS) of the National Space Development Agency of Japan(NASDA), and Envisat (Environmental Satellite) of the European Space Agency (ESA) (1992, dedicated S/W entitled BEAM). Most global marine observation satellites can detect the same site once one to several

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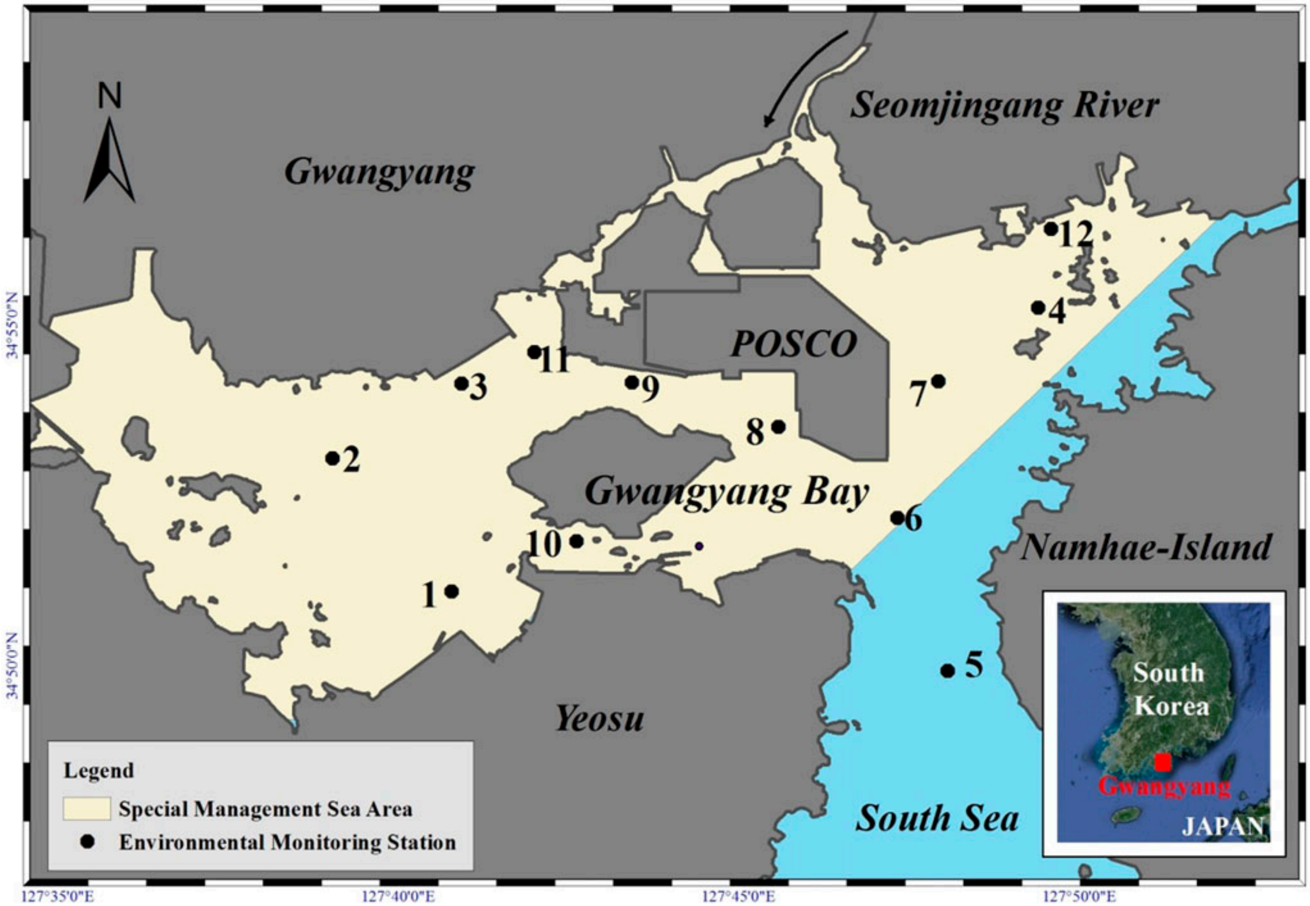


Fig. 1. Distribution map of EMSs for measuring water quality of Gwangyang Bay (12 sites).
Source: Map data ©2014 Google (South Korea map).

Table 1
Annual changes in chlorophyll-a concentration at the No. 7 EMS (Unit: μg/L)

Month	Units	2012 year	2013 year	2014 year	Average
February	μg/L	4.46	12.23	8.16	8.28
May	μg/L	5.36	1.16	2.78	3.10
August	μg/L	12.35	3.34	2.55	6.08
November	μg/L	3.01	2.18	0.06	1.75
Average	μg/L	6.30	4.73	3.39	

days because they are operated in a "polar" orbit. In addition, it is unsuitable to use them for observing small-scale red algae tides of less than 1 km because they have low spatial resolution with 1 km class.

The South Korean government launched Chollian, which is the world's first marine observation satellite capable of detecting ocean surface in a "geostationary orbit" and developed jointly by the Ministry of Land, Infrastructure and Transport (MOLIT), the Ministry of Education (MOE), the Korea Communications Commission (KCC), and the Korea Meteorological Administration (KMA). It serves not only as communications and weather satellites but also as a marine observation satellite and has provided satellite imagery information through the Korea Institute of Ocean Science & Technology (KIOST) and the Korea Ocean Satellite Center (KOSC) since 2011.

Geostationary Ocean Color Imager (GOCI) detects ocean surface "2,500 × 2,500 km" area centered on Korean Peninsula at 500 m spatial resolution 8 times a

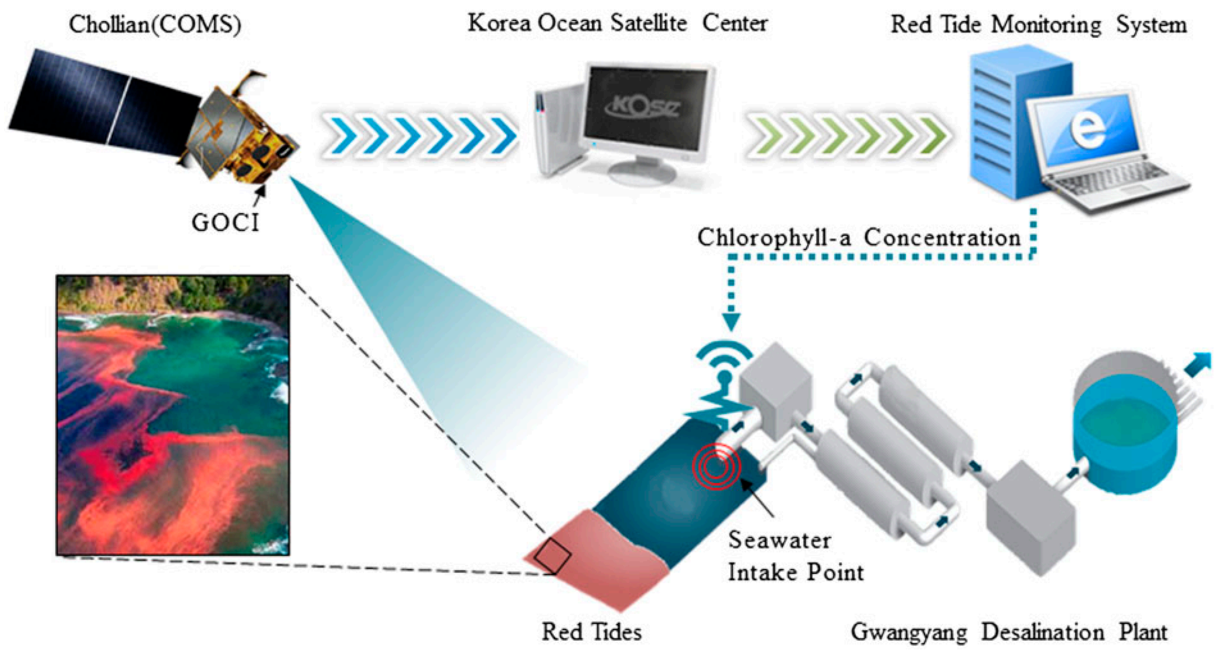


Fig. 2. FTP push server system for observing red tides to receive GOCI images.

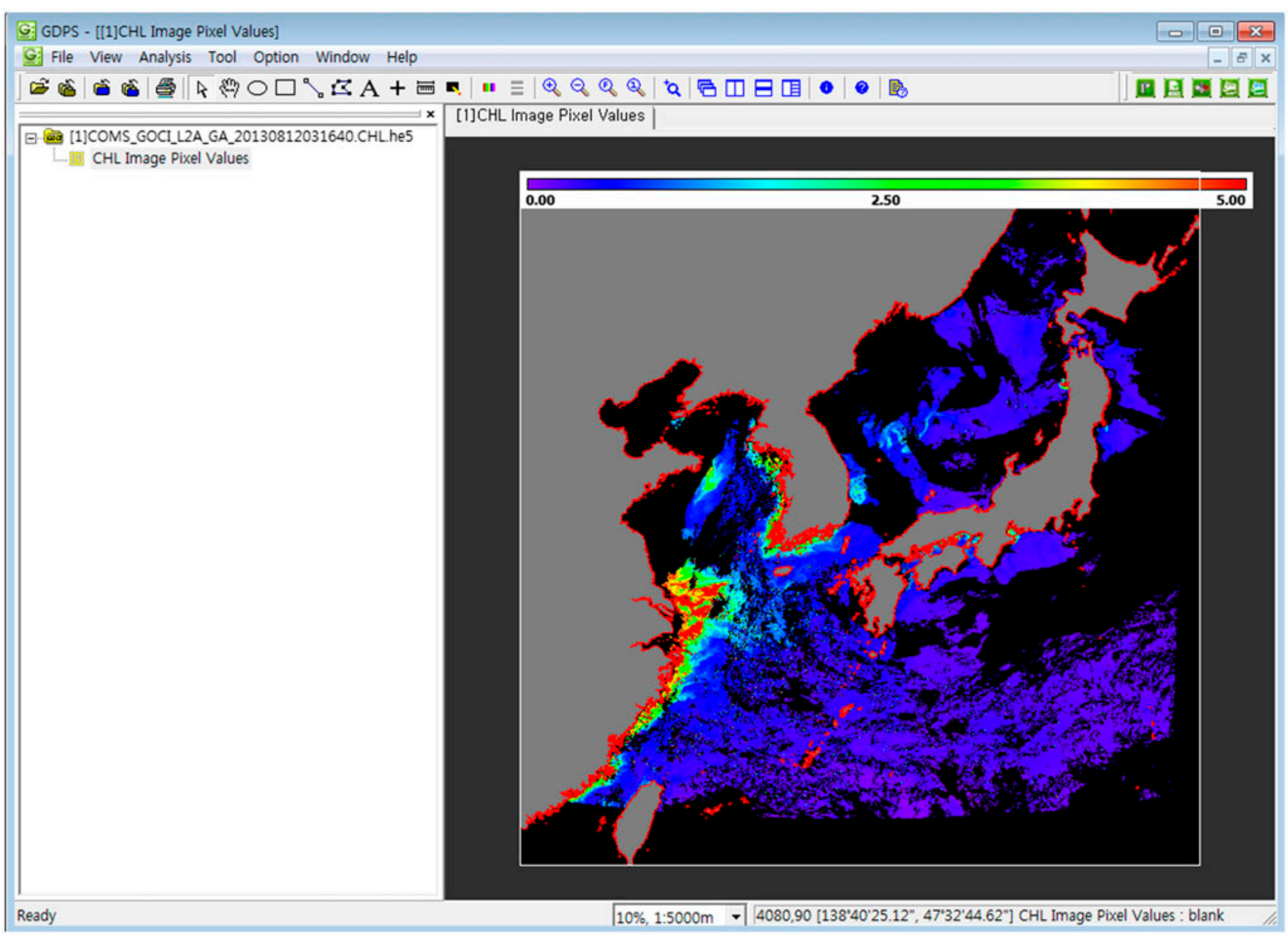
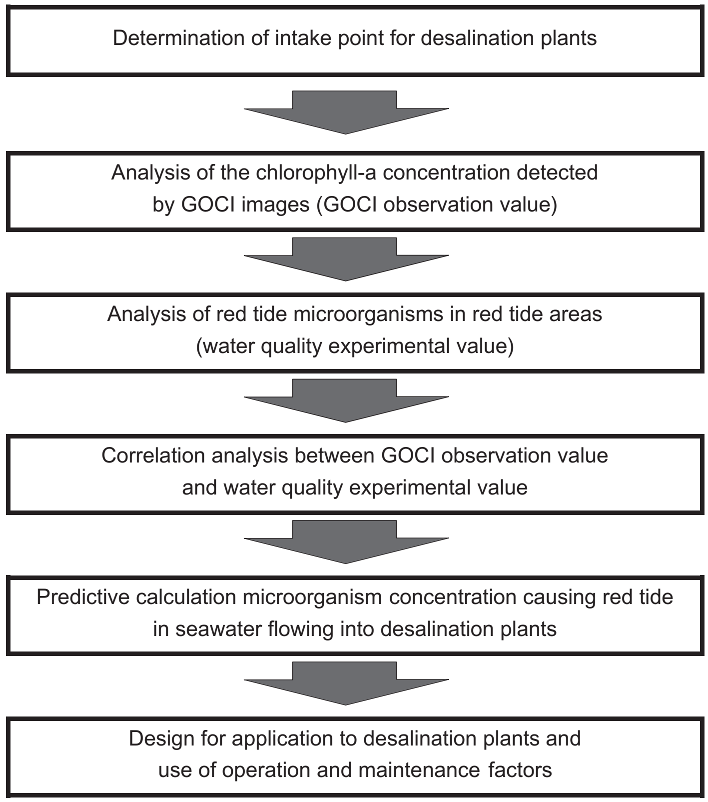


Fig. 3. Execusion result screen of chlorophyll-a concentration analyzed by GDPS software.
Source: Map data ©2014 Ministry of Ocean and Fisheries, Republic of Korea (Coast Line Status Map).

Table 2
Analysis of applicability of desalination using GOCI images



day during the daytime. It is the most appropriate marine observation satellite to detect the occurrence and movement of red tides because it detects the chlorophyll-a concentration and divides red tides by examining and interpreting the optical properties of seawater [1–4].

It is difficult to detect signals from red tide occurrence in Gwangyang Bay designated as a "Special Management Sea Area" due to the influence of suspended solids and soluble organic matters in seawater because the analysis algorithm of the chlorophyll-a was developed with a focus on clear sea areas.

On the other hand, marine pollution has been accelerated by problems such as global climate change, global warming, and industrialization, and red tides have occurred more frequently. Moreover, Gwangyang Bay in the South Sea where Korean desalination plants are located in is a "semi-enclosed bay" located between the Yeosu Peninsula and Namhae Island. It has been reported that Gwangyang bay is an appropriate marine environment for marine micro-organisms causing red tides to grow because ocean currents and tides do not flow smoothly. It has been also reported that Cochlodinium polykrikoides mainly occurred in the South Sea area around the Namhae Island [5–10].

Recently, there has been a need to extend the use of alternative water resources such as desalination and reuse of sewage and waste water because there has been an increase in restricted water supply areas due to periodic drought [11–14]. Active projects have been under consideration. Currently operating desalination plants include Gwangyang Seawater Reverse Osmosis (SWRO) plant (2014 year completion & Operation) (30,000 ton/d) and Gijang SWRO plant (2015 year completion & Operation) (46,000 ton/d).

Most of recent desalination plants use SWRO process, and chlorine cannot be used because the RO membrane in the main SWRO process is made of polyamide (PA). Therefore, it is very vulnerable to biofouling due to the influence of red algae and marine micro-organisms contained in seawater.

It is inevitable that initial investment costs increase because there is a need to improve unit process of desalination plants in order to control and treat red algae causing biofouling. Moreover, economic efficiency and stability of operation and maintenance (O & M) are compounded by an increase in operation

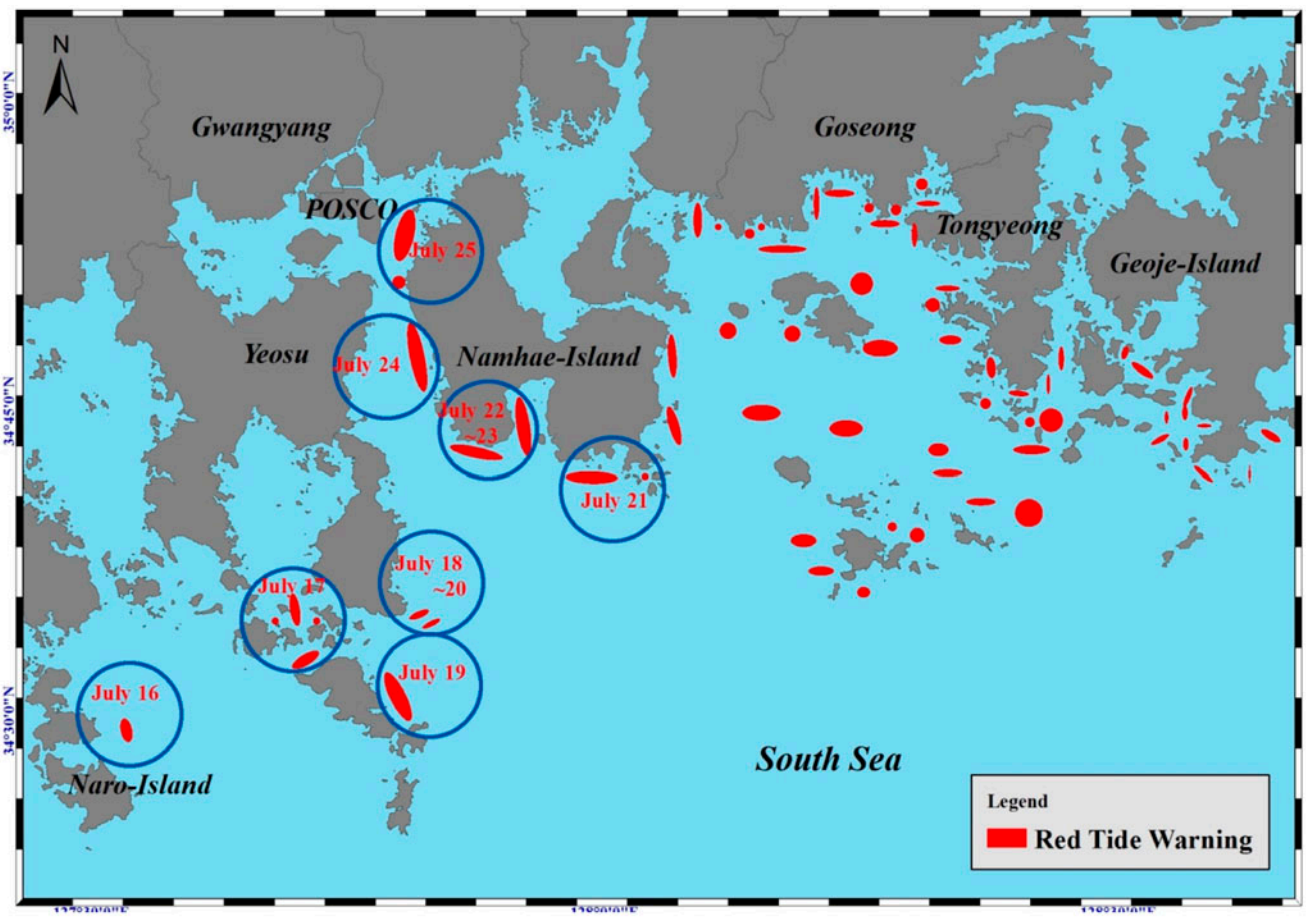


Fig. 4. Red tide occurrence and distribution (July 2013).

and maintenance costs (O & M costs) such as chemical cost and sludge treatment cost [15–17].

Therefore, with regard to seawater intake points of POSCO Gwangyang Works' SWRO desalination plants in Gwangyang Bay, this study aimed to evaluate the applicability of the "red tide monitoring system" capable of detecting and preventing the influx of red algae adversely affecting O & M of desalination plants using Chollian in advance.

2. Materials and methods

2.1. Current state of chlorophyll-a in Gwangyang Bay

As shown in Fig. 1, Gwangyang SWRO plant (Phase 1) is located in the south of POSCO Gwangyang Works, and No. 7 is the nearest environmental monitoring station (EMS) to the seawater intake point.

Gwangyang Bay is located between the Yeosu Peninsula and Namhae Island. It measures 27 km from East to West and 15 km from North to South and has 368 km coastline. More than half of the whole coastline consists of artificial coastline.

On the other hand, the sea area to the East of Gwangyang SWRO plant (Phase 1) consists of "rias" with indented and irregular coastline. In the area projecting into the sea, rocky shores such as cliffed coast and abrasion platform have developed. In the area of landlocked bay, tidal flats with a mixture of clay, sand, and gravel are formed. In particular, Gwangyang Bay has appropriate marine environments such as amount of sunlight, water temperature, salinity, and nutrient salts for micro-organisms causing red tides to grow.

Furthermore, Gwangyang Bay has been designated as "Special Management Sea Area" since 2010 because its marine water quality was polluted by the excessive use and development of the coast. Its marine environments and degree of seawater pollution have been monitored at 12 EMSs every February, May, August, and November.

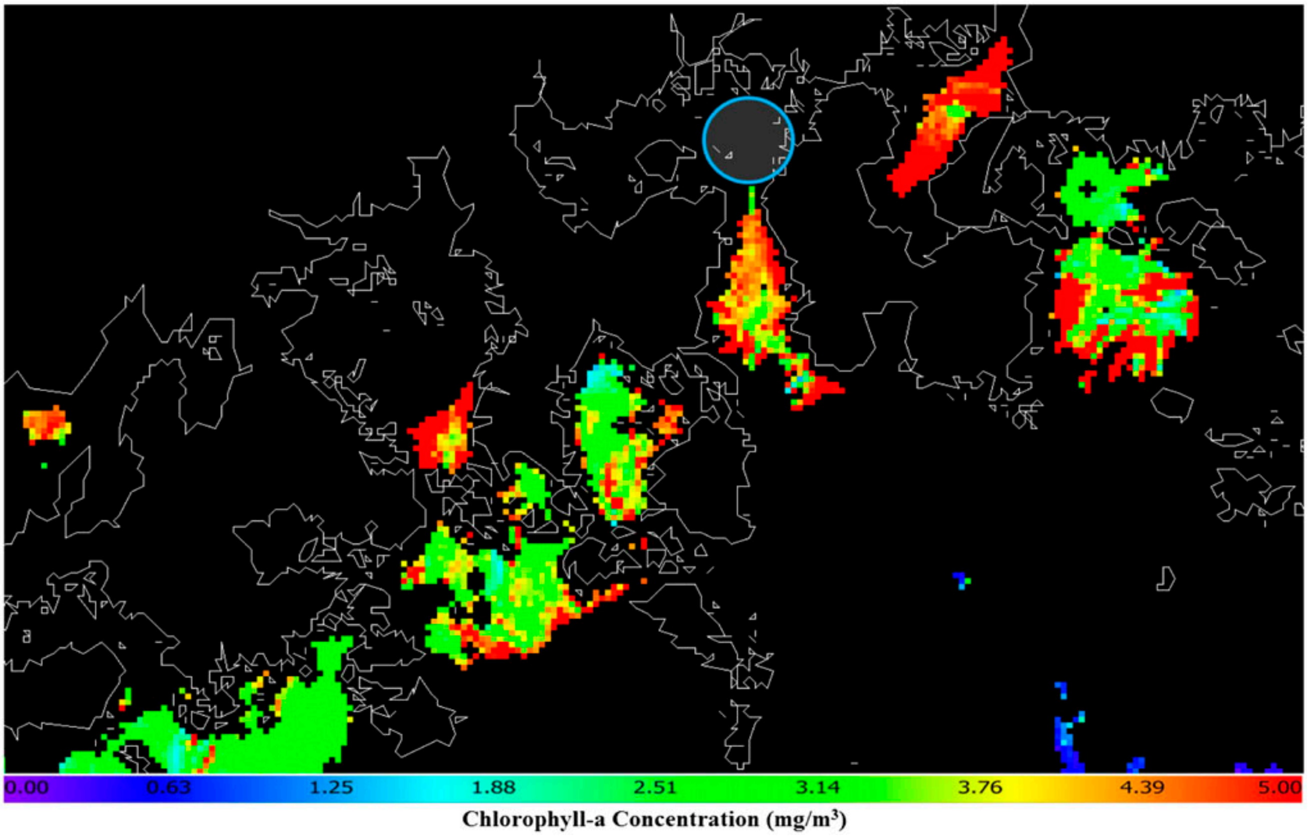


Fig. 5. Chlorophyll-a concentration analyzed by GDPS software (22 July 2013).
Source: Map data ©2014 Ministry of Ocean and Fisheries, Republic of Korea (Coast Line Status Map).

Chlorophyll-a is one of the water quality management factors measured in Gwangyang Bay. As shown in Table 1, the annual mean concentration of chlorophyll-a at the No. 7 EMS in Gwangyang Bay decreased from 6.30 μg/L in 2012 to 4.73 μg/L in 2013, and decreased to 3.39 μg/L in 2014. The monthly mean concentration of chlorophyll-a at the No. 7 EMS in Gwangyang Bay was 8.28 in February, 3.10 μg/L in May, 6.08 μg/L in August, and 1.75 μg/L in November.

Red tide caused 4.4 billion won damage to fisheries in 2012. Subsequently, ship observation to monitor red tide occurrence has been regularly performed by the National Fisheries Research and Development Institute (NFRDI) between March and November more than once a year. Therefore, the mean chlorophyll-a concentration in February was higher than that in August but was removed from the applicability evaluation because it had no result of ship observation. In August, summer season with the worst damage to fisheries, the applicability of Chollian ocean color satellite was compared with the results of the ship observation for evaluation.

2.2. Server system configuration

As shown in Fig. 2, Gwangyang SWRO plant (Phase 1) configured the FTP Push server system to observe red tides so that it can provide real-time monitoring of red tides occurring in the neighboring sea area.

"GDPS (GOCI data processing system) software" was used for image processing of GOCI to detect chlorophyll-a concentration. The analysis algorithm of the chlorophyll-a supported by GDPS was developed as observed data using ships in sea areas around the Korean Peninsula from 1998 to 2009. There were a total of 1,348 environmental monitoring stations (EMS), and most of them were observed in clear sea areas. In coastal areas, however, it is hard to detect red tide occurrence by bio-optical algorithm, problems with atmospheric correction methods, and spatial and temporal resolution due to the influence of suspended solids and soluble organic matters in seawater. As a result, the land is displayed in gray, and the coastline in red as illustrated in Fig. 3 [18,19].

The analysis algorithm of chlorophyll-a concentration in GOCI images is as shown in Eq. (1), and four

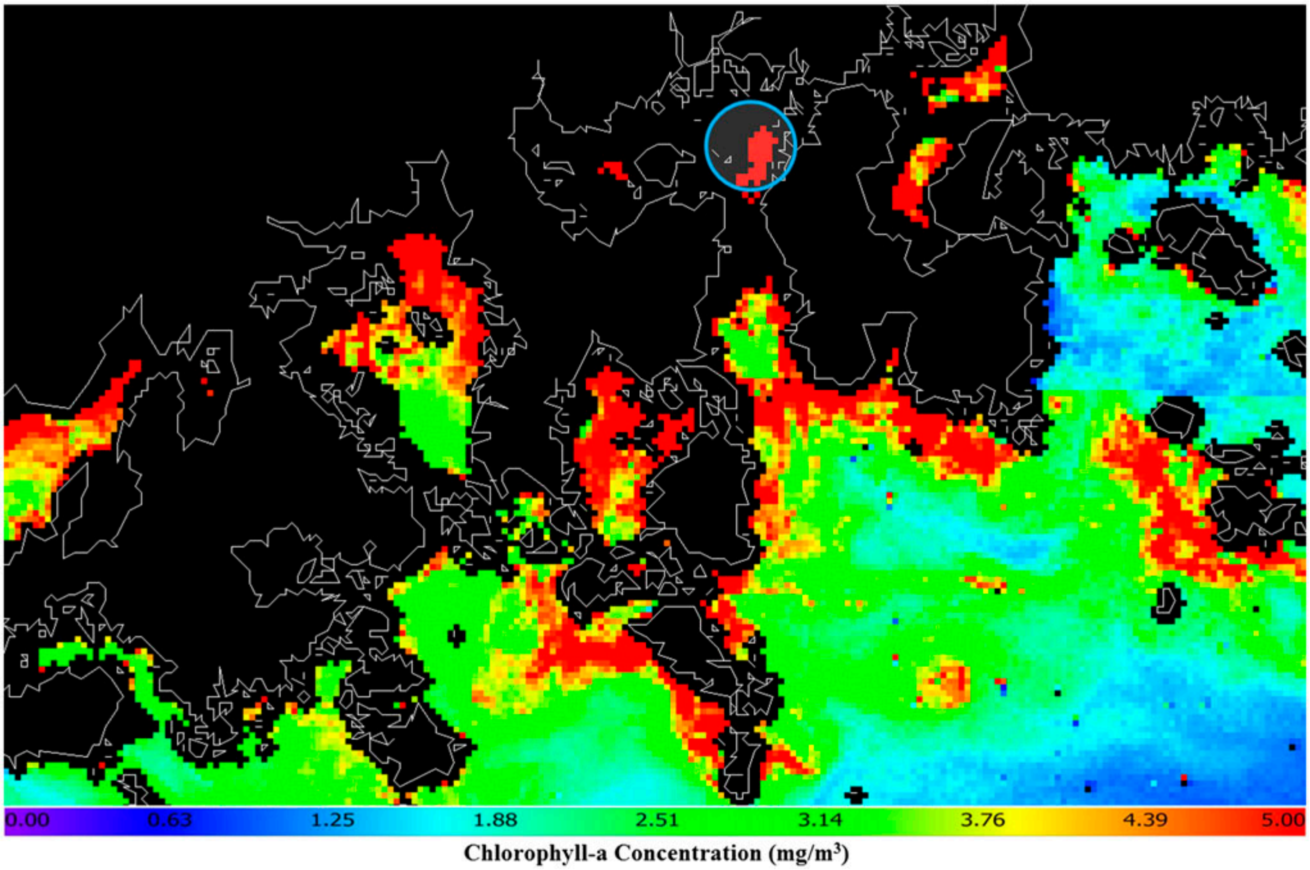


Fig. 6. Chlorophyll-a concentration analyzed by GDPS software (14 August 2013).
Source: Map data ©2014 Ministry of Ocean and Fisheries, Republic of Korea (Coast Line Status Map).

Remote Sensing Reflectance (R_{rs}) are calculated by the correlation between the combination of band ratio and chlorophyll-a concentration. In this case, R_{rs} (412), R_{rs} (443), R_{rs} (490), and R_{rs} (555) mean remote sensing reflectance for each wavelength band.

$$\mathrm{CHL} = 1.8528 \times R^{-3.263}\ (\mathrm{mg/m^3})$$

where

$$R = \frac{(R_{rs}\ 443 + R_{rs}\ 490) - R_{rs}\ 412}{R_{rs}\ 555} \quad (1)$$

2.3. Data processing methodology

As shown in Table 2, this study compared and analyzed the correlation with Cochlodinium polykrikoides causing red tides by the chlorophyll-a concentration based on GOCI images and specimens sampled from a boat by the control room of the NFRDI. In addition, this study referred to the aerial red tide map to examine when red tides occurred and disappeared [20–22].

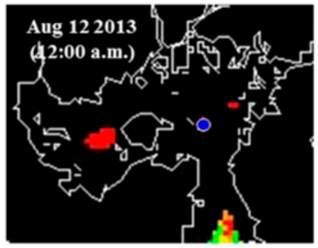
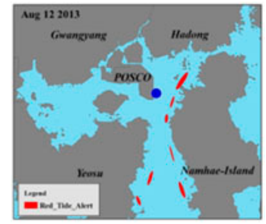
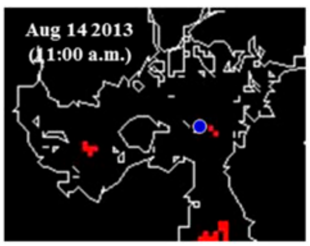
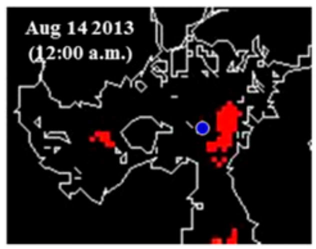
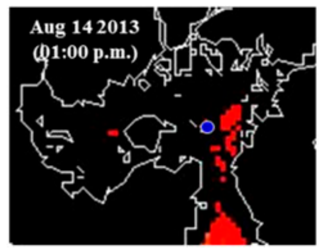
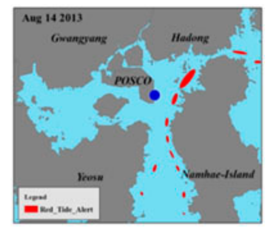
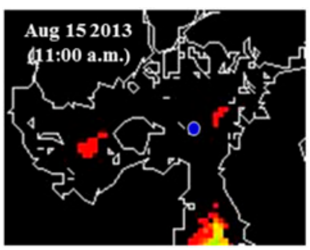
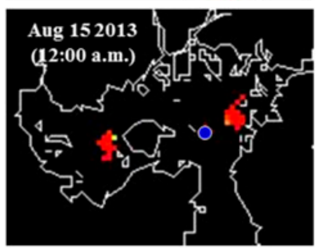
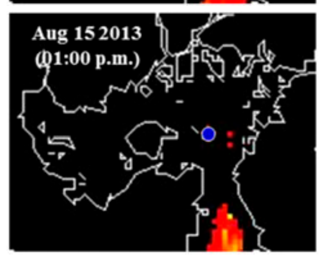
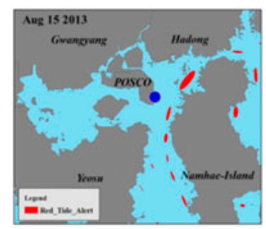
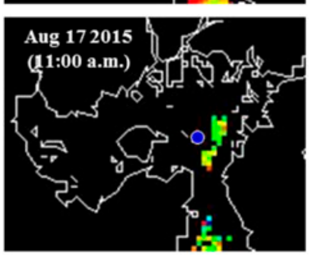
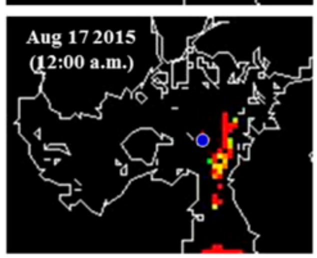
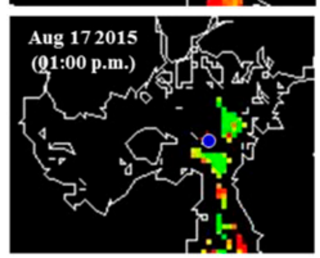
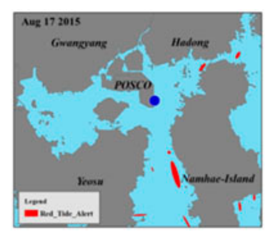
3. Results and discussions

3.1. Observation of influx of red tides into Gwangyang Bay

The South Korean government frequently takes aerial photographs of sea areas with red tide warning for early observation of red tide areas when red tides occur and has issued "red tide warning" to sea areas at a concentration of Cochlodinium polykrikoides of more than 1,000 cells/mL and red tide with a radius of more than 5 km (79 km^2).

Fig. 4 shows the process of red tide occurrence and proliferation as of 25 July 2013 when red tide initially occurred in Gwangyang Bay. Red tides initially appeared in the sea area neighboring Naro Island and Tongyeong on 16 July 2013 and expanded to the right and then proliferated to the sea area neighboring Geoje Island around the end of July. On 22 July when "red tide warning" was issued, large-scale red algae tides were formed in the southern sea area of Namhae

Table 3
Distribution of red algae tides flowing into Gwangyang Bay and chlorophyll-a detected by GOCI images

GOCI images			Red tide map
N.D. (Not Detected)		N.D. (Not Detected)	
			
			
			

Source: Map data ©2014 Ministry of Ocean and Fisheries, Republic of Korea (Coast Line Status Map).

Table 4
Comparison between concentrations of Cochlodinium polykrikoides sampled at the sites and chlorophyll-a detected by GOCI images

		Cochlodinium polykrikodies (cells/mL)	
Date	Chlorophyll-a concentration (μg/L)	Range	Median value
12 Aug 2013	7.93	500–9,200	4,850
14 Aug 2013	12.43	300–13,000	6,650
15 Aug 2013	10.85	200–13,000	6,650
17 Aug 2015	4.69	300–3,800	2,050

Island, and Cochlodinium polykrikoides was observed at a concentration of 400–2,000 cells/mL.

In addition, as shown in Fig. 5, the chlorophyll-a concentration was detected by GOCI images on the same day when "red tide warning" was issued on 22 July. According to the results, red tide concentration increases as the color approach red as shown in the legend, and the results showed the influx of red tides flowed into Gwangyang Bay, occurrence range and concentration of red tides.

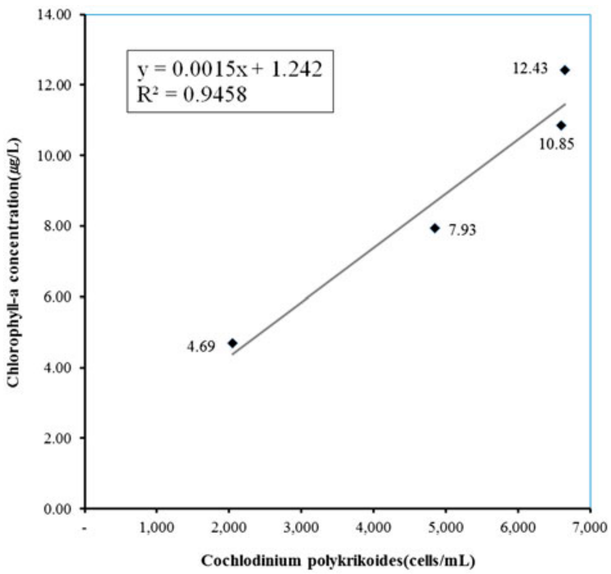


Fig. 7. Results of correlation analysis between concentrations of cochlodinium polykrikoides sampled at the sites and chlorophyll-a detected by GOCI images.

3.2. Prediction of red tide concentration in sea area with desalination plants

As shown in Fig. 6, in order to evaluate the applicability of "red tide monitoring system" in the sea area with desalination plants, this study analyzed GOCI images from 11 am to 1 pm on 12 and 14 August 2013 and 17 August 2015 by selecting the most cloud-free day (Table 3).

As shown in Table 3, the intake points of desalination plants are marked with a blue dot with the chlorophyll-a concentration using GDPS software. As a result, the interference of clouds in the sky made it difficult to analyze the chlorophyll-a concentration from 11 am to 1 pm on 12 August 2013.

Also, the chlorophyll-a concentration on 14 August 2013 was 9.84 μg/L at 11 am, 10.85 μg/L at 12 am, and 16.59 μg/L at 1 pm. This is because Cochlodinium polykrikoides were activated due to the increase in the water temperature with increasing hours of sunshine.

One thing to note here is that the points (blue dots) where the intake points of the desalination plants were located were very close to those where the chlorophyll-a concentration occurred in the analysis of GOCI images from 1 pixel (500 m) to 5 pixel (2,500 m). These results show that it is possible to detect red tides flowing into desalination plants by analyzing GOCI images of the ocean color satellite.

Table 4 shows the daily mean values of the chlorophyll-a concentration detected by GOCI images in Table 3 and analysis values of the water quality sampled from a boat. According to the results, the chlorophyll-a concentrations extracted from the GOCI images ranged from 4.69 to 12.43 μg/L, and the Cochlodinium polykrikoides concentration as an actual analysis value of the water quality at the sites ranged from 2,050 to 6,650 cells/mL. A linear correlation was found. In this case, the calculation and evaluation were performed using the mean value because the sampled results by section of red algae tides were used as Cochlodinium polykrikoides concentration.

As shown in Fig. 7, the chlorophyll-a concentration observed by the Ocean Color Imager was linearly proportional to Cochlodinium polykrikoides concentration of the experimental values sampled from the boat. This linear trend line showed a very high correlation at approximately 95% reliability (R^2).

Therefore, it is considered that the use of GOCI images of Chollian enables us to improve and support previous red tide monitoring methods based on water quality analysis of Cochlodinium polykrikoides concentration using boats. In particular, it is expected that they can maximize the stability of the overall O & M through the setting of "emergency operation mode" in the process of desalination by detecting and predicting the time when red tides occur and the influx concentration through the monitoring information of red tides flowing into desalination plants [23,24].

4. Conclusions

It is extremely likely to configure and apply the IT-based "red tide monitoring system" capable of detecting and predicting red tides flowing into desalination plants in real time using GOCI images of Chollian.

Assuming that there is a high correlation at approximately 95% reliability (R^2), it is possible to predict the optimal injection of coagulant and power activated carbon in the pre-treatment process of desalination plants because the chlorophyll-a concentration in the observation values of the Ocean Color Imager can be predicted in advance and converted to the concentration of red tides flowing into desalination plants. In addition, this study confirmed the possibility of configuring the "red tide monitoring system" capable of effectively responding from the perspective of operation of maintenance (O & M) of the whole desalination plant by quickly estimating and controlling the operational condition of the main process.

Furthermore, it is expected that the system can be effectively used to reduce initial investment costs and O & M costs because it can be actively applied to selecting intake site minimizing the occurrence of red tides using the "red tide monitoring system" in the feasibility study stage prior to installation of desalination plants.

On the assumption that the optimal intake site is selected and the "red tide monitoring system" is used with consideration of construction of additional desalination plants (Phase-2) in Gwangyang Bay in further studies in the future, economic evaluation will be performed on the effectiveness and benefits to apply dissolved air flotation (DAF) to the pre-treatment process as a safety device to solve the intermittent influx of red tides.

Acknowledgements

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