

than 100 cells/ml appeared 11 times and more than 1000 cells/ml appeared 7 times in that time. In 2013, more than 1000 cells/ml accounted 45 times for about 87%, it classified Yellow type when the red tide warned. More than 1000 cells/ml in August 2013 is the highest number of the red tide appearance from 2012 to 2015. In 2014, more than 1000 cells/ml in August and September appeared 20 times. Compared with 2012 and 2015, the number of red tide occurrence is similar, however, the concentration of 1000 cells/ml is more than three times of difference.

Table 2. The number of red tide occurrence according to the concentration of the *Cochlodinium polykrikoides* from 2012 to 2015

| <i>Cochlodinium polykrikoides</i> (cell/ml) | 2012 | | | | 2013 | | | | 2014 | | | | 2015 | | | |
|--|------|----|---|----|------|----|---|----|------|----|----|----|------|----|---|----|
| | 7 | 8 | 9 | 10 | 7 | 8 | 9 | 10 | 7 | 8 | 9 | 10 | 7 | 8 | 9 | 10 |
| < 10 | - | 4 | - | - | - | 1 | - | - | 4 | 6 | - | - | - | 1 | - | - |
| 10 > | - | 1 | - | - | - | - | - | - | - | 1 | - | - | - | 1 | 1 | - |
| 100 > | 5 | 11 | - | 1 | 1 | 5 | - | - | 2 | 10 | 9 | 5 | - | 5 | 4 | - |
| 1000 > | 2 | 7 | - | 1 | 16 | 29 | - | - | - | 20 | 20 | 4 | - | 22 | - | - |
| Total | 7 | 23 | - | 2 | 17 | 35 | - | - | 6 | 37 | 29 | 9 | - | 29 | 5 | - |

Figure 1 shows the mean sea water temperature between 2012 and 2015. Blue line is 2012, green line is 2013, yellow line is 2014, and orange line is 2015. Grey box shows the 22~25°C. In 2012, the sea water temperature is almost 30°C in August which shows the highest. In 2013, the sea water temperature between July and August almost remain between 22 and 25°C and it increases in September. In 2014 and 2015, most of the sea water temperature was highest in August.

By using sea water temperature data, it is investigated that how long does it takes from the beginning of the best sea water temperature(22°C) to the occurrence of the red tide. Figure 2 shows the sea water temperature from the day of 22°C to the end of the red tide occurrence in each year. In 2012, the sea water temperature was enough to cause the red tide from middle of June, and it occurred in 27th July, which is after 39 days. In 2013, it started from the beginning of July, the red tide occurred in 17th July, after 16 days. In 2014, it was reached from the end of June, the red tide started in 25th July, after 28 days. In 2015, it started from the beginning of July, and it started in 2nd August, after 31 days.

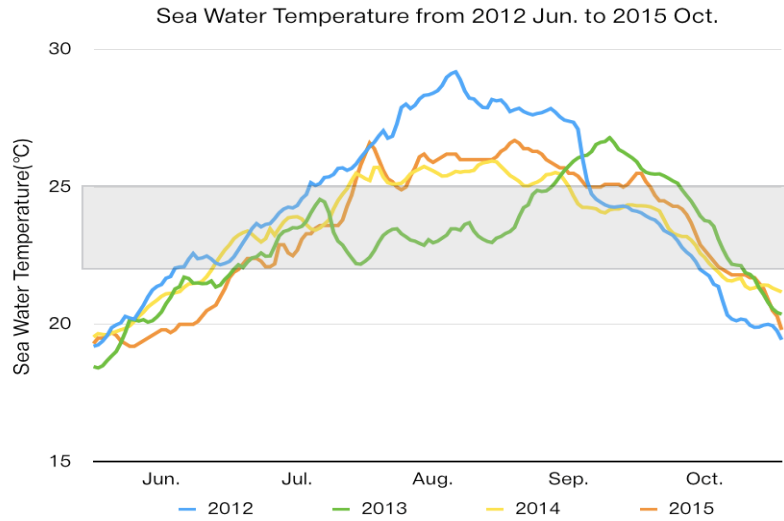


Fig. 1. Mean sea water temperature from 2012 June to 2015 October. Blue line is 2012, green line is 2013, yellow line is 2014, and orange line is 2015. Grey box shows the 22~25 °C.

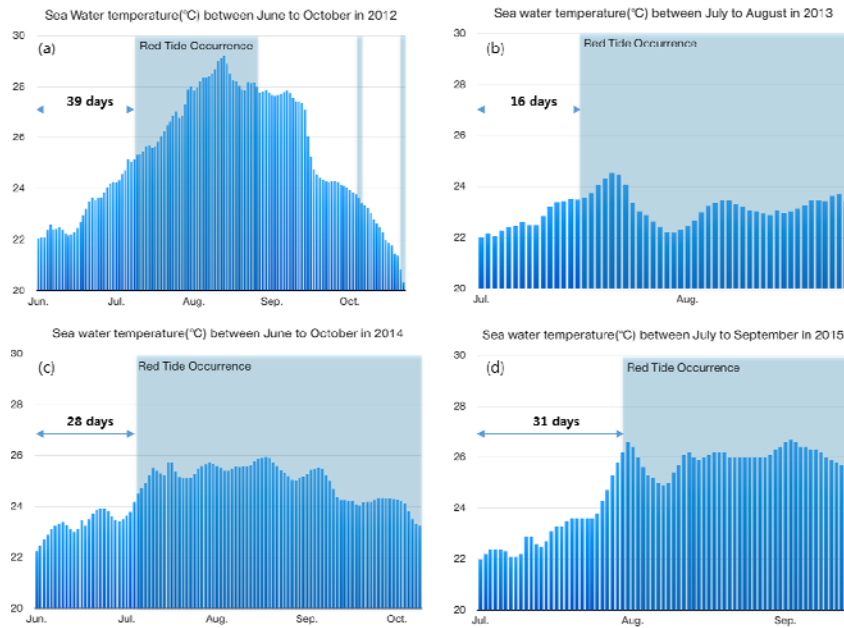


Fig. 2. Sea water temperature from the best sea water temperature to the end of the red tide occurrence. (a) shows the sea water temperature in 2012, which takes 39 days from 22 °C to red tide occurrence, (b) takes 16 days in 2013, (c) takes 28 days in 2014, and (d) takes 31 days in 2015.

For the red tide occurrence, the best sea water temperature starts from the end of June to the beginning of the July and the red tide is expected to occur about one month later. In 2013, the density of the *Cochlodinium polykrikoides* is high, however, red tide occurrence was short. It is considered that the best sea water temperature started earlier, and the sea water temperature in August was for 3~5°C lower than other years which is between 22 and 25°C.

4 Conclusion

In Tongyeong, the most of red tide occurred in August. The highest number of red tide occurrence was 2014 for 37 times. *Cochlodinium polykrikoides* concentration more than 1000 cells/ml in 2013 were 29 times. The red tide occurrence, the best sea water temperature is 22~25°C which starts from the end of June to the beginning of the July and the red tide is expected to occur about one month later. This study only compared the sea water temperature data for the red tide occurrence. The sea water temperature does not cover the all of red tide occurrence area. It would be concluded more accurate results by using the satellite data for the wide area and meteorological data such as air temperature, wind, and sun shine duration for the further study.

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References

1. Lee, M. O., Kim, B. K., Kim, J. K.: Marine Environmental Characteristics of Goheung Coastal Waters during *Cochlodinium polykrikoides* Blooms. J. of the Korean Society for Marine Environment and Energy. 18(3), 166--178(2015)
2. Park, B.Y.: A study on satellite image and numerical model for the drift diffusion of red tide. Sungkyunkwan University, Seoul (2015)
3. Korea Institute of Science and Technology Information: A Study on the Detection and Likelihood Assessment of HAB outbreaks using Big Satellite Databases. Korea Institute of Science and Technology Information, Seoul (2014)
4. Yoon, H.: Meteorological Information for Red Tide.: Technical Development of Red Tide Prediction in the Korean Coastal Areas by metrological Factors. The Korean Institute of Maritime Information and Communication Sciences. 9(4), 844--853(2005)
5. Oh, S., Park, J., Yoon, H.: Prediction of Red Tide Occurrence by using Oceanic and Atmospheric Data by Satellite. J. of the Korea Institute of Electronics Communication Sciences. 10(2), 311--318(2015)
6. National Institute of Fisheries Science, <http://www.nifs.go.kr/>
7. The Korea Hydrographic and Oceanographic Agency, <http://www.khoa.go.kr/>