Food Research International 68 (2015) 47–53

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Prediction of paralytic shellfish toxin based on a projected future climate scenario for South Korea

Yongsung Joo [a], Kyungjin You [a], Ki-Hwan Park [b], Hyang Sook Chun [b,*], Ju-Hyun Park [a]

[a] *Department of Statistics, Dongguk University—Seoul, Pil-dong 3-ga, Jung-gu, Seoul, South Korea*
[b] *Department of Food Science and Technology, Chung-Ang University, Anseong 456-756, South Korea*

ARTICLE INFO

Article history:
Received 31 March 2014
Received in revised form 24 August 2014
Accepted 30 August 2014
Available online 6 September 2014

Keywords:
Paralytic shellfish poisoning toxin
Environmental effects
Censored regression model
Future climate scenario

ABSTRACT

This study aimed to predict the seasonal patterns of paralytic shellfish poison (PSP) level in the next 90 years based on a future climate scenario, Representative Concentration Pathway (RCP) 8.5. To achieve this goal, we constructed a censored regression model using seawater temperature, weekly change in seawater temperature, salinity, rainfall, insolation, shell species, and areas prone to red tide as potentially influential environmental factors on PSP level in the coastal areas of South Korea. The censored regression model is used instead of the ordinary regression model because the PSP data had a large portion of non-detectable (ND) data. All of the continuous environmental covariates had significant quadratic relationships with the PSP toxin level except insolation. These results indicated that there are favorable ranges of seawater temperature, weekly change in seawater temperature, salinity, and rainfall to PSP production. To predict the future PSP distribution, we plugged the environmental condition data under a future climate scenario, RCP 8.5 scenario, in the estimated regression model. In the future, it is expected that the highest frequency of shellfish poisoning outbreaks will occur during the earlier months in the year, such as February and March, whereas most outbreaks of shellfish poisoning have occurred in April and May during recent years in South Korea.

1. Introduction

Paralytic shellfish poison (PSP) is a common seafood toxicity problem with a worldwide distribution, which is typically attributable to the consumption of contaminated molluscan bivalves and other shellfish (Bricelj & Shumway, 1998; Wiese, D'Agostino, Mihali, Moffitt, & Neilan, 2010). These shellfish are filter feeders that accumulate neurotoxins including saxitoxin (STX) produced by microscopic algae, such as dinoflagellates, diatoms, and cyanobacteria. The effects of PSP are primarily neurological and they can include tingling, burning, numbness, drowsiness, incoherent speech, and respiratory paralysis. Respiratory paralysis can result in death if respiratory support is not provided in a timely manner (FDA, 2013).

To protect public health, an action level or regulatory limit is defined for PSP. It is unlawful to harvest seafood when toxins exceed the established limit. A review of the regulatory limits in various countries was reported by the FAO (2004). In general, the limit is defined as 80 μg STX equivalents (eq)/100 g tissue, which is the action level in the USA and South Korea. However, a recent summary by the European Food Safety Authority (EFSA) stated the opinion that, based on the established acute reference doses, the current EU regulatory limit for STX-group toxins is not sufficiently protective (EFSA, 2009). Hence, they proposed a limit of 7.5 μg STX eq/100 g instead of the current limit of 80 μg STX eq/100 g.

The large-scale climate fluctuations attributed to industrialization have also been linked to events of harmful algal bloom (HAB). These blooms often have a red or brown hue and they are known colloquially as “red tides.” Epidemiologists have studied the relationships between human disease epidemics and unusual extreme events such as drought, heat, and heavy rainfall (Epstein et al., 1998). Similarly, climate fluctuations, accompanied by these extreme events, may be associated with marine biotoxin outbreaks including PSP toxin in aquatic species (Moore, Mantua, Hickey, & Trainera, 2010). For example, if the easterly winds of the Pacific Ocean are affected by climate fluctuations and they fail to transport cold, nutrient-rich water from the eastern Pacific to the west, the nutrient-rich water ultimately becomes concentrated in the east, thereby leading to HABs. The increased frequency of PSP in the Indo-Pacific has been linked to the occurrence of this phenomenon (Van Dolah, 2000). Large-scale climate fluctuations such as El Niño and La Niña usually occur 1–2 times per decade (Field et al., 2014; Harvell et al., 1999; Wang, Chang, & Wang, 2007). However, these extreme events have been more frequent and prolonged since 1970, which supports the correlation between HAB events and anthropogenic factors (Mann, Bradley, & Hughes, 1998; Moore et al., 2008; NRC, 1999; O'Neil, Davis, Burford, & Gobler, 2012).

In particular, increases in greenhouse gases caused by industrialization are correlated with HAB growth. The average global temperature

---

* Corresponding author. Tel.: +82 31 670 3290.
E-mail address: hschun@cau.ac.kr (H.S. Chun).

http://dx.doi.org/10.1016/j.foodres.2014.08.040
0963-9969/© 2014 Elsevier Ltd. All rights reserved.

reportedly increased by 1.1 °C between 1850 and 2010 (Hawkins & Jones, 2013). Because the oceans act as heat reservoirs that influence and respond to the global climate via thermohaline circulation, a change in the circulation of climate, nutrients, oxygen, and carbon dioxide has occurred (Mann et al., 1998). Ultimately, long-term increases in the sea surface temperature have modified the behavior of marine environment regimes. Increased sea surface temperature has been found to lead to decreased surface nutrient concentrations, which favor the smaller dinoflagellates that are responsible for numerous HAB events (O'Neil et al., 2012; Rodrigue et al., 1990). In turn, these changes resulted in a higher frequency of shellfish poisoning outbreaks such as PSP (Van der Fels-Klerx et al., 2012). Thus, understanding the distributions of PSP toxins with the environmental conditions may provide deep insights into the associations between climate change and HAB events (EPA, 2013).

Prediction models for the PSP content in seafood are useful tools for control authorities and the industry to avoid or limit potential food safety problems. A further prediction for the PSP level under the future climate change is also necessary to establish adaptive strategies. In general, the factors that are considered to affect the generation of PSP toxins comprise of seawater temperature, rainfall, insolation, and salinity (FAO, 2004; O'Neil et al., 2012). Eutrophication, wind, tidal current and freshwater runoff also affect HAB event and the generation of PSP toxins (Moore et al., 2010; O'Neil et al., 2012; Van Dolah, 2000). It is known that rainfall stimulates the growth of phytoplankton (*Alexandrium* spp., *Gymnodinium catenatum* and *Pyrodinium bahamense*), which increases the production of PSP toxin (EPA, 2013; Moore, Mantua, Hickey, & Trainer, 2009). It is expected that the effect of rainfall requires an average of several weeks to cause an increase in the PSP toxin level (Chang et al., 1988; Moore et al., 2008; O'Neil et al., 2012). In addition, based on the results of Parkhill and Cembella (1999) and Etheridgea and Roeslerb (2005), sunny days after rainfall are expected to have a positive effect on the growth of phytoplankton. Seawater temperature and salinity are most likely to affect toxin-producing plankton and/or the production of PSP toxin (Etheridgea & Roeslerb, 2005). Favorable seawater temperatures for toxin-producing plankton, i.e., 13–22 °C (Kaspar & Tamplin, 1993), occur in two seasons (spring and fall), but the plankton blooms mainly in spring (Kwak, Choi, & Cho, 2001). Red tide is caused by a "population explosion" of plankton such as dinoflagellates. Environmental factors, which promote explosive growth, include warm surface temperatures, high nutrient content, low salinity, and calm seas (Smayda, 1990). However, there are insufficient data to draw any conclusions about the impacts that changes in environmental conditions might have on toxin-producing plankton and the production of PSP toxin.

Thus, the present study investigated the effects of environmental conditions and shellfish species on PSP toxins along the coastlines of South Korea. Furthermore, we predicted the seasonal patterns of PSP occurrence over the next 90 years based on Representative Concentration Pathway (RCP) in future climate scenarios (Edenhofer et al., 2014; Field et al., 2014; Stocker et al., 2013).

2. Materials and methods

2.1. Data collection

A total of 5258 PSP toxin measurements (as saxitoxin) were obtained from four shellfish species (oyster, warty sea squirt, Manila clam, and mussel) by the Korean Marine Products Laboratory at 51 locations near the coastal areas of South Korea, as shown in Fig. 1. The data were collected between March 2007 and June 2012. Numbers of PSP measurements are shown in Table 1.

The seawater temperature and salinity data were extracted from the database of the Korean Oceanographic Data Center (www.kodc.nfrdi.re.kr). If seawater temperature and salinity data were not available for the same dates and/or the same locations where the shellfish samples were collected, data from the closest location and/or date were used instead.

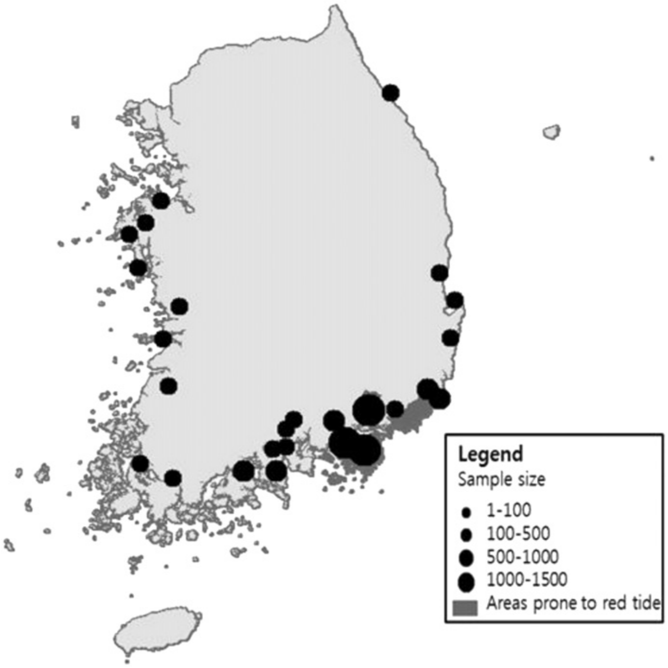

Fig. 1. Data collection sites used to assess paralytic shellfish poisoning toxin levels in South Korea.

The rainfall and insolation data were obtained from the homepage of the Korea Meteorological Administration (www.kma.go.kr).

For the fitted model equations, a list of environmental covariates and PSP toxin were used (Table 2): seawater temperature on the shellfish sample collection date (SWT), average seawater temperature over the last 1–7 days minus average of seawater temperature over the last 8–14 days (SWTC), salinity on the shellfish sample collection date (SAL), average rainfall over the last 8–14 days before the shellfish sample collection date (RAIN), average insolation over the last 1–7 days before the shellfish sample collection date (INS), and amount of PSP toxin (TOX).

2.2. Data analysis and model development

In the exploratory data analyses, we examined the distribution of PSP with one covariate at a time to determine how each environmental factor affected the amount of PSP toxin, where "non-detected" (ND) observations were replaced with half of the detection limit (Health Canada, 2003), as shown in Fig. 2.

For the generation of the predictive model, the censored regression model in comparison with the ordinary regression model was used in this study because the PSP data had a large portion of non-detectable (ND) data. An ordinary linear regression was also fitted to the data where all the ND values were imputed with half of the detection limit. The logarithmic transformation of the PSP toxin level was considered in the regression models because of the heteroscedasticity of the original measurements. Further, all of the continuous covariates in the models were centered to avoid potential multicollinearity among the polynomial terms (Kutner, Nachtsheim, Neter, & Li, 2005). The centered variables were denoted with the subscript C. For example, $\mathrm{RAIN_C} = \mathrm{RAIN} - \overline{\mathrm{RAIN}}$, where $\overline{\mathrm{RAIN}}$ is the mean RAIN value. The averages of the environmental covariates are shown in Table 2. After fitting the censored regression models, a stepwise variable selection procedure was applied to ensure that the models were concise and to exclude nonsignificant covariate effects. For censored regression analysis and other statistical computations, we used R software with censReg package, which is available at http://www.r-project.org/.