Environmental Science and Pollution Research (2022) 29:88839–88851
https://doi.org/10.1007/s11356-022-21944-x

RESEARCH ARTICLE

Public willingness to pay for eradicating a harmful marine organism: the case of *Aurelia aurita* in South Korea

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Received: 8 April 2022 / Accepted: 6 July 2022 / Published online: 16 July 2022

Abstract

Aurelia aurita (AA), a legally registered harmful marine organism in South Korea, is damaging marine human leisure activities, local residents' tourism income, fisheries, and cooling water intake at power plants. The government is therefore seeking to eradicate AA by removing AA-attached larvae (polyps). This article looks into the public willingness to pay (WTP) for the eradication, utilizing a contingent valuation. For the sake of eliciting the WTP response, the one-and-one-half-bounded (OB) model was adopted. For comparison, the single-bounded (SB) model, which uses only the response to the first question in the OB model, was also applied. A spike model with a considerable plausibility that could explicitly deal with zero WTP responses was employed. Consequently, the estimation results of the SB model were used for further policy analysis. The household average WTP was estimated as KRW 3,911 (USD 3.49) per year, securing statistical significance. The national value was KRW 80.46 billion (USD 71.71 million) per annum. This figure can be interpreted as public value of the AA eradication project and used as essential basic data to evaluate the economic feasibility of implementing the project. Some factors such as income and education level significantly positively affected the intention of paying a suggested bid.

Keywords Harmful marine organism · *Aurelia aurita* · Eradication · Willingness to pay · Contingent valuation · Zero observations

Introduction

Marine organisms that damage human life or property are called harmful marine organisms. The Korea Ministry of Oceans and Fisheries (KMOF) has legally designated and managed a total of seventeen species of marine organisms as harmful marine organisms. All of them frequently appear on the coast and have been identified as dangerous (Hayes 1997; Champion and Clayton 2000; Neves et al. 2021). In particular, *Aurelia aurita* (AA), which was designated as a harmful marine organism in 2013, appears in all the seas of South Korea and has the largest population among several jellyfish. Therefore, the government is trying to eradicate it by selecting it as a major management target. It emerges in large quantities from June to August, gradually decreases from September, and then disappears naturally in November. However, due to the recent rise in temperature caused by climate change, the frequency and duration of the emergence of a large number of AA has been increasing (Holst 2012).

Although there are various species of jellyfish inhabiting each region, the occurrence of jellyfish and damage caused by it have gradually increased not only in South Korea but also in other countries around the world (Condon et al. 2012). In general, the fishing and tourism are the sectors most affected by the increase in jellyfish populations (Ghermandi et al. 2015; Gómez and Gutiérrez-Hernández 2020). For example, Graham et al. (2003), Uye (2011), Kim et al. (2012), and Quiñones et al. (2013) reported fishing losses due to jellyfish outbreaks in the Gulf of Mexico,

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Japan, South Korea, and Peru, respectively. In Australia, box jellyfish have caused about 70 deaths and hundreds of injuries (Currie and Jacups 2005). In addition, there have been cases of damage caused by the invasion of jellyfish in coastal desalination plants and nuclear and coal-fired power plants (Purcell et al. 2007; Vörösmarty et al. 2010). Therefore, the need to design and implement measures to mitigate the damage caused by the increase in jellyfish population has increased.

AA, which is frequently appeared in South Korea, is causing damage in various fields (e.g., Graham et al. 2003; Palmieri et al. 2014; Ghermandi et al. 2015). The first field is fisheries. For example, when a large number of AA is found, fishery activities are often suspended due to major disruptions, such as damage to fishing nets (Kim et al. 2012; Purcell et al. 2013; Bosch-Belmar et al. 2020). Second, seawater is used as cooling water in seaside nuclear and thermal power plants, and when a large number of AA occur, the seawater intake is blocked, causing the power plant to shut down (Korea Ocean Research & Development Institute 2005).

Third and more importantly, AA interferes with human leisure activities (De Donno et al. 2014). For example, tourists were often stung by AA while swimming at the beach. Some were only injured, in pain, or itchy, but other people experienced blood circulation disorders or shock. In severe cases, shock deaths were also feared. The number of damages caused by jellyfish stings among vacationers is gradually increasing, with 802 in 2017, 1249 in 2018, and 1252 in 2019 (Kim 2019). For this reason, the KMOF has introduced an AA appearance warning system that is issued when five or more of the jellyfish are found per 100 m^2. The AA warning was issued in nine regions in June 2020 and four regions in June 2021.

To prevent damage caused by AA in advance, the KMOF has established the "Medium and long-term plan (2018–2022) for managing jellyfish attachment larvae" to remove the AA-attached larvae (polyps) (Korea Ministry of Oceans and Fisheries 2018). A polyp is an attachment larva that attaches to marine structures before becoming an adult jellyfish. One polyp can multiply to a maximum of 5000 adults. This removal project has two main advantages (Yoon et al. 2018). First, the cost of removing polyps is only about 0.8 to 3.1% of the cost of exterminating adults. In particular, since the number of adults can be reduced by about 90% through removal of polyps, the removal is very cost-effective in preventing mass occurrence of AA in advance.

Second, the removal of the polyps does not negatively affect the marine ecosystem. This is because the removal is performed as follows. After divers search for a large habitat of the polyps, they spray seawater at high pressure on the attached polyps living in artificial structures. The polyps fall off the structure and disappear naturally, as they are no longer able to feed. In short, the removal method not only requires a relatively low cost, but also does not significantly affect the marine ecosystem.

The KMOF intends to carry out the project continuously to remove the polyps throughout the South Korean seas for the next 10 years from 2023 to 2032, even after the plan is completed in 2022. If the project is successfully implemented, almost all populations of AA are expected to be eradicated nationwide, and no AA warning may be issued. Because the cost involved in executing the project would be covered by the taxes levied on citizens, the consent and support of the public are required for the execution. In particular, the KMOF wants to know how much value the public places on the project.

The objective of this article, therefore, is to provide the KMOF with how much value the public puts on eradicating AA by assessing it quantitatively. The public value can be measured with people's willingness to pay (WTP). This study utilizes a contingent valuation (CV) for measuring the WTP for the eradication. More specifically, by conducting a CV survey of 1000 households extracted from all over South Korea, data on the WTP are collected and analyzed. Three sections comprise the remainder of the article. Materials and methods are contained in **"**Materials and methods**"** section. Results and discussion are provided in "Results and discussion" section. The final section reports conclusions.

Materials and methods

Short review of former studies

There are several studies empirically evaluating the public value of managing species that have a negative impact on marine ecosystem, such as harmful marine organisms or marine invasive alien species. For example, Nishizawa et al. (2006), Lehrer et al. (2011), Ghermandi et al. (2015), Risén et al. (2017), Ofori and Rouleau (2020), and Xu et al. (2021) appraised the public value of eliminating alien fish in Japan, eradicating *Acacia saligna* in Israel, solving the jellyfish recurrence problem in Israel, managing beach-cast alae in Sweden, removing invasive seaweeds from the beach in Ghana, and eradicating *Ulva prolifera* bloom in China, respectively, using CV.

In addition, there are some studies that estimate the economic value of mitigating the damage caused by jellyfish outbreaks. Nunes et al. (2015) reported that the annual economic value arising from reduction of jellyfish blooms on the Catalan coast was around EUR 422.57 million, applying choice experiment (CE). Remoundou et al. (2015) analyzed the public's WTP on mitigating the negative effects of climate change on the oceans by applying CE. At this time, the number of days the beach was closed due to jellyfish

blooms from the influence of climate change was included as an attribute. Ruiz-Frau (2022) investigated potential beach visitors' WTPs for various jellyfish management measures through CE. Specifically, the WTPs for the use of information panels on how to behave in the event of jellyfish stings, first aid when stung by jellyfish, and the presence of beach screens that significantly reduce jellyfish presence were EUR 4.8, EUR 8.9, and EUR 12.4, respectively. A summary of the main results of these prior studies is provided in Table 1.

Two implications can be obtained from the short review of the prior studies. First, the method used for this research corresponds with that used for the former studies. CV is clearly the most widely used method in evaluating the public value of eradicating or managing harmful species. Thus, this research seeks to make a contribution to the related literature. Second, although there are a number of related previous studies, case studies that accurately deal with the eradication of AA, the subject of this research, are not found in the literature. Thus, this study seems to be the first one appraising the public value of eradicating AA through the CV approach. Of course, this is a judgment based on the authors' knowledge.

Method: CV

Unlike goods that we observe being traded in the market, there are some goods that are not found in the marketplace. These are non-market goods. CV is one of the techniques for obtaining the economic value related to consuming a non-market good (Ahn et al. 2020; Kim and Yoo 2020; Kang et al. 2021). The CV technique is classified as one of the stated preference approaches, using data obtained by asking about preferences instead of using data expressed by people's behavior. A survey is essential to ask for people's preferences. When a particular technique deals with data collected from surveys, the validity and reliability of the technique become an important issue.

In this regard, Perni et al. (2021) recently evaluated validity and reliability using two CV survey data and concluded that WTP estimates derived from CVs are appropriate to infer the economic value of non-market goods. The rationale was that CV surveys could induce reasonable behavior without hypothetical bias from respondents. As Foster and Burrows (2017) pointed out, CVs using hypothetical questions can suffer from hypothetical bias. However, well-designed CVs can greatly reduce hypothetical bias. In addition, Carson et al. (1997) stated that the WTP estimates from their data were not affected at the time of the survey, arguing that CV also satisfies temporal reliability.

Of course, Bishop and Boyle (2019) emphasized that further research should be conducted as the work of verifying the validity and reliability of CVs that is not yet complete. Therefore, since CV itself does not guarantee validity and reliability, it is important for researchers to carefully design an CV application to reduce any bias (Johnston et al. 2017). In particular, it is crucial for CV applications to adhere well to the methodological guidelines set forth by Arrow et al. (1993), Johnston et al. (2017), and Sajise et al. (2021). As will be described later, this research sought to comply well with these studies.

Preparation of the CV questionnaire

Determining and clearly defining the good to be assessed is the first work of employing CV. The object evaluated in CV should be the change from the current consumption state to the target consumption state, not a specific good itself. Therefore, clearly setting these two states is important in applied CV works. The current state is that damages caused by AA continue to occur. Meanwhile, the target state is the reduction of damage caused by AA to the level where an AA

Table 1 Summary of the main findings from related prior studies

Sources	Object to be valued	Countries	Main finding for the public value	Method [a]
Nishizawa et al. (2006)	Eliminating alien fish living in Lake Biwa (largemouth bass and bluegill)	Japan	JPY 876.6 million (EUR 6.6 million) per annum	CV
Lehrer et al. (2011)	Eliminating *Acacia saligna*	Israel	USD 8.83 per household per annum	CV
Ghermandi et al. (2015)	Solving the jellyfish recurrence problem	Israel	EUR 14.8 million per annum	CV
Risén et al. (2017)	Managing beach-cast algae	Sweden	EUR 28 per person per annum	CV
Ofori and Rouleau (2020)	Removing invasive seaweeds from the beach	Ghana	USD 5.48–12.42 per month	CV
Xu et al. (2021)	Eliminating *Ulva prolifera*	China	CNY 54.98 per household per annum	CV
Nunes et al. (2015)	Reduction of Jellyfish blooms	Spain	EUR 422.57 million per annum	CE
Remoundou et al. (2015)	Climate change mitigation	Spain	EUR 18.77 to 41.51 per annum	CE
Ruiz-Frau (2022)	Mitigation measures (information, first aid, and exclusion nets) of jellyfish impacts	Not available	EUR 4.8, EUR 8.9, and EUR 12.4	CE

[a]CV and CE indicate contingent valuation and choice experiment, respectively

warning is not issued through successfully carrying out the AA eradication project.

There are three main steps in the subsequent procedure. The first step is the preparation of the CV questionnaire. In the CV questionnaire, it was clearly explained to the respondents the object to be valued and background information such as that an AA warning would be issued if five or more AAs are found per 100 m^2 of sea area. In addition, cases of damage caused by AA in South Korea mentioned in the "Introduction" section were described through photos and pictures. This step has the importance of requiring the most attention among the three steps. The step will be described in more detail below. The second step is the performance of the survey, which will be described in detail in "Description of the CV survey" subsection. The third step is the analysis of the collected data, which is covered in more detail in "Model for dealing with the data" subsection.

In this study, two measures were taken to modify a draft version of the questionnaire. First, the authors had a meeting with a supervisor affiliated with a professional polling agency to modify rough or difficult expressions. Next, the modified questionnaire was further refined to reflect the comments obtained from conducting a preliminary survey of a focus group consisting of 30 people. The final version of the questionnaire includes three main components. The first component consists of questions asking for general recognition and attitudes related to the good being evaluated. Since CV uses hypothetical questions, it needs to prepare respondents for immersion in the hypothetical market rather than straightening out questions about WTP. Thus, this part has the nature of preparing respondents to be immersed in the hypothetical market.

The second component is filled with content that elicits the respondent's WTP while explaining the good to be evaluated. The payment principle, how to elicit WTP, the survey unit, and the payment vehicle should be determined. First, in relation to the payment principle, it was explained that the project could be implemented if the interviewee agreed to the payment of the given amount, but that the project would not be implemented if not. Moreover, it was stressed during the survey that there are a number of projects that the government should conduct and that the project covered in this survey is only one of them. It was also mentioned that the respondents' responses were not correct or wrong and that they should be comfortable in reporting their opinions.

Second, a method should be selected among several methods of eliciting WTP. Usually, there are two methods for eliciting WTP: open-ended and close-ended questions. In the case of open-ended questions, even if supplementary means, such as payment cards, are provided, respondents may have difficulty in responding, resulting in a number of protest responses being observed. Therefore, open-ended questions are not well used in recent empirical studies. A close-ended question method asking the respondent if she/he agrees to pay a specified bid is adopted in this study.

There are several versions of this method. For example, a single-bounded (SB) model requires only one WTP question (Hanemann 1984). When collecting data from CV surveys conducted at a considerable cost, it can be inefficient to ask only one question. Accordingly, Hanemann (1985) proposed a double-bounded (DB) model that adds one more question and asks a total of two questions, which has been widely applied in the literature. Hanemann et al. (1991) has mathematically demonstrated that analyzing responses from DB question is much more efficient than analyzing responses from SB question. In other words, when β_{SB} and β_{DB} are parameter estimates obtained by applying the SB model and the DB model, respectively, $Var(\beta_{SB}) - Var(\beta_{DB})$ is a positive semi-definite matrix. At this time, two additional important issues arise.

First, if the DB model produces statistically more efficient results than the SB model, is it not better to apply a multiple-bounded model such as a triple-bounded (TB) model? In fact, Langford et al. (1996) applied the TB model. Since further questions narrow the scope of WTP by providing more information about respondents' WTPs, it is natural that the multiple-bounded model brings more efficient results compared to the DB model. However, according to the results of Monte Carlo simulation by Cooper and Hanemann (1995), the improvement in efficiency caused by adding a third question compared to the DB model is relatively small. Most of the statistical improvements that can be obtained through additional questions are already sufficiently obtained when using the DB model instead of the SB model. Furthermore, the use of the TB model increases the likelihood of response effects that impair internal consistency, while statistical efficiency is only slightly increased (Hanemann and Kanninen 1999).

Second, when applying the DB model instead of the SB model, even if there is a significant degree of statistical efficiency improvement, the possibility of some bias may increase. For example, Cameron and Quiggin (1994) pointed out the inconsistency problem in the DB model by giving two reasons why the response to the second question might not be consistent with the response to the first question and then empirically confirming it. First, even though an individual has to say "no" to the second question in view of her/his true WTP, there is a possibility that she/he feels sorry for the interviewer asking an additional question and falsely responds "yes." Second, even if a respondent has to answer "yes" in view of her/his true WTP, there is a possibility that she/he feels annoyed by the interviewer asking one more question and falsely states "no." McFadden (1994) concluded that the DB model lacks internal consistency in that the hypothesis that the first and second responses came from the same distribution in the DB model can be rejected

at the 1% level. For this reason, the studies have also pointed out problems related to the use of DB models (e.g., Alberini et al. 1997; Carson et al. 1997; McLeod and Berland 1999; Bateman et al. 2001; Burton et al. 2003; Carson and Groves 2007).

Since the SB model and the DB model, which are widely applied in empirical CV studies, have limitations in terms of inefficiency and bias, respectively, the need for a new model to improve efficiency and reduce bias has emerged. In response, Cooper et al. (2002) proposed a one-and-one-half-bounded (OB) model requiring one or two WTP questions. The OB model improves efficiency compared to the SB model, enjoying a significant portion of the efficiency enjoyed by the DB model, while significantly reducing the response effect of the DB model and securing a significant portion of the consistency enjoyed by the SB model. The DB model requires a second response from all respondents, but the OB model requires a second response from only some respondents. Thus, the OB model can reduce bias, which has been demonstrated through experiments in Cooper et al. (2002) study. In summary, the OB model is known to be able to enjoy the advantages of other models while avoiding the disadvantages of other models to some extent. This research collects data by applying the OB model. Of course, the OB model can cause a problem of the response effect that can appear in the DB model, which will be investigated later.

Third, the unit of appraisal required in the CV study should be decided. In this respect, there are two alternatives to individuals versus households. Theoretically, there should be no difference in the estimation results of the total WTP, whichever of these two is used. That is, since the WTP in an individual unit is smaller than the WTP in a household unit and the number of individuals is larger than the number of households, there should be little difference in the total WTP. However, from an empirical point of view, it is fortunate that there is no difference, but it is necessary to select the appropriate units because there may be differences. If there is a difference between the two, the total WTP obtained using households would be less than the total WTP obtained using individuals. Thus, Korea Development Institute (2012) proposed that from a conservative standpoint, households should be used as units of surveys instead of individuals in applied CV studies conducted in South Korea. This research determined households as units of surveys.

Fourth, with respect to the appropriate payment vehicle, how to pay, how often to pay, and how long to pay shall be decided. Concerning how to pay, one of the donations, funds, taxes, product prices, etc. may be selected. Regarding how often to pay, there are alternatives such as one time, once a year, and once a month. With regard to how long to pay, there are alternatives such as for the next 5 years and for the next 10 years. The three criteria used to determine the payment vehicle are typical: to be familiar to respondents, not to be constrained by a particular expenditure, and to be related to the good being assessed. In this study, household income tax once a year over the next 10 years was established as the final payment vehicle by applying these three criteria and referring to the prior studies conducted in South Korea. In addition, the Korea Development Institute (2012) also recommended using household income tax once a year as a payment vehicle.

The third component of the questionnaire consists of questions that collect characteristic variables related to the respondents. Examples included questions about personal characteristics as well as household characteristics, such as residential area, gender, age, whether the respondent is a household head, size of family, level of education, and income. Some of these variables are reflected as covariates in modeling the CV data. These variables are also used to determine whether a sample can be representative, ensuring that the nature of the sample is consistent with that of the population shown in the 2020 census.

Description of the CV survey

There are four issues to be determined in relation to the performance of the CV survey: the method of survey, areas to be surveyed, survey supervisor, and size of the sample. First, in relation to the survey method, this research performed a person-to-person interview after visiting individual households. Other survey methods using postal service, telephone, and Internet required less cost than the method adopted in this research. However, postal surveys have a very low collection rate in South Korea, telephone surveys cannot provide respondents with various visual aids, and Internet surveys are probably not free from sample selection bias. Considering the circumstances of the COVID-19 pandemic, person-to-person individual interviews were conducted with maximum attention to the prevention of COVID-19 infection by using alcohol hand sanitizers and masks.

Second, the areas surveyed were intended to cover basically the whole country. However, Jeju Island is not usually included in applied CV studies for South Korea since it has a relatively small population. For example, the Korea Development Institute (2012) suggests that since the inclusion of Jeju Island in the areas surveyed is not beneficial compared to the involved cost, a CV survey should be conducted only in the rest of the nation except Jeju-do. Thus, the areas subject to the CV survey in this study are nationwide except Jeju Island.

Third, in this study, rather than directly supervising the survey, the authors requested a professional survey company to do the sampling and individual interviews. The company had specialized know-how in scientifically sampling households from the 16 provinces based on data from the 2020 census conducted by Statistics Korea. In other words, the

company was required to take samples maintaining consistency with the values in the census from the perspective of regional population, income, and gender.

Fourth, the size of the sample shall be determined. If scientific sampling is possible, in fact, the sample size does not have to be too large. What to do with the size of the sample is an important issue under the precondition that a survey company has done scientific sampling. In this respect, the guidelines listed by Arrow et al. (1993) could be considered as important. Moreover, the Korea Development Institute (2012) has presented a number of suggestions specialized in South Korea for applying CV. Since both studies suggested a suitable sample size of 1000, the sample size of 1000 was chosen in this study.

Model for dealing with the data

As mentioned above, this study uses an OB model to elicit WTP responses. The theoretical aspects of the OB model are presented in the study by Cooper et al. (2002). To carry out surveys applying the OB model, two proposed amounts must be designed in advance. These two amounts comprise a smaller and a larger amount. After dividing the entire respondents into two groups, the first group is presented with the smaller amount first and asked if she/he accepts the payment of the amount. If "yes" is answered, the larger amount will be additionally offered and asked if she/he has an intention of paying the amount. If "no" is answered, no further questions are required. The second group is asked whether she/he has an intention of paying the larger amount after it is presented first. Responding "yes" eliminates the need for further questions. If "no" is answered, the smaller additional amount is presented and it is asked if she/he accepts the payment of it.

To decide the two proposed amounts, a three-step approach was taken. First, the distribution of WTP was derived with only positive WTP values, excluding zero WTP values from the WTP values obtained using a focus group interview. In a preliminary survey conducted on the focus group of 30 people, respondents' WTP was investigated through open-ended questions. Second, the values of the points cut by 15% each from the left and right sides of this distribution were found to be KRW 1000 and 15,000. Third, using these two values, seven sets of the two proposed amounts were decided to be (1000, 3000), (2000, 4000), (3000, 6000), (4000, 8000), (6000, 10,000), (8000, 12,000), (10,000, 15,000) in Korean won, where the first element was the smaller amount and the second element the larger amount.

Hanemann (1984) suggested the utility difference approach to model WTP responses. This study adopts that approach. When the bid amount is F and WTP is S, the probability of answering "yes" is stereotyped as:

$$\begin{aligned} \Pr(\text{yes}) &= \Pr(S \geq F) = 1 - G_S(F;\theta) \\ \Pr(\text{no}) &= \Pr(S < F) = G_S(F;\theta) \end{aligned} \quad (1)$$

where θ is a parameter vector, (θ_0, θ_1), for $G_S(\bullet)$, which is a cumulative distribution function of S, and often specified as a logistic function. Following Hanemann's (1984) suggestion, the parentheses of $G_S(F;\theta)$ are often formulated as $\theta_0 - \theta_1 F$. Thus, $G_S(F;\theta) = 1/[1 + exp(\theta_0 - \theta_1 F)]$ is derived. If covariates such as income and age are additionally reflected, $\mu' u$ can be substituted with θ_0, where u is a covariate vector and μ is its corresponding parameter vector.

Compared to the SB model that asks only one WTP-related question, the OB model is quite efficient. In addition, the possibility of bias occurring is greatly reduced compared to the DB model that asks two WTP-related questions. Therefore, the OB model has the advantage of reducing the bias to the level of the SB model while achieving the efficiency at the level of the DB model. On the other hand, the problem that the SB model is inefficient compared to the DB model and the problem that the DB model may cause bias compared to the SB model can also be seen in the OB model.

Usually, the first problem is not a big issue, while the second problem can be an important one. When the OB model is applied, some respondents are asked only one WTP-related question, while the others are asked two WTP-related questions. Thus, there is criticism that procedural invariance does not hold due to the response effect involved in respondents' responses to the second question. While the SB model is incentive-compatible, as the use of data obtained through a single question does not cause response effect, the OB model may bring bias.

Therefore, this study will present and compare the estimation results of both the OB and SB models. If there is not much difference between the former and the latter, the response effect can be considered not to be a problem, whereas if there is a significant difference, it may be suspected that the response effect has occurred. When estimating an SB model, only responses to the first WTP question are used. The SB model may lead to a loss of efficiency by not using answers to an additional question, but it may have the advantage of being free from response effects.

One more thing to consider is that not a small number of respondents reported a WTP of zero. That is, those who answered "no" to the smaller amount were asked additionally whether their WTP was 0 or between 0 and the smaller amount. The former can be viewed as a respondent with zero WTP. There are several models that can be applied to this case. In this study, the OB and SB spike models proposed by Kriström (1997) are used. This is because the model is most widely applied in empirical studies for analyzing WTP responses with zeros (Yoo and Kwak 2002). That is, this research estimates the model that combines the OB and SB models with the spike model.

Table 2 Sample characteristics

Variables	Sample[a]	Population[b]
Gender		
Female	50.0%	49.9%
Male	50.0%	50.1%
Region		
Seoul	20.1%	19.5%
Busan	7.2%	6.7%
Daegu	5.0%	4.7%
Incheon	5.7%	5.6%
Gwangju	2.9%	2.8%
Daejeon	3.0%	2.9%
Ulsan	2.3%	2.1%
Sejong	0.4%	0.6%
Gyunggi	23.9%	24.7%
Gangwon	3.1%	3.2%
Chungbuk	3.1%	3.3%
Chungnam	4.1%	4.3%
Jeonbuk	3.7%	3.7%
Jeonnam	3.6%	3.9%
Gyungbuk	5.4%	5.5%
Gyungnam	6.5%	6.5%
Household income[c]	KRW 5.22 million	KRW 5.01 million

[a]The number of respondents is 1000

[b]Comes from Statistics Korea (2022)

[c]Means the average

Results and discussion

Data

The representativeness of the sample has been secured by conducting sampling based on the Census gathered in 2015 by Statistics Korea. In this regard, a comparison of the characteristics of the sample with those of the population is reported in Table 2. It can be seen that there is not much difference between the values for the sample and those for the population.

The numbers of responses collected in this study are summarized in Table 3. The total number of observations was 1000. A preliminary survey of the focus group enabled this study to determine a total of seven sets of bid amounts. They are (1000, 3000), (2000, 4000), (3000, 6000), (4000, 8000), (6000, 10,000), (8000, 12,000), and (10,000, 15,000) in Korean won where the first and second elements mean a lower bid amount and a higher bid amount, respectively. The 1000 respondents are divided into seven groups. Each group consists of a similar number of observations. Each set was presented to each group. The upper and lower parts of Table 3 refer to the case where a higher and lower bid amounts are offered first, respectively.

The "no–no-no" and "no–no" responses mean $S = 0$, corresponding to 555 (=280 + 275) of the total. The responses mean a WTP of zero. It is surprising that 55.5%, more than half of all respondents, said they would not pay a penny. Many of the respondents with zero WTP said the eradication project should be carried out with the taxes already paid, not additional taxes. Some responded that they thought

Table 3 Description of the answers obtained in the survey

Bids[a]		Number of responses				
First	Second	"yes"	"no-yes"	"no–no-yes"	"no–no-no"	Totals
3000	1000	19	12	2	38	71
4000	2000	13	13	8	38	72
6000	3000	10	13	9	40	72
8000	4000	10	14	11	36	71
10,000	6000	14	3	14	40	71
12,000	8000	12	4	11	44	71
15,000	10,000	11	3	14	44	72
Totals		89	62	69	280	500
First	Second	"yes-yes"	"yes–no"	"no-yes"	"no–no"	Totals
1000	3000	8	25	3	36	72
2000	4000	7	17	13	35	72
3000	6000	7	17	6	41	71
4000	8000	8	16	11	36	71
6000	10,000	4	8	8	51	71
8000	12,000	4	15	12	40	71
10,000	15,000	2	14	20	36	72
Totals		40	112	73	275	500

[a]They are expressed in Korean won. The exchange rate at the time of the survey was USD 1.0 = KRW 1122

the eradication project was not important to them. Others stated that they could not afford to pay additional taxes. In any case, the fact that a considerable number of respondents revealed the WTP of zero suggests that it is necessary to apply not the conventional model but the spike model in this study.

Results

The OB spike model applied in this study may or may not include covariates. As explained above, if the covariates are included, the parentheses of $G_S(F;\theta)$ becomes to be $\theta_0 - \theta_1 F + \mu' u$ Table 4 reports information on the six covariates employed here. The Education, Income, Gender, Knowledge, Age, and Metro variables mean education level of the respondent in years, monthly income of the respondent, gender of the respondent, dummy for the respondent's having heard of AA, age of the respondent, and dummy for the respondent's dwelling in the Seoul Metropolitan area, respectively.

Two OB models are constructed depending on whether covariates are included. Table 5 presents the results from estimating them by the use of maximum likelihood estimation method. The Wald-statistics imply that both models hold statistical significance at the 1% level. The average WTP is derived as $\left(1/\theta_1\right)[1 + \exp(\theta_0)]$. Looking at the estimation results of the covariate-free model, both the two coefficients and the average WTP secure statistical significance. The spike also possesses statistical significance. The value is 0.5575, which is not much different from the sample ratio

Table 4 Description of the variables

Variables	Definitions	Mean	Standard deviation
Education	Education level of the respondent in years	14.36	2.15
Income	Monthly income of the respondent (unit: million Korean won)	2.58	1.71
Gender	Gender of the respondent (0 = male; 1 = female)	0.50	0.50
Knowledge	Dummy for the respondent's having heard of *Aurelia aurita* (0 = no; 1 = yes)	0.05	0.22
Age	Age of the respondent	48.14	9.65
Metro	Dummy for the respondent's dwelling in the Seoul Metropolitan area (0 = no; 1 = yes)	0.53	0.50

Table 5 Estimation results of the one-and-one-half-bounded models

Variables[a]	Model without covariates		Model with covariates	
	Coefficient estimates	*t* values	Coefficient estimates	*t* values
Constant	−0.2312	−3.67#	−2.4945	−3.50#
Education			0.1077	3.06#
Income			0.1132	2.23#
Gender			0.5185	3.08#
Knowledge			0.3497	1.27
Age			−0.0093	−1.30
Metro			1.0860	8.24#
Bid amount	−0.1927	−19.47#	−0.2088	−19.70#
Spike	0.5575	35.86#	0.5614	34.28#
Yearly household average willingness to pay [b]	KRW 3,031 (USD 2.70)	16.70#	KRW 2,765 (USD 2.46)	16.62#
95% confidence interval [c]	KRW 2,696 to 3,428 (USD 2.40 to 3.06)		KRW 2,454 to 3,114 (USD 2.19 to 2.78)	
Wald statistics (*p* values)	278.92# (0.000)		276.30# (0.000)	
Log-likelihood	−1215.90		−1155.35	
Sample size	1,000		1,000	
McFadden's pseudo-R^2	0.050			

[a]They are explained in Table 3

[b]The exchange rate at the time of the survey was USD 1.0 = KRW 1122. # means statistical significance at the 5% level

[c]They are obtained from adopting the method of Krinsky and Robb (1986)

of 0.555. This finding suggests that applying the spike model in this study was an appropriate strategy.

To explicitly deal with the uncertainty related to the estimation of average WTP, a confidence interval (CI) can be computed. Therefore, Table 4 also provides 95% CIs for the average WTP derived through utilizing the method of Krinsky and Robb (1986). The method consists of four steps as follows. First, in step 1, a multivariate normal distribution with a vector of the estimated coefficients as the mean and the variance matrix for the estimated coefficients as the variance is assumed, and then a vector of coefficients is randomly extracted from the distribution. In step 2, the average WTP is calculated from the extracted vector of coefficients. In step 3, the empirical distribution of the average WTP is obtained by repeating steps 1 and 2 with the number of 5000 times. In step 4, the CI is calculated after cutting an appropriate amount from the left and right sides of this empirical distribution. For example, the 95% CI can be obtained by cutting 2.5% from the left and right sides of the empirical distribution.

The estimation results of the model including covariates are not significantly distinguishable from those of the model without covariates. The R^2, which is the most frequently employed information for the goodness-of-fit of an estimated equation, cannot be defined for the covariate-free model. On the other hand, McFadden's pseudo-R^2 suggested by Herriges (1999) is defined for the model including covariates. It was calculated to be 0.05. In the model with covariates, independent variables explain the variation of the dependent variable by about 5%. This value must be quite low. However, when estimating the model using cross-sectional data, the value is often low. Thus, there will be no problem in further analysis with the estimation results.

The coefficient estimate for a covariate itself does not mean much, but its sign has an important meaning. If the sign is positive, the size of the variable has a positive association with the probability of responding "yes" to the offered bid amount. Among the six covariates, coefficient estimates for the Education, Income, Gender, and Metro terms hold statistical significance at the 5% level and all have positive signs. It has the following meaning: the higher the income or education level, the greater the probability of accepting the payment of the suggested bid amount; women have greater likeliness to state "yes" to the presented bid amount than men; and people dwelling in the Seoul Metropolitan area have greater likeliness to accept the payment of a presented bid than others.

Which of the two models to use is an issue. With respect to the model with covariates, there is a problem that the estimation results of the average WTP vary depending on which set of covariates is to be determined. For this reason, the model including covariates is mainly used to examine internal consistency or theoretical validity rather than for policy analysis. However, the model without covariates is not affected by this problem. Consequently, for policy analysis, the estimation results of the covariate-free model are usually used. This study will also conduct a welfare analysis using the estimation results of the model without covariates instead of the model including covariates.

Discussion of the results

Four major discussions will be offered on the results. First, the OB model can suffer from the response effect (Bateman et al. 2009). To deal with this, comparison of the results from the OB model with those from the SB model that uses only the response to the first bid is needed. To this end, two versions of the SB model are estimated. The results are contained in Table 6. The average WTP estimates obtained from the SB models are greater than those from the OB models. Looking at the 95% CI, they do not overlap with each other. Using the overlap test, the null hypothesis that the two estimation results are the same can be rejected.

In other words, the estimation results of the two models differ significantly. Thus, it is judged that the response to the OB model does not hold procedural invariance in the data obtained in this research. This implies that the estimation results from the OB model may suffer from response effect. The cause of this is difficult to clarify, but it can be inferred that the response effect is a problem in the OB model adopted in this research. As mentioned earlier, the SB model is free from response effect because it utilizes only responses to one WTP question. Therefore, it is appropriate for policy analysis to use the SB model rather than the OB model.

Second, it is necessary to derive the average WTP from the estimated SB model with no covariates and then calculate the national value expanded to the population with it. The household average WTP was estimated as KRW 3911 (USD 3.49) per year, which held statistical significance at the 1% level. From a national perspective, the sample value can be expanded to the population value. Before performing the expansion, the representativeness of the sample becomes an issue and thus should be checked for.

In this study, the authors believe that the representativeness of the sample is sufficiently secured because a professional polling agency administered the sampling work. When the survey was implemented, South Korea had 20,573,060 households. The population value can be calculated through the multiplication of the household WTP by the total number of households in the country. Thus, the public value of eradicating AA from a country-wide perspective is KRW 80.46 billion (USD 71.71 million).

Third, this figure can be used as essential basic data to evaluate the economic feasibility of implementing the AA eradication project. In other words, a comparison of

Table 6 Estimation results of the single-bounded models

Variables[a]	Model without covariates		Model with covariates	
	Coefficient estimates	*t* values	Coefficient estimates	*t* values
Constant	−0.2416	−3.83#	−2.5651	−3.59#
Education			0.1059	3.00#
Income			0.1259	2.44#
Gender			0.5747	3.36#
Knowledge			0.3070	1.11
Age			−0.0086	−1.20
Metro			1.0789	8.10#
Bid amount	−0.1482	−15.36#	−0.1621	−15.52#
Spike	0.5601	36.02#	0.5638	34.38#
Yearly household average willingness to pay [b]	KRW 3,911 (USD 3.49)	14.08#	KRW 3,536 (USD 3.15)	14.12#
95% confidence interval [c]	KRW 3,434 to 4,523 (USD 3.06 to 4.03)		KRW 3,089 to 4,096 (USD 2.75 to 3.65)	
Wald statistics (*p*-values)	198.34# (0.000)		199.38# (0.000)	
Log-likelihood	−989.80		−930.89	
Sample size	1,000		1,000	
McFadden's pseudo-R^2	0.060			

[a]They are explained in Table 3

[b]The exchange rate at the time of the survey was USD 1.0 = KRW 1,122. # means statistical significance at the 5% level

[c]They are obtained from adopting the method ofKrinsky and Robb (1986)

the national public value with the related cost allows us to weigh the social desirability of implementing the project. The authors were able to obtain the cost information by contacting the KMOF. The total cost involved in carrying out the eradication project for 9 years from 2013 to 2021 was estimated as KRW 6.16 billion (USD 5.49 million). Therefore, the annual cost was about KRW 684 million (USD 610 thousand).

This amount is unlikely to change much in the future from the perspective of constant prices. It is clear that the annual cost (KRW 684 million) is significantly smaller than the annual public value (KRW 80.46 billion). Because it is socially profitable to perform the AA eradication project, the project should be continuously promoted. Although it is difficult to accurately estimate future costs at the current level and the costs may increase in the future, this qualitative judgment will not change. This discovery may be the most interesting part of this study.

Fourth, the factors affecting the intention of accepting the payment of a given bid can be discussed. It was found that several factors related to the interviewee significantly affected the likelihood of reporting "yes" to the presented bid. For example, the higher the level of education or the more the household income, the greater the possibility of responding "yes" to the presented bid. Thus, both income and education level made a positive contribution to the acceptance of the payment. Female interviewees were more likely to say "yes" to the proposed bid than male interviewees.

Those dwelling in the Seoul Metropolitan area are more prone to respond "yes" to the presented bid than others. Since about 50% of the South Korean population lives in the area, this finding is a positive point for stably and continuously promoting the AA eradication project. On the other hand, it was found that the respondents' prior knowledge of AA and age did not significantly affect the probability of answering "yes" to the presented amount.

Conclusions

Since AA causes damage in a wide range of areas such as fisheries, power generation, and recreational activities, the South Korean government has been and will be eradicating AA. The government wanted to know how large the public value of eradicating AA was. In response, this paper strived to appraise the public value by conducting a CV survey of 1000 people and analyzing the data on WTP for the eradication. The yearly public value per household was obtained as KRW 3911 (USD 3.49), holding statistical significance. The national public value was KRW 80.46 billion (USD 71.71 million) per annum. Although the cost incurred by implementing the AA eradication project in the future has not been accurately

estimated, when considering the cost required in the past, the public value seems to be greater than the required cost.

South Korea is a peninsula country surrounded by the sea on three sides. AA appears in all the waters of the country, disrupting the marine ecosystem and causing damage to the fisheries and tourism industries. As mentioned in the "Introduction" section, because removing the AA-attached larvae, polyps, can dramatically reduce the cost compared to removing AA's adult body, the Government has been carrying out the project of eradicating polyps. The fact that the public places a considerable value to the eradication project is an important and interesting discovery of this study. Therefore, the project to partially remove polyps needs to be expanded and implemented throughout the country. In order to expand the project, additional budgets must be secured and executed. In addition, the Korea Maritime Environment Corporation (KOEM) is in charge of the project at the request of the KMOF. The KOEM should develop a technology that can make the removal more effective and distribute it to small businesses that are actually performing the removal project ordered by the KOEM.

In terms of research, this article makes three contributions to the literature. First, this study is the first case of quantitatively examining the public value of eradicating AA, which is the most commonly appearing jellyfish in the country. Second, statistically significant results were obtained by employing the CV approach to appraise the public value of eradicating AA. It has been confirmed that it may be useful to apply CV to an issue of assessing the public WTP for eradicating a harmful marine organism. Third, a combination of using the spike model to handle the zero WTP values and comparing the estimation results of the OB model and the SB model was an appropriate approach.

To supplement the implications of this research more abundantly, two additional studies can be conducted in the future. First, if a study is conducted similarly to the structure of this study on harmful marine organisms other than AA, the priority for the management of the species can be derived through comparison of each estimation result. As addressed above, there are a total of seventeen species designated as harmful marine organisms in South Korea. Since the government has to manage all the species with a limited budget, information on the priority for the management of the species is required. Second, if regional surveys are conducted and analysis results are derived by region, regionally differentiated implications can be derived. To this end, efforts must be made to raise the number of the entire observations by securing a sufficient survey budget.

Authors' contributions This article was written through the cooperation of the three authors. Ju-Hee Kim prepared the survey questionnaire, wrote half of the paper, and analyzed the collected data. Se-Jun Jin performed data curation, interpreted the estimation results, and edited the draft article. Seung-Hoon Yoo conceptualized the contents of the research, secured the necessary finances for the survey, and administrated the entire process of the study. All authors read and agreed to the final manuscript.

Funding This study was supported by the Research Program funded by the SeoulTech (Seoul National University of Science and Technology) (2022–0565).

Data availability The datasets used in the study are available from the corresponding author on reasonable request.

Code availability The code used in the study is available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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